The Engineer's Cost Handbook

Edited by
Richard E. Westney, P.E.

Tools for Managing Project Costs

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To my father, Richard B. Westney,
who gave us his love of original thought and shared self-expression

Preface

All engineers work with variables. The mechanical engineer's variables may involve dynamics; the electrical engineer's, power; or the civil engineer's, loads. Yet there is one variable that affects every engineer's work, a variable so powerful that, if it is not analyzed properly, no engineering project can succeed. It is the variable that, today more than ever, governs the work that all engineers do. That variable, of course, is *cost.*

Cost determines which projects will go ahead. Once a project is approved, costs often determine the design approach to be used. And once the project is completed and operations begin, costs determine whether it will be a success.

Successful engineers today understand that technical work is merely part of a cost-driven business process. In most companies, the successful project is *not* necessarily the one that has the most sophisticated design—more likely it is the one that makes the most money. Modern engineers know that a project that was a technical success will be judged a business failure if costs are not analyzed and controlled.

The purpose of *The Engineer's Cost Handbook* is to enable engineers to work with cost with the same confidence, competence, and skill that they can apply to any other variable. Costs can be studied, analyzed, and optimized like any other engineering variable, so they are something with which an engineer can feel comfortable.

As with most engineering applications, cost engineering is a disciplined process. This handbook is organized into three parts that track the natural flow of a project through cost estimating, economic evaluation, and cost control. Each chapter is written by a cost engineer with top credentials who has distilled his experience into guidelines that are easy to pick up and use.

PART I: ESTIMATING PROJECT COSTS

An engineer's involvement with a project sooner or later leads to the need to prepare an estimate of the project's cost. Often, the same engineer who is doing the design work will prepare the estimate, or supervise an estimator in doing so. In either case, a sound knowledge of estimating principles is essential.

Basic Estimating Concepts. In Chapter 1, "The Estimating Process," and Chapter 2, "Estimating Methodology," Larry Aaron and John Hollmann provide a clear insight into what a cost estimate is, and how it goes together. There's a lot more to it than most people think! Mastering these estimating concepts will make all the other chapters in Part I fall into place.

Preparing the Base Estimate. In Chapter 3, "Estimating Engineering Costs," Chapter 4, "Estimating Engineered Equipment Costs," Chapter 5, "Estimating Bulk Material Cost," and Chapter 6, "Estimating Construction Labor and Indirect Costs," Bill Janda, Kul Uppal, Allen Hamilton, and Tom Taylor explain how these key elements go together to create a base estimate.

Reflecting Project Conditions. The base estimate must now be adjusted to reflect overall project conditions. In Chapter 7, "Productivity Analysis," Jim Neil shows how to adjust for the many factors that determine productivity and, hence, much of the project's cost. In Chapter 8, "Cashflow Analysis," Sam Speed explains how to develop cashflow requirements from the cost estimate.

Since escalating costs are a part of most projects, in Chapter 9, "Estimating the Cost of Escalation," George Stukhart explains what drives escalation and how to calculate its effect on project costs. The project's location affects many aspects of the cost estimate, so, in Chapter 10, "Location Factor Analysis," Bernie Pietlock shows how to work with location factors. Finally, many sites will require environmental restoration, and in Chapter 11, "Estimating the Cost of Environmental Restoration," Richard Selg and Ronald Stillman explain these costs.

PART II: EVALUATING RISK AND RETURN

Once project costs have been estimated, economic and risk analysis will determine whether the funds will be approved.

In Chapter 12, "Risk and Contingency Analysis," Sam Shafer shows how the risk of cost overruns can be evaluated. Methods for calculating the potential return are described by Nick Lavingia and Paul Redden in Chapter 13, "Profitability Analysis," which also shows how to use a simple spreadsheet program to make the calculation. We now must put all this together—the cost estimate, the profitability analysis and the risks—to make a decision, and, in Chapter 14, "Investment Decision-Making," John Schuyler shows us how.

PART III: CONTROLLING PROJECT COSTS

Basic Cost Control Concepts. All the estimating and analysis counts for nothing if costs are not controlled during project execution. In Chapter 15, "Cost Control Systems," Kurt Heinze and Dick Westney describe the general principles for controlling costs.

Controlling Engineering-Related Costs. The engineering aspect of a project not only involves a considerable part of project costs, but also drives many other cost elements. In Chapter 16, "Controlling Engineering Costs," Sy Meyers shows how to control the cost of the engineering work. Engineering drives the cost of equipment and materials, and the control of these costs is explained by Wes Querns in Chapter 17, "Controlling the Cost of Engineered Equipment," and Ken Cressman in Chapter 18, "Controlling the Cost of Materials."

The juxtaposition of cost control and design engineering concepts is found in value engineering, a fascinating process that inevitably yields major savings. In Chapter 19, "Applying the Principles of Value Engineering," Doug Mitten explains how you can use these techniques to reduce costs in your projects.

Controlling the Cost of the Work. Most project costs tend to be associated, directly or indirectly, with the cost of people doing work. In Chapter 20, "Controlling the Cost of Construction Labor," Joe Orczyk explains the key concepts.

The quality of the work is, of course, always an issue, and in Chapter 21, "Controlling the Cost of Quality," Garrison Haskins, Clay Meyers, and Ed Condolon explore the cost implications of a quality program. Along with quality, safety is always a major concern. In Chapter 22, "Controlling the Cost of Safety," Bob Kimmons shows how to plan and budget for an effective safety program. And in Chapter 23, "Controlling the Costs of Shipping," Bruce Martin explains the methods and costs available to get your materials to the site.

Project success often means finishing on or under budget, and a claim at the end of a contract can be an unpleasant surprise. In Chapter 24, "Avoiding Claims," Gui Ponce de Leon along with Timothy McManus, Jerry Klanac, and John Knoke share their experience in helping to ensure that claims will not spoil your project's success.

On behalf of the 31 other authors, I trust *The Engineer's Cost Handbook* will help your projects, your company, and you to succeed.

Richard E. Westney, P.E.

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About the Contributors

The authors of *The Engineer's Cost Handbook* represent the highest level of cost engineering expertise and experience. Bringing these experts together to create this book would not have been possible without AACE International, (formerly The American Association of Cost Engineers). A brief description of each author's background is provided below.

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1

The Estimating Process

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I. INTRODUCTION

The purpose of this chapter is to:

Outline and provide perspective on the estimating process by discussing each step in detail.

Define standard estimating terms and provide useful checklists and forms.

Present an overview of the many types of estimates differentiating the end user, application, and accuracy of each. A detailed explanation of various *estimating techniques* is presented in Chapter 2.

Introduce the basics of the estimate design basis, content, and format.

Because the estimate is one of the most comprehensive documents prepared on a project, it impacts the entire project team and many project-related activities. This overview will prepare the reader to better understand many of the chapters throughout this book and, particularly, the estimating subtopics that are discussed in-depth in Chapters 2–6.

II. FROM WHOSE PERSPECTIVE?

The approach to estimating varies greatly with the point of view of the estimator. Owners have a much different perspective and approach than contractors, and novice estimators use different procedures than experienced personnel. The estimating process used will vary depending on the point of view and experience of the individual, employer, and the work culture in which they work. Since perspectives vary significantly, the issue of perspective must be discussed for the sake of clarity to the reader.

The owner's estimating process is likely to be quite different than the contractor's due to their different viewpoints, concerns, risks in conducting business, depth of involvement, accuracy required from estimates, and uses of estimates. An owner studying the feasibility of a new process in the research and development phase will need to consider process technologies and implementation risks, funding strategies, site studies and the impact on marketing, shipping, operations, logistics, and contract management strategies. Each of these has a contribution to risks and cost. The owner is heavily involved in the feasibility stage of a project, turning over responsibility to a contractor as major decisions are made and design and construction proceed.

Although not without risks, a contractor's scope tends to be more focused than the owner's. The contractor produces designs and/or constructs a facility as specified by the owner's primary conditions. Contractors typically become most heavily involved in the intermediate and final stages of a project when the owner's intent is clearer and many of the alternatives have been studied and rejected or accepted. Due to their unique focus and stage of involvement, contractors' approaches and tools-of-the-trade are quite different.

III. WHAT IS AN ESTIMATE?

According to AACE International, the Association for Total Cost Management, an estimate is:

> an evaluation of all the costs of the elements of a project or effort as defined by an agreed-upon scope. Three specific types based on the degree of definition of a process industry plant are: 1) Order of Magnitude Estimate, 2) Budget Estimate, and 3) Definitive Estimate [1].

Typically an estimate is an assessment, based on specific facts and assumptions, of the final cost of a project, program, product, or process. As will be explained in this chapter, you will see that the results of this process vary with the:

type, amount, and accuracy of scope and estimating data available
phase of the project

time allotted to prepare the estimate
perspective of the preparer (contractor, designer, owner)
skill of the estimator
calculation technique
cost accuracy desired
business risk assessment

The word "estimate" in this chapter shall mean "capital cost estimate."

IV. ESTIMATE USES

Having defined what an estimate is, we now examine the six purposes that an estimate can serve:

1. Provides an *assessment of capital cost* for a specified piece of work.
2. Forms the basis for *planning and control* by defining the *scope of work* and its associated *estimated cost.*
3. Provides much of the basic information (hours, resources, tasks, durations) which are needed for preparing a *schedule.* It also states general *resource requirements* such as labor, material, and construction equipment.
4. Provides the financial input required to prepare a *cash flow* curve.
5. Provides a stimulus to *assess productivity and risks.*
6. Is a *catalyst for discussion*, idea generation, team participation, clarity, and buy-in. It ties together much of the relevant project information within a single document.

We will now examine each of these six purposes in detail.

A. Assessment of Capital Cost

When used as an assessment tool, a capital cost estimate may serve a variety of subpurposes:

To be a *basis for funding and/or investment decision making* strategies. From an owner's viewpoint, an estimate may be used to substantiate a request for internal capital appropriations, borrowed funds or bonds, or other types of investments. Capital cost estimates are often used as a basis for discussion with these funding organizations. Cost estimates can be used for financial planning or "what-if" games. Different scenarios can be developed by using required capital and time as variables.

To be the *basis for a proposal, bid, or contract baseline document.*

To calculate a *break-even point*, rate of return and payout time by incorporating the capital costs with the operating costs as part of a life cycle or value engineering study.

To *compare* it with other estimates to *validate* accuracy and, thereby, raise confidence levels. This type of estimate is sometimes required by owners and construction managers to validate bids from contractors and subcontractors. It is prepared by government prime contractors and government agencies to validate estimates from other government contractors. This comparative type of estimate is called an Independent Cost Estimate (ICE).

To be a *basis for preparing other estimates*. An estimate can be used as a basis for another estimate if 1) it is dated, 2) identifies scope to sufficient detail that allows scaling or substitution of scope elements, and 3) is indexed to a base time, location, and unit of currency.

B. Basis for Planning and Control: Scope of Work and Estimated Cost

An estimate defines *the scope of work and associated cost* regardless of the amount of itemized detail provided. In so doing, it becomes a *baseline for scope and change control*. However, as estimate items are specified or quantified, each estimate item becomes a basis for measuring deviations. Capacities, specifications, materials, and sizes can all be used to measure changes from the baseline. Cost projections can be provided as design develops.

In this capacity, estimates function as *early warning systems* for management. With information in hand, managers are equipped to reduce scope and associated costs or take steps to make additional funds available. Due to its budgetary emphasis and defined scope, the estimate can be used as the financial baseline, or budget, to measure cost performance on a project. This is done with a cost reporting system. Schedule control systems may also evolve from estimates.

The cost of a project is very dependent on the *pace of the project*. The pace affects how the engineering is done and the types of construction contracts that are prepared. Fast track engineer/construct projects are time constrained and, therefore, schedule has more impact than capital funds. Projects related to emergencies, consumer products, shutting down and restarting production, and providing necessary services (power, water, etc.) are also often schedule constrained. When timing is of less concern than budget or when funds are tight, engineering funds will be allocated and contracts will be prepared to reflect minimum-cost efforts.

The way the projects/contracts are managed (cost plus vs. lump sum), the form of installation labor (plant vs. contractor supplied), and other project management factors also impact the estimated cost. Estimates may encourage these and other types of decisions to be made during the estimate preparation/review process or, at a minimum, require a statement of assumptions to document the cost impacts of the project management strategies for the project.

C. Establish Schedule Baseline and Resource Requirements

An estimate can provide an order-of-magnitude assessment of the number of people (by discipline/trade) or other resources (materials, equipment) required on a project. The estimate is therefore a useful planning tool for developing schedules. The estimated hours of effort and resource requirements that come from estimates of engineering or field labor can usually be turned into an activity-based schedule when a logic sequence is applied to the itemized activities.

D. Prepare Cash Flow Analyses

By combining budgets and scheduled activities, a cash flow curve can be developed. This curve is helpful in developing a funding income plan as is commonly done for public works projects or to approach bonding/loan agencies. It is also useful for planning progress payments or meeting any date that requires the payment of cash. Cash flow curves can also be used by contractors and fabricated equipment suppliers to establish a progress payment schedule. Cash flow analysis is discussed in detail later in Chapter 8.

E. Assess Productivity and Risks

Project risks should always be reflected in capital costs estimates. The estimating process encourages project participants to assess risks by establishing a reasonable estimate for *contingency*. According to AACE International, contingency is:

> an amount added to an estimate to allow for changes that experience shows will likely be required. [The assessment of contingency] may be derived either through statistical analysis of past project costs or by applying experience from similar projects. [A contingency allowance] usually excludes changes in scope or unforeseeable major events such as strikes, earthquakes, etc. [2].

For owners, whether projects are self-funded or funded through outside sources, the need to keep capital costs and interest payments to a minimum is a strong motivator for careful risk planning and analysis. For contractors, risks must be assessed so confidence levels can be established in the estimate, particularly if the contractor is preparing a lump sum bid. Some of the factors that are considered in risk assessment are productivity, quantity/quality of scope, contractual uncertainties, and general unknowns such as weather, underground obstructions, etc. Contingency and risk assessment are discussed in full detail later in Chapter 12.

F. Catalyst for Discussion

By specifying scope, specifications, procedures, assumptions, responsibilities, resources, risks, opportunities, time frames, and money, the estimating process can cause early planning to begin and responsibility agreements to be made. In many ways, the estimate is an effective team building tool in that it can secure the project team participants' agreement with the project objectives at a very early stage in a project.

Another benefit of these discussions is that in the review process, many people get involved with trying to reduce the total project cost. In efforts to reduce cost estimates, alternative methods, procedures, and specifications are often discussed during the estimating stage. By combining and eliminating unnecessary details, large amounts of work and expenditure can be eliminated. By studying existing processes, procedures, and customs, work can be streamlined for a faster, cheaper, safer, and better project.

V. CAPITAL COST ESTIMATING TERMINOLOGY

A. Types of Estimates

Estimate types may be classified by:

1. How the estimate will be used
2. The type/quality/amount of information available for preparing the estimate
3. The range of accuracy desired in the estimate
4. The calculation technique used to prepare the estimate
5. The time allotted to produce the estimate
6. The method of input/form of output (computer, manual forms) in preparing estimate
7. The phase of project (feasibility, appropriation, construction) related to the estimate
8. The perspective of preparer (owner, contractor, insurance company) (See Chapter 2 for a discussion of estimate types.)

B. Estimating Definitions

Contingency An amount added to an estimate to allow for changes that experience shows will likely be required. May be derived either through statistical analysis of past project costs or by applying experience from similar projects. Usually excludes changes in scope or unforeseeable major events such as strikes, earthquakes, etc. [1].

Direct Cost [In engineering/construction, the] cost of installed equipment, material, and labor directly involved in the physical construction of the permanent facility [1].

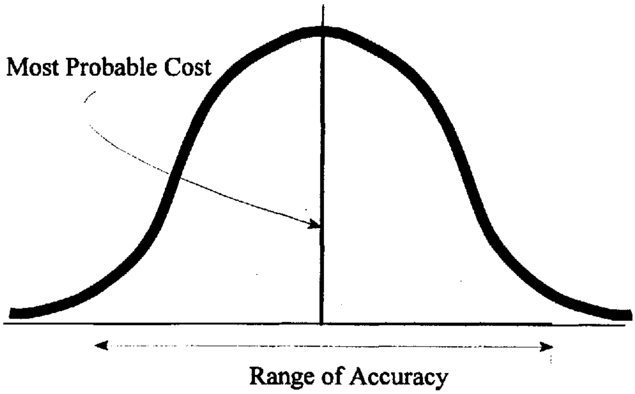

Figure 1 Most probable cost and range of accuracy.

Escalation The provision in actual or estimated costs for an increase in the cost of equipment, material, labor, etc., over that specified in the purchase order or contract due to continuing price level changes over time [1].

Indirect Cost In engineering/construction, all costs which do not become a final part of the installation, but that are required for the orderly completion of the installation and may include, but are not limited to, field administration, direct supervision, capital tools, start-up costs, contractor's fees, insurance, taxes, etc. [1].

Most Probable Cost The *most probable cost* is that cost that is most likely to occur. It includes all the itemized known items and a contingency estimate (allowing for those unknowns which would be expected to occur) that together invoke a 50% degree of confidence. (Figure 1 shows the relationship between most probable cost and *range of accuracy*.)

Range of Accuracy The range of accuracy is a statement of the least expected cost and highest expected cost, as compared to the most probable cost. It is a function of the quality of estimate, scope definition, project risks, unknowns, and estimate pricing at the time of estimate preparation.

VI. THE ESTIMATING PROCESS

A process is "a series of steps or actions which produces a result." Estimating is one of many steps in the project management process, yet it is a process unto itself. It has 11 steps (see Figure 2) [2].

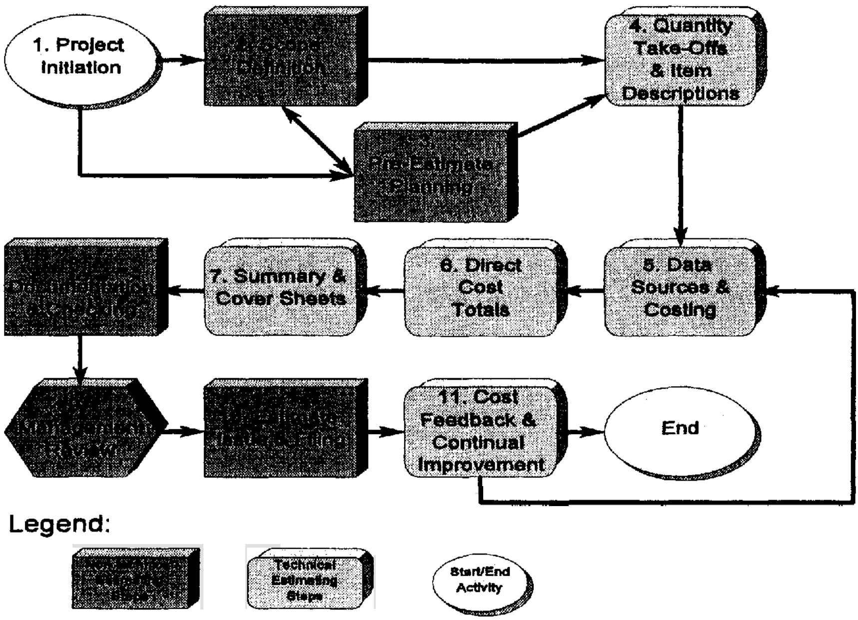

Figure 2 The 11-step estimating process.

1. Project initiation
2. Scope definition
3. Pre-estimate planning
4. Quantity take-offs and item descriptions
5. Data sources and costing
6. Direct cost totals
7. Summary and cover sheets
8. Documentation and checking
9. Management review
10. Estimate issue and filing
11. Cost feedback/continual improvement

Each step in the estimating process is discussed in detail. The purpose of each step and the function of the estimator in each are also discussed.

A. Project Initiation: The Estimating Process, Step 1 (See Figure 2)

Although this step is not instituted by the estimating department, it is *the* activity that initiates the estimating process. Project initiation occurs when there is a motivation or justification to consider expending the resources on a project. One of the first needs is to see if there is a cost justification for the project undertaking. Therefore, an economic study will soon be required and some form of a capital cost estimate will need to be produced.

B. Scope Definition: The Estimating Process, Step 2 (See Figure 2)

By knowing how well-defined the design basis and scope of work are, the estimator can determine the main function of the estimate. Scope Definition answers the questions "Why?" and "How?" about the project and associated estimate. The estimator must also consider several structural requirements of the estimate because they provide a format which organizes the scope into logical, meaningful groupings. These are: design basis, detailed scope of work, work breakdown structures, categorical breakdowns, code of accounts, and formatting required by end users.

Examples of the types of considerations that are addressed at this time are the 1) project goals, objectives, and basic purpose, 2) company's goals and expectations of the project, 3) design basis or capacity, 4) physical configuration of the final facility as conceived, 5) contract strategies, 6) roles and responsibilities of major project participants such as owner, contracting organizations, suppliers, municipalities and agencies, and suborganization, 7) specification of the detailed scope including work methods, 8) organization and format of the estimate, and 9) other important fundamental information.

The Design Basis

The design basis is a statement of the *intent* of the project. It provides the functional requirements which must be met by the completion of the project. It is considered good practice for the owner, who is responsible for providing the design basis, to commit it to writing.

The design basis should always state the reason for the project. Examples of some design bases are:

Replace heat exchanger E-2's cooling water supply system with new 2800 gallons per minute cooling tower and associated pumps. This will accommodate an increased heat load to the exchanger and replace the existing, deteriorated tower as part of the plant's Utility Upgrade Undertaking.

Provide a 3–bedroom, 2½-bath, 2–story, 2400 SF brick home on lot 4C in the Wolverine Den subdivision in Ann Arbor, Michigan. A home office will also be provided. A masonry block foundation to be used as crawl space. The home shall have city sewer and water supply. All utilities are underground including 2–line telephone, gas feed for furnace and water heater, and 200 amp power supply. This home is being built to accommodate a growing family and home business.

The Detailed Scope of Work

From the design basis, scope statements are developed. Scope statements are specifications and descriptions of items that fulfill the functional design basis. Examples of scope statements developed from the first two design basis bullets above are:

Purchase and install a new cooling tower processing 2800 g.p.m. of process X cooling water and a temperature drop of 15 °F. Scope includes pumps (sizes stated), piping (sizes, materials of construction, and routing, if known, are stated), foundations (sizes, concrete and rebar specs, etc.), and electrical distribution and new starters for two-60 horsepower motors in an existing motor control center. Flow control to be provided on the input side of the cooling tower and level control in the pit. (Location, structural information and any clarifying drawings and sketches could also be provided. Demolition and other construction scope items would also be listed.)

Home (as stated above) to be constructed of #2 white pine framing and asphalt shingle roof (type X). Windows to be of Brand Y or equal, (similar specs for doors, foundation, cabinets, appliances, etc.) or refer to drawing numbers.

Process requirements (mass and energy balance)
⇓
Process equipment and controls identification (P&IDs)

⇓	TM	⇓
Structural loads	Pipe specifications, materials, sizes	Electrical loads
⇓	TM	⇓
Foundation, steel calculations	Pipe orthographic drawings	Electrical specifications
⇓	TM	⇓
Foundation, steel sizes	Piping bill-of-materials	Single line diagrams

Figure 3 "Trickle-down" effect from design basis to scope definition (engineering project).

Scope statements are generated for each of the major categorical disciplines of work (equipment, piping, structural, etc.). Scope statements may evolve 1) sequentially through a "trickle-down" effect or 2) iteratively. In many cases, the design basis can be followed immediately by a sequential series of detailed scope statements that "trickle down" one to the next. Figure 1.3 shows the evolution or "trickle-down" effect of a chemical process on the various disciplines of work on an engineering project. Calculations, specifications, drawings, and bills-of-materials are the deliverables.

Oftentimes, however, it is necessary to reiterate the design basis. An *iteration* or *looping* effect may be caused when a higher level scope requirement is impacted by a secondary requirement. For example, a process requirement may require a specific amount of floor space and ceiling height. The floor space and height are secondary requirements because they were caused by the process requirement in the primary design. The floor space or height requirements, however, may demand more space than is available (due to personnel access, future expansion plans, aviation height restrictions, or other reasons of which the process designer may have been unaware). These secondary space limitations will cause a reconsideration and modification of the process requirements or start a search for another site.

Defining the scope of the estimate requires that the design basis information be analyzed and assigned a functional and systematic structure. This working structure for a project and estimate is referred to as a work breakdown structure (WBS).

The Work Breakdown Structure (WBS)

One way to help clarify your scope is to prepare a work breakdown structure (WBS). A WBS is to an estimate as a table of contents is to a book—the

Pulp and paper project

- Pulp mill
  - Log storage
  - Debarking
  - Refining
  - Digesting
  - Bleaching
  - Interim storage
- Paper machine #1
  - Stock prep
  - Chemical storage
  - Paper stock feed
  - Paper machine
    - Wet end
    - Dry end
  - Parent roll storage
- Off-sites
  - Roads
  - Railways
  - Administration building
  - Maintenance/shops
  - Boiler house
  - Switchyard/power distribution
  - Waste boiler
  - Warehousing
  - Process utilities
  - Water treatment

Figure 4 WBS (diagrammatic style) of a pulp and paper mill (partial).

Pulp and paper project

1. Pulp mill
   a. Log storage
   b. Debarking
   c. Refining
   d. Digesting
   e. Bleaching
   f Interim storage
2. Paper machine #1
   a. Stock prep
   b. Chemical storage
   c. Paper stock feed
   d. Paper machine
      i. Wet end
      ii. Dry end
   e. Parent roll storage
3. Off-sites
   a. Roads
   b. Railways
   c. Administrative building
   d. Maintenance shops
   e. Boiler house
   f. Switchyard/power distribution
   g. Waste boiler
   h. Warehousing
   i. Process utilities
   j. Waste treatment

Figure 5 WBS (outline style) of a pulp and paper mill (partial).

former is an outline or guide to the latter. The WBS is typically a cascading outline of scope that lists the project as the topmost level of the structure and then subdivides into functional systems, physical areas, sequential phases, or other major subdivisions. Figure 1.4 depicts a partial WBS for a typical pulp and paper mill. Figure 1.5 is an equivalent "outline-style" WBS.

The lowest level of the WBS results in a list of items similar to the scope item details discussed above. If budgets and actual costs incurred are to be associated with the WBS, then the code of accounts is established at the appropriate level of the WBS. See the subsection *Code of Accounts*, below.

Categorical Breakdowns

In addition to the WBS, the estimator, in conjunction with the project team and company standards, typically selects practical *categorical* subdivisions of the work. "Categorical" means those items which are grouped by similar physical characteristics or the common disciplines of engineering/architecture such as process equipment, process piping, instrumentation and controls, structural, electrical distribution, etc.

For projects that are primarily buildings and commercial construction, it is common to use the Construction Specification Institute (CSI) MASTERFORMAT subdivisions as shown in Table 1. The CSI categories emphasize many of the architectural specialties that are common on building-type projects such as structure, exterior skin, building ventilation, building lighting/power distribution, carpentry (including windows and doors), and architectural specialties found in churches, schools, auditoriums, etc.

On industrial-type projects, it is more common to see a variation of this author's Industrial Categorical Breakdown (ICB) structure such as the one in Table 2. These categories put less emphasis on CSI's buildings, carpentry, and architectural specialties and more emphasis on process piping/ductwork, process equipment, electrical distribution, and process controls. These categories and numerical assignments vary from company to company to fit in with their business operation. For example, a company that specializes in electrostatic precipitator erection may have "Precipitators" and "Other Support Equipment" as distinct categories of work rather than the solo "05–Equipment" shown in Table 2.

Other type projects may require alternative types of categorization. For instance, in a regulatory environment, categories may be science, engineering, construction, regulations and licensing, and environmental safety and health.

Both the CSI and the ICB formats organize estimate items into specialties which correlate design/architectural scope with the physically installed quantities of work. Both breakdowns support the development of cost and schedule tracking systems since the design activities can be correlated with the construction activities, and almost any combination of work items can be linked

Table 1 CSI MASTERFORMAT Division Codes

CSI code	Description
01	General requirements
02	Site work
03	Concrete
04	Masonry
05	Metals
06	Wood and plastics
07	Thermal and moisture protection
08	Doors and windows
09	Finishes
10	Specialties
11	Equipment
12	Furnishings
13	Special construction
14	Conveying systems
15	Mechanical
16	Electrical

or sorted in a report grouping regardless of whether the work is performed by the designer or the constructor.

See Chapter 2 for a further description of *Work Breakdown* and *Cost Coding* systems.

Code of Accounts

A code of accounts is:

> a systematic numeric method of identifying various categories of costs incurred in the progress of a job; the segregation of engineering, procurement, fabrication, construction, and associated project costs into elements for accounting purposes [1].

As mentioned above, the code of accounts can be identical to the lowest level of the WBS or can be a finer level of detail if the WBS is not defined at the cost-capture level.

Formatting Required by End Users

The estimator needs to identify sorting, selection, and summaritzation/roll-up report requirements so that a code of accounts can be designed to meet any specific reporting need. "Sorting" is self-explanatory. "Selection" means being able to choose any single grouping or categorization of items to meet an end

Table 2 Typical Industrial Categorical Breakdown (ICB)

01	Site/civil
02	Foundations/structural (often split up as below grade/above grade or as concrete/steel)
03	Architectural/buildings
04	Building services (HVAC, plumbing)
05	Equipment
06	Instrumentation and controls
07	Piping and process duct
08	Electrical
09	Field overhead (general/special conditions)
10	Engineering
11	Contingency and management reserve
12	Escalation
13	Special (spares, owner costs, cost containment opportunities, etc.)

user's specifications. A "roll-up" is a summary of several subitems or subgroups. Through careful planning of cost codes, the estimator will be able to sort the estimate, divide it into distinct pieces, and distribute them to end users that need to see specific portions of the estimate.

"Sort, select, and roll-up" reporting are featured in most project management and standard office software applications. Since computers can provide information in a variety of formats and sorts to meet individual requirements, a well-planned code of accounts is essential to providing project team members with their work activities' associated budgets and costs. If all sort, select, and summary criteria are not identified at the planning stage of an estimate, they may not be able to be added later in the project.

C. Pre-Estimate Planning: The Estimating Process, Step 3 (See Figure 2)

Due to expediency and pressures to finish estimates, some estimators overlook, at least in part, this third step in the estimating process—Pre-estimate planning. It is a recognized fact, that when preestimate planning is practiced, it reduces the total effort to develop the estimate, provides associated information to other project participants, and minimize rework and hassle for the project team, not just the estimator.

Planning can mean determining resource needs, analyzing cost-time trade-offs, or assessing approaches, structures, processes and formats. Here is a checklist of common and necessary questions to aid in the estimate planning process:

- What will the estimate be used for?
- Considering the design basis and scope of the project, how defined is the scope?
- What estimate accuracy is required and with what risk?
- How/in what documents/formats will the scope be expressed?
- What estimating technique/algorithm should be used?
- What sources of estimating data are available?
- Who are the primary end users of the estimate product?
- Are there other less obvious end users of the estimate?
- What sorts, selects, and summaries are required?
- What is the format of the final estimate?
- What company standards and forms are to be used?
- By when is the estimate to be completed?
- Who should contribute to the estimate preparation process?
- What will the review process be and who will be involved?
- What will it cost to prepare the estimate?
- What are the units of measure to be used (monetary denomination and weights/measures)?
- Are there opportunities for scope reduction or constructability input?

There are numerous dimensions which need to be explored and each step will be discussed in detail:

1. Estimate purpose
2. Estimate type
3. Estimate accuracy
4. Estimate end users
5. Estimate format and forms
6. Estimate contributors
7. Estimate timing and review
8. Estimate preparation costs
9. Estimate units of measure

Many of the items discussed in Step 3 may seem redundant at first with items in Steps 4 through 9. However, this is not the case. The points in Step 3 have to do with *planning the execution* of Steps 4 through 9. The discussions on Steps 4 through 9 pertain to the *actual execution of estimating* at each of those steps.

Estimate Purpose

Planning the *estimate's purpose* means determining how the estimate will get used. Will the estimate be used: 1) for an appropriation, 2) to figure a life cycle cost including operations and maintenance, 3) for competitive bidding, 4) to verify the validity of a contractor's bid, 5) or used for some other purpose?

The estimate purpose is the main driver of the amount of time, money, and resources that will be required for estimate preparation. It is also the main determinant of estimate input requirements.

Estimate Type

The *estimate type* is the nomenclature that is used to describe one of the several estimate functions as explained previously in Section V.A.

Estimate Accuracy

As already stated, the required *estimate accuracy* is one of the main criteria which needs to be established at this stage. The required accuracy is directly related to the availability of information/scope, time, available resources (people, equipment, money), and estimating methodology or algorithm.

These four trade-offs describe the classic Estimating Paradox—the more accurate the estimate, the more information is required; the more information required, the more time is required to produce the estimate; the more time required to produce the estimate, the more resources are required to develop the estimate; the more resources required, the more money it will cost to produce the estimate; the more money spent, the more pressure to reduce resources, time, information, and accuracy.

Accuracy Depends on the Availability of Information/Scope. Estimate accuracy depends on how much is known about a project. An estimator should try to ascertain whether the project can best be described using either 1) physical sizes/quantities and equipment capacities/model numbers, or rather 2) a broadly stated intention to deliver a certain capacity per year. The most common approach to defining the scope is to define the "knowns." This is usually done with the aid of a work breakdown structure and code of accounts. Figure 6's [2] blackened space defines the boundary of the scope by emphasizing that which is included in the project.

It is also very useful to focus on that which is *excluded* from the scope to eliminate as much as possible, thereby, highlighting everything that remains. Refer to Figure 7 [2] to see how defining that which is excluded from the scope (Figure 7's blackened area) defines the boundary of the scope. The stating of both the included and excluded portions of the scope is referred to as an *"includes-excludes" scope specification/description.* This is a very powerful tool that reduces confusion and misunderstandings, thereby enhancing communication and documentation. As assumptions, paradigms, traditions, and standards are specified, fuzzy boundaries become clearer.

The quality of available estimating data also affects estimate accuracy. It is not uncommon for owners to use old estimates from projects that were never started as the basis for new estimates. Despite the lack of a project outcome, this approach may be quite adequate depending on the purpose of the estimate, the accuracy needed, and the time allotted.

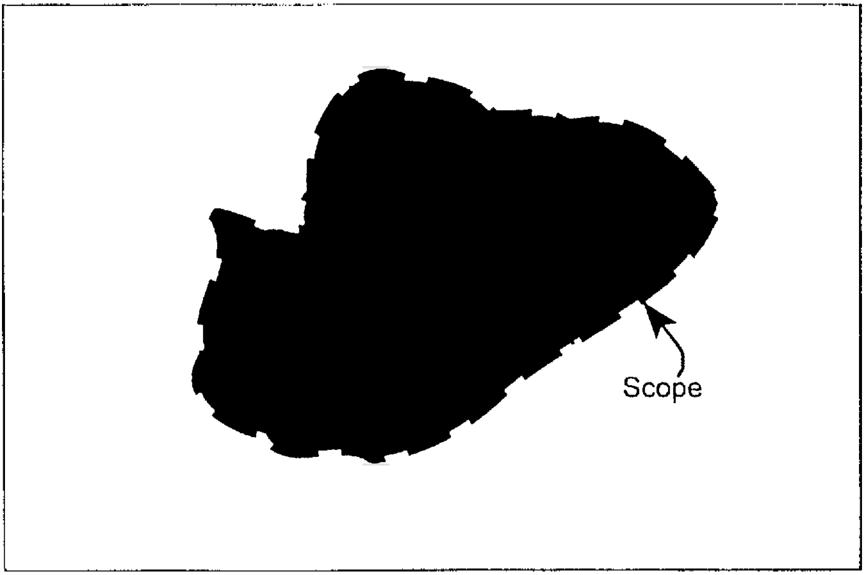

Figure 6 Scope defined as "included items."

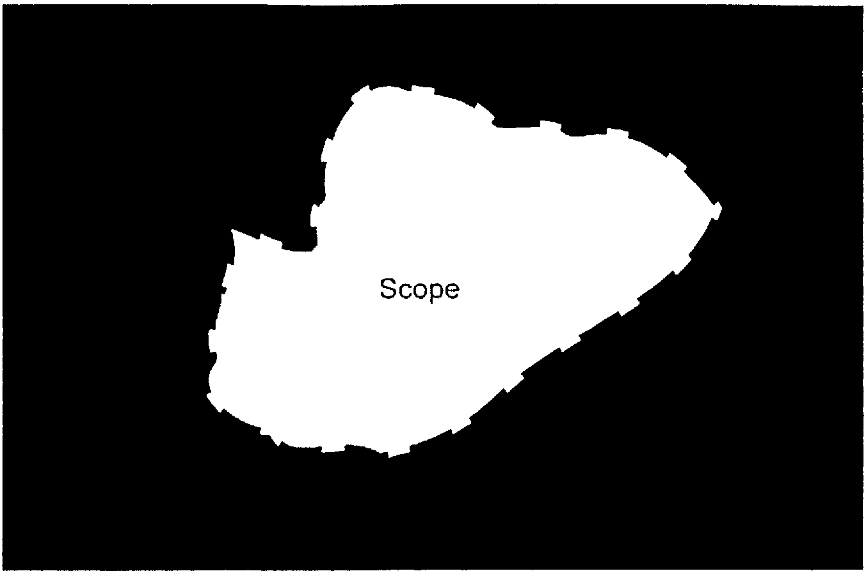

Figure 7 Scope defined by "excluded items."

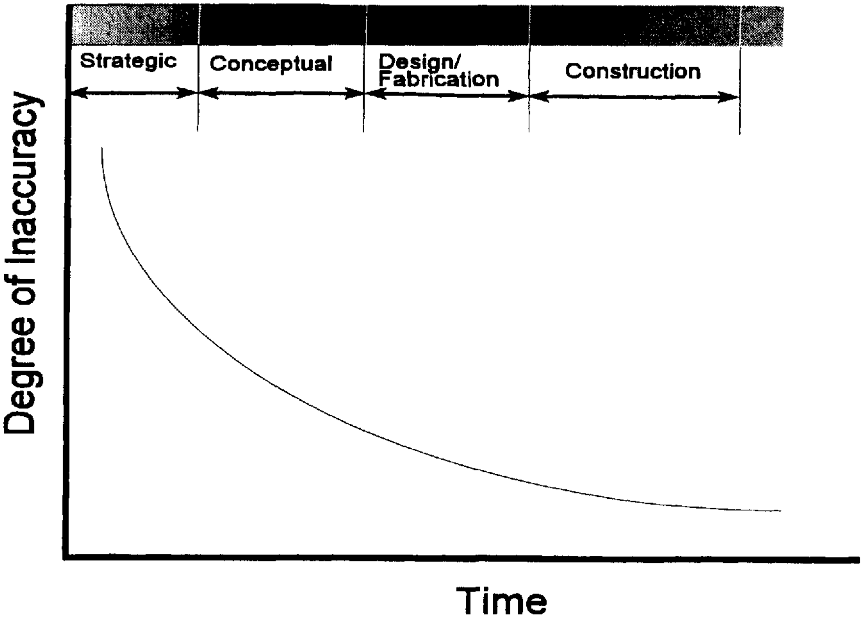

Figure 8 The effect of time on estimate accuracy.

Accuracy Depends on the Amount of Time Available. Consider the following four scenarios of having to prepare a project estimate in 1) three hours, 2) three days, 3) three weeks, or 4) three months. These four extremes are common in the estimating world and reflect different situations. The three-hour and three-day situations may fit a need to determine project feasibility as the capital cost is being compared to the operating cost. The project owner may need to know if the project will cost $100 million or $10 million. Depending on the resulting economics, risks, and opportunities, the company may have to decide whether to proceed with additional research and development activities. The three-week estimate would be a more detailed feasibility assessment, appropriation estimate, or contractor's submittal of a lump sum bid. The three-month estimate may be a detailed check of an in-progress large project to assess the final project cost based on final quantities.

Refer to Figure 8. In general, estimating accuracy increases (inaccuracy decreases on the curve) over time (project phase), mainly because of the availability, accuracy, and specificity of information. (Accuracy *could* change drastically at any point in time if major changes occur in the design basis.)

Accuracy Depends on Available Resources. The kind of issues that come into play here are 1) the number and qualifications of personnel to define the scope of the estimate and prepare the estimate, 2) the type/number of equipment resources such as computer hardware and specific software applications, 3) the amount of money available to prepare the estimate, and 4) the sources of estimating data.

Accuracy Depends on Estimate Type and Algorithm. The primary determinant of the estimate accuracy will be based on the amount and type of detailed information available. There are numerous algorithms which may be applied to produce an estimate, including the detailed quantity take-off, curve, parametric, and a variety of factoring algorithms. Estimating algorithms are covered in detail in Chapter 2.

The estimate purpose is the main driver of the amount of time, money, and resources that will be required for estimate preparation. It is alsto the main determinant of estimate input requirements.

End Users

Besides the original estimate requester, the estimator must also know in advance for what purpose the *end users of the final estimate* will use it. This information allows the estimator to determine which estimate summary reports and backup information will be required. By determining this information, the estimator can cross check against Step 2's scope definition criteria to validate the degree of accuracy, type of estimate required, estimate algorithm to use, amount of time to be expended, and the number/type of resources that are required to produce the estimate. Also, the estimator may be able to make arrangements to meet special needs. For instance, a project engineer may need to develop an equipment list to begin the procurement process. With the right tools and enough advance planning, the estimator can code the estimate so that all purchased equipment items (including complete specifications and descriptors) can be printed for the project engineer. Another example: the electrical department may need a rough estimate of horsepower demands to size an electrical distribution system for the project. This information may be be supplied by using the right computer tools.

Additional byproducts that come from estimates are 1) material quantities by category, discipline, or department; 2) manpower schedules; 3) cash flow data; 4) construction equipment demand list; 5) critical path schedules; 6) escalation backup calculations, etc. The estimator can provide any of this information *with the proper advance planning and resources.*

Estimate Format and Forms

The *estimate format* is the plan for organizing information in the estimate. Some common questions that are asked to define the estimate format are:

- What forms should be used for recording details, summaries, etc.?
- What are all the elements that go on the cover sheet?
- What summary information is required and how should it be presented?
- Are specific estimate breakdowns, sorts, and summaries needed (phases, systems, responsibilities)?
- If you are a contractor, does the owner have any specific sorting or reporting requirements?
- How will management want to see information to analyze the accuracy of estimate?
- What WBS naturally falls from the scope content and format requirements?
- What categorical breakdowns should be used (CSI, ICB)?
- How should the code of accounts be structured?
- What are the needs of engineers, contractors, construction managers and site supervisors with regard to estimate analysis and reporting?
- How will the contract strategy affect the format of estimate?
- How will productivity be estimated and tracked? Will it require a special breakdown of the estimate?
- Are there requirements for project cost trending, end of job cost feedback, or project scheduling that need to be considered before beginning the estimating process?
- What backup/tables/explanations should be incorporated?
- Do the estimate format requirements demand a computerized estimating system?
- What are the capabilities/limitations of the user's/company's estimating, cost control, financial, and scheduling software? How may they aid/inhibit estimate summarization, cost tracking, and scheduling? (NOTE: It is generally recommended that software be selected/designed to meet the reporting requirements, not the other way around—a commonly misunderstood concept found frequently in industry and government. Software is a tool to aid in the reporting of project costs, which itself is a tool in managing a project. As is the case with any tool, each should be designed to fit its specific application.)
- What are the company's standards with respect to a) code of accounts, b) direct costs, and c) indirect and other costs?

The estimate compilation is a major consideration in Pre-Estimate Planning. The estimate compilation is the manner in which the estimate is assembled—that is, which pages will encompass the estimate (cover, detail sheets, summary, backups) and which columns are required on the estimate detail/summary sheets.

In addition to items already discussed like WBS, code of accounts, and sort/select/summary reports, the estimator must select the appropriate estimating forms. Four types will be discussed briefly.

Estimate Detail Forms. Detail forms contain the deepest level of scope item descriptions and associated direct costs. Prior to the development of the estimate detail items (Step 4), the estimator must possess all documentation that defines the scope of the project. Written design basis and scope statements, drawings and sketches of any type, quotes and purchase orders, specifications, etc. are used to formulate the estimate details.

This discussion provides some guidelines in choosing and designing forms with regard to estimate planning. Many companies have choices of standard forms based on: 1) whether the labor is plant labor or contract labor, 2) whether construction equipment is considered a direct cost or an indirect cost, 3) whether the job will have subcontractors involved, 4) varying plant locations, or 5) other distinctions.

Table 3 lists the types of columns (fields) found on many standard estimate detail sheets and software. An example of an estimate detail form is shown in Figure 9.

Estimate Summary Sheet. The estimate summary sheet generally itemizes 1) the subtotal of each direct cost category (as determined in "sort/select/ summary" planning and 2) the subtotal of each indirect cost category. The calculation of these indirect costs on the summary sheet are covered in Step 7. See the example estimate summary form in Figure 10.

Estimate Cover Sheet. See Step 7 for a list of questions that are often used on cover sheets.

Estimate Assumptions/Documentation. The documentation of assumptions is critical to the understanding and interpretation of an estimate. Sufficient planning should be done up-front so that all critical documentation gets recorded during the traditional estimating process. The logging of drawing and specification changes may have an effect of putting forth a claim for extra work. Change order logs, responsibility matrices, and other general project management tools can be used to document the basis for the estimate.

Estimate Contributors

It is not uncommon for the estimator to receive an incomplete scope statement—a good list of process equipment, instrumentation, and piping, yet weak in site, buildings and associated support systems, structural, electrical, and off-sites considerations. On any size project, these missing items can have significant impact on costs. On detailed estimates, it is important for the estimator to have sufficient discussions with the primary and secondary scope providers to explore the technical correctness and completeness of the scope. Conceptual estimates need to be explored for missing items because many techniques deal with battery-limit processes and the off-sites are add-ons.

Table 3 Column Descriptions for Estimating Forms

Item number	A sequential number, code of account, WBS, or other reference number. (Best if in an ordered sequence, thus making lookup and reference convenient.)
Item description	Descriptive and pricing information, assumptions, qualifiers, and adjustments about each scope item. See Step 4 on how to write an adequate item description.
Quantity and unit of measurement:	Often incorporated with item descriptions. Need to be a discrete entry when computers accumulate common quantities or multiply unit prices and quantities. [Example: 5 CY]
Labor unit rate:	The rate at which the work is to be accomplished. Either expressed in hours per quantity and used as a multiplier or expressed in quantities per hour and used as a divisor. Used in conjunction with the "quantity" field, above, to compute the total hours of effort. [Example: 10 CY per hour used with the 5 CY from above would yield ½ hour of work.] The rate may be that of a single craft or a composite crew.
Labor wage rate:	In most companies, the wage rate (expressed in dollars per hour) that is paid to the laborer or crew. For field labor, this generally includes hourly fringe benefits.
Labor type:	Relates to the labor unit rate above and may be a single craft/trade or a combination of craft personnel into a crew. Only used for plant maintainance or contracted construction field labor. Excludes labor performed by 1) subcontractors, 2) home office or field staff, or 3) the engineering/design function. Also excludes the labor portion of fabricating purchased equipment or materials.
Labor hours:	Some types of estimates don't have enough detail to state this information. In some estimates, the estimator will estmate the number of people and time duration needed to accomplish the item. This is called *crewing*. In another circumstances, the hours are computed from the quantity and the labor unit rate.
Labor $:	May be a direct dollar entry, the result of an estimate algorithm, or the extension of quantity, labor unit rate, and wage rate.
Material unit rate:	The estimated unit price of materials (expressed as $ per quantity). Used in conjunction with the "quantity" field, above. [Example: $45/CY]

Table 3 (cont.)

Material $	May be a direct dollar entry as a result of an estimate algorithm, quotation, or the extension of quantity and material unit price. Note: Sometimes the Material $ is split into 2 or more sets of columns—one for owner or design contractor purchases, another for construction contractor/field purchases, and a third category could be materials that are to be withdrawn from the plant stores/warehouse. As computer systems become more sophisticated, many owner companies are integrating their estimating systems with the stores warehouse inventory so materials can be allocated to the project and ordered if in short supply. May also include freight, duty. Sales/use taxes are usually excluded here.
Subcontract unit rate	Although rarely used, it is similar to the labor unit rate in that it is the rate at which the subcontracted work should be accomplished. If used, it would be used in conjunction with the "quantity" field, above.
Subcontract $	May be a direct dollar entry as a result of an estimate algorithm or quotation, or may be the extension of quantity and subcontract unit price.
Construction equipment unit price	For companies that treat construction equipment as an indirect cost, this field is not applicable. However, when it *is* treated as a direct cost, this is the unit price at which the construction equipment is rented, or, if owned, the charge out rate for that equipment. When equipment is rented, the price excludes the labor for operating the equipment when the laborer is an employee of the contractor. When the equipment is rented as M&O (maintained and operated), then the labor to operate and maintain the equipment is incorporated with the equipment rental rate and is in the price that's reflected in this column. When used, it's used with the "construction equipment duration" field, below.
Construction equipment duration:	The amount of time for which an item of equipment is needed for a particular item. This is only used when construction equipment is treated as a direct cost.
Construction equipment $	This may be a direct dollar entry as a result of an estimate algorithm, quotation, or the extension of the duration and construction equipment unit price.

Description	Quantity and unit	Hrs	$Labor unit price	$Labor	$Material price	$Equipment unit price	$Equipment	$Subcontract	$Total

Figure 9 Sample estimate detail form (labor, material, construction, equipment, and subcontract). Construction equipment is often given as an indirect cost.

Description	Hours	Labor $	Material $	Equipment $	Subcontract $	Total $
Direct costs						
1. General requirements						
2. Site work						
3. Concrete						
4. Masonry						
5. Metals						
6. Wood and plastics						
7. Moisture-thermal control						
8. Doors, windows, and glass						
9. Finishes						
10. Specialties						
11. Equipment						
12. Furnishings						
13. Special construction						
14. Conveying systems						
15. Mechanical						
16. Electrical						
SUBTOTAL-direct costs						

Indirect costs						
Labor payroll burdens						
Construction equipment (not listed above)						
Field overhead						
Office overhead						
Overtime (L) and sales tax (M)						
Cleanup						
Other (permits, licenses)						
Bond [for general contractors]						
Constructor's fee						
Engineering						
Escalation						
Contingency and risk protection						
Owner costs						
Miscellaneous adjustments, rounding						
SUBTOTAL-indirect costs						
Estimate review adjustments						
GRAND TOTAL						

Figure 10 Example of estimate summary sheet (CSI format).

Depending on the situation, the estimator may require additional technical assistance from other contributors. Work peers and supervisors are certainly potential "internal" contributors. Equipment and material suppliers, consultants, professional colleagues and association contacts, contractors, competitors, municipalities and agencies are potential "outside" contributors to the estimate.

A final consideration is the number of/specialty of required estimators. There may be technical and estimating expertise within the company that can be an aid to the assigned estimator. On larger projects, a team of estimators is often assembled with a lead estimator assigned the responsibility to coordinate the entire estimating process for this project. On these types of projects the lead estimator will incorporate the details of the other specialty estimators; review their work; put together the estimate summaries, subsorts, assumptions, documentation and cover pages; and coordinate the review/sign-off process.

All estimate contributors and reviewers should be documented during the application of Step 8—documentation and checking.

Estimate Timing and Review

Estimate timing involves finding out when the estimate is due. The ability to make the deadline is dependent on the amount of estimating to be done (scope detail), the number of estimating resources available, and the estimate review cycle. Estimate reviews can be time intensive and may lengthen the estimate preparation schedule. Before starting the estimating process, estimators should always inquire as to who will review the estimate so the review process can be incorporated into the estimate preparation schedule.

Consider the following checklist of questions to plan the estimate's timing and review:

What is the due date of the estimate?
Who has estimate review responsibility?
Who has estimate signature authority?
Is the reviewer sequence important?
Are there reviewers from outside the estimator's company that must review/sign (client, supplier, contractor, subcontractor)?
Will any of these people be unavailable for participation in the review process at the time the estimate is scheduled to be issued for review?
Are there special summaries which the reviewers will require to best assess the estimate?

Step 9 in the estimating process discusses carrying out the estimate review process.

Estimate Preparation Costs

Prior to starting work on a large estimate, many owners request an "estimate of the estimate"—that is, an estimate of the cost required to prepare the estimate.

Estimate Units of Measure

As international competition grows and international standards like ISO 9000 are being stressed, estimators need to consider money denominations, English/metric conversions, and even foreign language translations.

D. Quantity Take-Offs and Item Descriptions: The Estimating Process, Step 4 (See Figure 2)

With planning and formatting complete, the estimating process now accelerates. At this point, the "estimator" gathers all available scope definition documents and then begins to develop the details of the estimate (often called "scoping"), first for the direct costs and then the indirect costs. In effect, Steps 4 and 5 are done twice—once for the direct costs on estimate detail sheets (Figure 9) and again for the indirect costs on the summary sheet (Figure 10) with accompanying support backup.

This step includes the performing of quantity take-offs (QTOs), when applicable, and noting all scope items on estimate detail sheets. Regardless of the type of estimate (feasibility, detailed, etc.), estimate items *must* be listed. Estimate request forms, written design basis, drawings/sketches, specifications, contracts, purchase orders, and bids are some of the source documents used for developing detailed estimate scope items. QTOs may be done manually or by using electronic digitizers in conjunction with estimating software. Since the QTO for detailed estimates is one of the most time-intensive activities in the estimating process, computer systems are being used more frequently by contractors and owners. Estimating software is available both commercially and in nearly-free shareware.

The description may be the *most* significant factor affecting pricing variability on any estimate item (other than contingency unknowns). This is so because the quality of the estimate item description is highly variable from estimator to estimator. *Here's the acid test for an adequate estimate item description*:

> An estimate item description is adequate if a different estimator reads the estimate item description and, using the same source of data, derives the same estimated costs as the original estimator did.

A complete description includes: a quantity and applicable measurement unit; a physical description of the item in as much detail to meet the adequate estimate item definition, above; the "includes-excludes" clauses which clarify the scope boundaries as explained earlier in the chapter and as highlighted in Figures 6 and 7; qualifications or assumptions which further define the scope boundaries, and the basis for any adjustments that were made; and sources of estimating data. Regardless of how detailed or conceptual in nature the estimate is, *always leave an audit trail.* Descriptive audit trails will help others later if they need to retrace your thought processes.

Quantity and Measurement Unit

The *quantity* comes from looking at the source material and performing a quantity take-off in the case of construction drawings, a series of items that comprise a composite item such as a conceptual sketch, process flowsheet, or floor plan/layout drawing; or, on a larger scale, a full or subprocess/building. The *measurement unit* (cubic yards, lineal feet, units) must also be supplied to carryon numeric extensions of like units.

Physical Description

The *physical description* normally amounts to such items as capacity, function, materials of construction, manufacturer, size/dimensions, weight, assumed work method, QTO source such as the drawing/sketch number, specification, etc. Often a reference to the estimating data source (described in Step 5) is included here.

"Includes-Excludes" Clauses

As discussed above, the "includes and excludes" statements can add a great deal of clarity to the scope of the estimating item by specifically stating any ambiguities or assumptions and by documenting any diversions from traditions, paradigms, conventions, or standards.

Study this example of a description for a detailed estimate item:

> Place concrete for foundation F2 for Pump-101 per drawing CU-007; 1' × 3' × 8' = 1 CY (including 5% waste). Concrete in-place includes rebar, formwork (2 uses including installation and removal), anchor bolts, concrete placement, and finishing, excavation and backfill. Excludes QA tests and construction equipment costs. Assumes work is performed at grade in average working conditions. Use productivity as 0.85. Data is from Means Construction Cost Data, 1993, data item 14–380.

This example demonstrates three important features of any scope item's description by: 1) listing all subitems *included* in the scope (concrete, rebar, formwork with two uses, etc.), 2) listing all subitems *excluded* from the scope (QA and construction equipment), and 3) leaving an audit trail by clarifying items that are unclear, ambiguous, or a variation from a standard (clarifying the "concrete in-place" paradigm of working at grade with average working conditions, productivity stated). Although the scope is not priced out, it is likely that another estimator would derive the same cost figures as the original. If a different cost figure *were* derived, there would be a basis for discussions to resolve the differences in approach.

Qualifications, Assumptions, and Basis for Adjustments

Qualifications and assumptions are stated for each item to document what is known and what is not known about a project. Since many people review and use a given estimate, a variety of different interpretations can result within a team.

Sources of Estimating Data

Take as much time as possible to select the most adequate data sources that you can for each estimating task. A broad range of estimating data sources is discussed in Step 5.

Remember, the most detailed estimate is not always the most adequate. Conceptual estimates are expected to have less detail, less accuracy, and more contingency and risks. Estimate data sources are discussed in detail in Step 5.

E. Data Sources and Costing: The Estimating Process, Step 5 (See Figure 2)

This step is the money step. It deals with two different money-associated activities: obtaining data from data sources and costing.

Obtaining Data from Data Sources

Data sources come in many forms and are similar to the physical states of matter—solid, gel, liquid, and gas. The "hard" numbers are purchase orders (POs), quotes, and the like; "gel" numbers come from cost histories or commercially available data sources; "watery" numbers come from old estimates in the estimating files or from a team's best assessment of the estimated value; and a "gaseous" number that, in effect, is a guess.

Many published estimating data sources are available and are listed in Table 4. There are other resources that can be used for estimating such as the National Electrical Contractor's Association (NECA) "Manual of Labor Units" for electrical work (and other trade publications); labor agreements from labor brokers; estimating standards housed within many contracting and owner company's libraries (usually not for the general public's use, however); numerous publications available from professional associations such as AACE International, Morgantown, WV, the American Society of Professional Estimators, Wheaton, MD, or the Society of Cost Estimating and Analysis, Arling-

Table 4 Commercial Publishers of Capital Cost Estimating Data [3]

Associated Equipment Distributor's Compilation of Averaged Retail Rental Rates for Construction Equipment	Associated Equipment Distributors	Oak Brook, IL
Austin Building Cost Index	The Austin Co.	Cleveland, OH
Boeckh (several publications)	American Appraisal Association	Milwaukee, WI
Bureau of Labor Statistics (several publications)	Bureau of Labor Statistics, US Department of Labor	Washington, D.C.
Chemical Engineering (several publications)	McGraw-Hill, Inc.	New York, NY
Engineering News-Record (several publications and indices)	McGraw-Hill, Inc.	New York, NY
Fuller Building Cost Index	George A. Fuller Co.	New York, NY
Handy-Whitman Index of Public Utility Construction Costs	Whitman, Requardt, and Associates	Baltimore, MD
Marshall and Swift (several publications/indices)	Marshall and Swift	Los Angeles, CA
Means Construction Cost Data	R.S. Means Co.	Kingston, MA
Richardson Process Plant Estimating Standards	Richardson Engineering Services, Inc.	Mesa, AZ
Smith, Hinchman, and Gryllis Cost Index	Smith, Hinchman, and Gryllis, Inc.	Detroit, MI
Turner Building Cost Index	Turner Construction Co.	New York, NY
U.S. Federal Highway Administration (FHWA) Highway Construction Price Index	U.S. Federal Highway Administration	Washington, D.C.
U.S. Department of Commerce Composite Construction Cost Index	U.S. Department of Commerce	Washington, D.C.
Walker's Building Estimator's Reference Book	Frank R. Walker Co.	Lisle, IL

ton, VA; tables of weight and measures for unit conversions; currency exchange tables; etc. Other sources are consultants in the estimating field, your work colleague, or an associate from a professional or trade association.

Costing

To compute an estimate for an item, you need to know the scope from Steps 2 through 4 and have a source of cost data. Once found, the cost data and the scope are combined to establish the cost for each estimate item—both direct and indirect costs. This process is called *costing*. The estimated amounts are entered on the estimating detail form.

The costing process may require 1) extending unit rates and quantities to obtain the cost, or 2) allocating the amount of money directly to the labor, material, or subcontract (LMS) portions of the item. To obtain the direct cost totals of any category, we apply the costing process to all scope items which have been priced in Step 5 of the process. [Note: Sometimes, but rarely, construction equipment is treated as a direct cost. When labor, material, subcontracts, and construction equipment are all direct cost items, we will refer to these as LMSEs rather than LMSs.]

Labor costs should specify, if at all applicable, all field craft/crew levels for scheduling and manpower planning needs. Plant labor should be distinguished from contractor's and shift work should be noted. Wage data, crew sizes, productivity, etc. should be documented in a backup sheet.

In some cases, labor costs are allocated as a "chunk"—an educated guess by the estimator. In other cases, labor is derived by estimating the number of people working for an estimated amount of time to accomplish the task. This is referred to as *crewing*. Labor costs may also be derived from quantities, unit production rates, and wages as follows in Figure 11:

Materials are often separated into classifications such as owner's purchases and contractor's purchases. The contractor's purchases are sometimes differentiated between those purchased by home office and purchased by field. This separation helps in procurement management. Some owners differentiate materials bought by themselves, the engineering contractor, and the construction contractor. Some owners itemize materials that come from the owner's existing inventories or from corporate parts warehouses.

$$\$\text{Labor} = \text{Quantity} \times \text{production} \times \text{wages}$$

$$\$\text{Labor} = \text{Quantity} \times \frac{\text{hrs}}{\text{Quantity}} \times \frac{\$}{\text{hr}}$$

Figure 11 Calculation of labor from quantities and unit productions.

Estimating techniques differ with the type of estimate being prepared. Labor, material, subcontract, and construction equipment costs are estimated using ratios, parameters, cost chunks, or extension/multiplication methods (see Chapter 2). You now see how the estimated costs are obtained from data sources and are applied to scope items. Let's move to Steps 6 and 7 to see how costing is applied to direct and indirect costs.

F. Direct Cost Totals: The Estimating Process, Step 6 (See Figure 2)

Before explaining the methods for obtaining costs, it's necessary to understand the difference between *direct* costs and *indirect (other) costs*. Near the beginning of this chapter under Capital Cost Estimating Terminology, *direct cost* is defined as:

> the cost of installed equipment, material, and labor directly involved in the physical construction of the permanent facility

and *indirect cost* is defined as:

> all costs which do not become a final part of the installation, but which are required for the orderly completion of the installation and may include, but are not limited to, field administration, direct supervision, capital tools, start-up costs, contractor's fees, insurance, taxes, etc.

The subtotaling of direct costs takes place here in Step 6 using the extension method or direct dollar entry method. The subtotaling of indirects is done on the summary sheet in Step 7, below.

Now add the subtotals of all direct cost categories (or whatever category of organization you've chosen) and transfer the subtotals of each group to the summary sheet.

G. Summary and Cover Sheets: The Estimating Process, Step 7 (See Figure 2)

This section briefly describes the preparation of an Estimate summary sheet and Estimate cover sheet

Estimate Summary Sheet

The purpose of the summary sheet is to state the total estimated cost for the project by providing a format for recapping all the project's *direct costs* and a checklist for itemizing, costing, and recapping the *indirect costs*. Regardless of the type of estimate that is being prepared, management generally will expect to see a summary sheet. The summary sheet provides a quick overview of the project costs. If desired, it can also provide the ratios of costs for comparison to known standard/common ratios. Ratio checking is a common method to see if any costs are "out of range."

Direct Costs. The estimate summary sheet's direct cost section should reflect the categories that were used for the detail sheets. Additional summaries are provided based on agreements made at the pre-estimate planning sessions. Note that the summary sheet in Figure 1.10 recaps the direct cost values plus functions as a checklist of common indirect cost items.

Indirect Costs. The indirect costs don't usually take as much time to estimate as the direct costs do, but their cost contribution is *significant* and, at times, exceeds the direct costs. Indirect costs may include any of the following items [4]:

Direct labor payroll burdens (social security, unemployment insurance, worker's compensation)
Overtime (premium pay portion) on field labor
Sales taxes on the direct and indirect materials and, when applicable, labor
Clean up
Field overhead (includes the field staff, payroll and payroll burdens, office, small tools and construction equipment, consumable supplies, and temporary construction facilities such as power, trailer, roads, etc.)
Office overhead (home office, staff support, payroll, and payroll burden)
Engineering
Bond (for general contractors)
Contractor's profit/fees
Escalation
Contingency/management reserves (risk assessment)
Nonproductive time such as rework, training, safety meetings, "show-up pay" due to bad weather
Other (permits, general insurance premiums, royalties, licenses, and freight/duty when not included with direct costs)
Owner's costs
Adjustments (includes rounding, late adds, estimate changes that result from estimate reviews. Even though these may be direct cost adjustments, it's often convenient to make these adjustments on the indirect cost summary sheet as a one line entry.) If used, leave an audit trail so adjustments can be alloted to the appropriate item for cost control purposes

Many of the indirect costs are related to the direct costs. Some companies use a range of ratios or factors which are applied to the direct labor and material to calculate the indirects. Labor burdens, sales tax, small tools and consumable supplies may be related to the direct costs. Depending on the type of estimate, office and field overhead, construction equipment, and non-productive time may be calculated from the directs using a factor or may be scoped in detail and computed. Escalation and engineering costs are often estimated in detail or can be factored as a percentage of the subtotal of direct and the field-related indirect costs (often called construction costs).

Contingency costs are put in the estimate to *add funds for uncertainties that will most likely occur*. Contingency does *not* cover scope changes or major unforseen events such as natural disasters or strikes. *Allowances* for scope items which are known but not quantifiable should be treated as *direct costs—not contingency*. Many owner companies treat contingency as funds which make the risk of overrunning/underrunning the project a 50–50 probability. Additional contingency funds, often called *management reserve* or *risk protection funds*, may be added to lower the chances of overrunning. A number of software programs are available that analyze the risks associated with the project scope, schedule, etc.

Estimate Cover Sheet

The estimate cover sheet is the first sheet that anyone sees so it should have the following basic information:

Name of project and location
Name/initials of estimator, checker, requester
Estimate number
Date of preparation/revision and revision number
Any security information clearly marked (such as "Confidential")
Type of estimate (order of magnitude, appropriation, bid check, etc.)
Brief design basis
Sources of labor, project management, and engineering
Assumed method of contracting
Estimated total cost and range of accuracy
Schedule-related items that affect cost (assumed duration, assumed appropriation date)
Name of the software and version number used to prepare the estimate, if applicable
Other broad assumptions or qualifications that affect the estimated total cost
Comments on items of special interest to current end user and potential future users
Indices that were used in the estimate (may be of value if used in the future to prepare other estimates
Any items which the estimator finds as optional/discretionary with associated cost values for each
Signature lines including name and date

You should prepare your cover sheets with the current project participants and end users in mind. Also provide adequate information so that the estimate can be properly used in the future to prepare other estimates.

H. Documentation and Checking: The Estimating Process, Step 8 (See Figure 2)

The documentation and checking step involves writing down the basis for the estimate if not already stated. The following checklist can serve as the ABCs for documenting an estimate:

Anything on the cover sheet checklist from Step 7 but not itemized on the cover sheet

Basic lists, documentation, or assumptions that support the estimate such as lists of applicable drawings and specification with revision numbers, special codings used in the estimate, sources of estimating data and indices, etc.

Calculation backup to support contingency, escalation, crew wage rate buildups, etc.

Documentation and assumptions that govern the estimate such as working conditions, procurement strategies, assumed productivity levels, job condition factors, and working conditions, etc.

Explanations of adjustments in the estimate such as changes made during the final review

Finishing touches such as correctness and thoroughness on cover sheet, summary sheet, and all necessary backup attached

Checking involves:

Verifying that calculations (extensions and addition) are valid

Using Step 4's "acid test for an adequate description and cost"

Revalidating estimating data sources where time, risk avoidance, or judgement so indicates. Consider doing this particularly when computerized estimating techniques are used. Don't assume that an estimate is necessarily correct just because it's computer generated.

Verification that category ratios (as a percentage of direct cost), labor-to-material ratios, and other factors used by the company to verify the estimate are logical. Take advantage of company historical records and the experience of management, the estimating supervisor, and the checker.

Conducting peer reviews by company or other professional colleagues to bring fresh perspectives to the estimating/project team. Get the field involved with the estimate preparation or review, if possible. *They* have to live with it.

When making comparisons, make sure that you're comparing "apples with apples" rather than "apples with oranges." In other words, "Grow apple orchards or you'll end up with fruit cocktail."

Few and wise are the companies that spend the time and money routinely utilizing all these estimate checking methods.

I. Management Review: The Estimating Process, Step 9 (See Figure 2)

There's an old estimating saying:

> There's no such thing as a good estimate—if the job underruns, then it was either well designed or the team did a great job. If the job overruns, it was due to a bad estimate!

Whether you agree with this philosophy or not, management plays a big part since 1) they are usually responsible for oversight of estimate preparation and 2) they typically have the insight and experience to know "what could go wrong."

J. Estimate Issue and Filing: The Estimating Process, Step 10 (See Figure 2)

Since estimates contain an extensive amount of project-related information, they are working documents to the project team on active projects. Due to their historical value, they need a degree of protection. In either case, they require a dependable, systematic method for storage, reference, and control.

Estimates are usually numbered and then filed in a known location. In some cases, this is a secured area with access granted to specific personnel only. A database can be kept that journals the general estimate cover sheet information (Step 7) keyed to the estimate number, estimator, locations, or other important indices.

Estimate numbering systems need to be well-thought out so that retrieval is easy and convenient for the users and that end users benefit from the system. Numbering systems are generally designed with the corporate structure in mind—that is, if company has a central estimating group then estimates may be numbered consecutively or divided by customer/project type. In decentralized organizations, estimate numbering systems are generally maintained and assigned within each distinct company division. Number control is important and must be maintained so that estimate numbers are not duplicated and the numbering system maintains its integrity.

Master copies of the estimates are maintained with good document quality control practices to ensure that:

Each estimate has a unique number.
All copies that are lent out are trackable and get returned. Estimate sign-out logs or file folder "place holders" work well in some environments.
Volume of estimated costs and numbers of estimates can be accrued for reporting to management.
The filing system is secure. Some estimates can become legal evidence, so estimate storage security must be maintained.

K. Cost Feedback Continual Improvement: The Estimating Process, Step 11 (Figure 2)

A project remains incomplete until the construction site is cleaned up, the contractors are gone, all claims are settled with final payments made, and the owner has signed off on the final acceptance report. So too the estimating process is not done until: 1) a final project close-out report is prepared, 2) all actual costs from the cost reporting system have been turned over, and 3) the historical data has been processed into a cost data collection system. This is extremely important so that the accuracy of the estimating data, estimator performance, and project histories may be developed.

Contractors and owners should consider spending extra time, money and effort at the end of project to produce these project/estimate completion records. They are invaluable in recording lessons learned and in compiling data to support estimating.

VII. SUMMARY: ESTIMATING TIPS

The following statements are repeated from the chapter for emphasis and others added for additional information.

The estimator is to assume a role beyond that of the stereotypical "dollars-and-cents number-cruncher" by examining the entire project's infrastructure and the basic organization requirements of the estimate.
Ask questions to clarify end users' needs, design basis, scope, and format—and assume nothing.
There are 11 Steps to the Estimating Process.
Plan, PLAN, **PLAN**!
As speech writers need to know their audience, and as advertisers need to know their target market, so too, the estimators need to know their end users.
The description could be the *most* significant factor affecting cost variability on any estimate item.

An "includes-excludes" scope specification/description is a very powerful tool that reduces confusion and misunderstandings and enhances communication and documentation. Use both parts.

Document everything: assumptions, references, sources, dimensions, capacities, boundary conditions (includes/excludes).

Don't assume that an estimate is necessarily correct just because it's computer generated.

Always leave an audit trail.

Data sources come in many forms and are similar to the physical states of matter—solid, gel, liquid, and gas.

Prepare your cover sheets with the current project and end users in mind.

The only thing that's constant is change. The only way to manage it, is to document it!

Get construction involved with the estimate preparation or review, if possible. *They* have to live with it.

Estimates serve many functions, one of which is to determine the cost of the scope of work.

Estimate accuracy depends on the amount of information, time, and resources that are available, and estimate type/algorithm.

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2
Estimating Methodology

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I. INTRODUCTION

This chapter discusses the methods used to implement the estimating process described in Chapter 1. *An effective methodology consists of a standard set of cost estimating practices, resources, and tools that are consistently applied in all estimates.* This includes: a variety of estimating calculation techniques that are tailored to the information available at each project phase, a relevant cost estimating database with a hierarchical structure that provides continuity in information management and project controls, and tools and software that efficiently apply the calculation techniques and data to produce reliable cost estimates.

Specifically, the elements of methodology described in this chapter include:

Algorithms/cost estimating relationships (calculations and adjustments)
Cost estimating database (factors and parameters for use in algorithms)
    Data sourcing (obtaining, manipulating, or creating cost estimating data)
    Data management (organization/structure/coding, storage, maintenance)
Cost feedback (historical cost analysis, benchmarking, methodology calibration)

Tools (forms, hardware, and software; linkages to other project process tools)
Procedures (organization and approach to make the process work)

Each type of algorithm is described in detail and illustrated with examples. The remaining topics from the list above are discussed in the context of how they relate to the various algorithm types and the estimating process phases described in Chapter 1. References are provided where the length of the chapter prohibits in depth discussion.

II. ALGORITHMS OR COST ESTIMATING RELATIONSHIPS (CERS)

A. Estimate Types and Naming Conventions

Before jumping into the details of the methodologies, it is useful to understand the terminology used to label estimate types. Engineers should be aware that estimate naming conventions are the source of a lot of confusion. Names such as "budget" estimate or "rough order of magnitude" estimate tend to describe only a single characteristic of an estimate methodology, when in fact there are at least four main characteristics that need to be defined in order to understand what the estimate is all about. The four defining estimate characteristics that need to be specified by an estimate name or description are shown below along with a brief indication of how each characteristic changes with the progress of the project cycle;

1. End use of the estimate—changes from screening to control
2. Estimate content and input information—changes from summary to detailed
3. Accuracy range—changes from broad to narrow
4. Calculation technique—changes from stochastic to deterministic

As an example of how these characteristics change, consider the word "budget. While it is intended to reflect the *end use of the estimate*, many individuals will also *incorrectly* assume that it also reflects a *calculation technique*. As another example, the term "conceptual" estimate has been used interchangeably to indicate an *accuracy range* or a *calculation technique*.

For these reasons, there is currently no universally accepted naming or categorization approach. However, Figure 1 attempts to show most of the naming schemes to be found, showing their relationship to the four characteristics described above. Note that the accuracy ranges shown only apply to estimates for the process industries.

As can be seen, engineers must not rely upon a single word name to convey an estimate's characteristics. It is essential to describe each of the estimate's four defining characteristics in the estimate basis (see Figure 1). A statement such as a rough, order-of-magnitude, capacity factored, screening estimate based upon a block flow diagram with an accuracy range of +50/–30%" will yield much better understanding than just calling the estimate "rough." Further definition of these characteristics and terms will be provided later in this chapter.

B. General Form

Basic Algorithm Formats and Terminology

At the root of all estimating techniques is an estimating algorithm or formula. The algorithm in effect transforms project technical and programmatic descriptive information into cost terms. These estimating algorithms are often referred to as cost estimating relationships (CERs). In a very simple, but common form, a CER may appear as:

Cost resource = factor × parameter

where:

Cost resource	=	\$ (total, labor, or material, etc.), or time (labor hours, equipment rental hours, etc.)
Factor	=	a unit cost factor in terms of resource/unit of measure
Parameter	=	units of measure of the estimate item

In mathematical terms, the CERs are either stochastic in nature (based on conjectural cost relationships and statistical analysis), deterministic (based on conclusive, definitive cost relationships), or some combination of these. In cost engineering terms, the stochastic approaches are often called *parametric estimating* and the deterministic approaches are called *detail unit cost* or *line-item estimating*. To see how the generic CER form above could be applied for either detail unit costing (deterministic) or parametric estimating (stochastic), consider the following two simplistic examples of a cost estimate for a concrete foundation to support a large pump:

- Detail unit cost estimating:

$$\begin{aligned}\$\text{ of concrete} &= \$500/\text{m}^3 \times 12\text{ m}^3 \\ &= \$6{,}000\end{aligned}$$

- Parametric estimating:

$$\begin{aligned}\$\text{ of concrete} &= \$5\text{ concrete}/100\$\text{ of pump cost} \times \$120{,}000\text{ pump cost} \\ &= \$6{,}000\end{aligned}$$

The first example is deterministic "unit cost" estimating because the parameter or independent variable in the CER is a *direct or definitive measure*

Phase of estimating cycle (and typical estimate type headings)	Typical process industry accuracy range and contingency (90% confident that actual $ will fall within)	Typical data input available	Typical end uses	Typical techniques
Class V (also order-of-magnitude, ROM, ball-park, rule-of-thumb, WAG, SWAG, seat-of-the-pants, guesstimate)	–30% to +50% before contingency Typical contingency = 15–40%	Engineering < 2% complete; general function; rough capacities and outputs	Project screening; brain-storming	Judgment or Parametric including: capacity factoring, parametric cost models, gross unit costs/ratios
Class IV (also conceptual, top-down, evaluation, study, factored, predesign study)	–15% to +30% before contingency Typical contingency = 10–20%	Engineering 1–5% complete; capacities and outputs; block layouts and diagrams; preliminary equipment list; soils data assumed	Project screening; concept evaluation; feasibility studies; budget previews	Parametric including: equipment factored, gross unit costs/ratios, parametric cost models

Class III (also, budget, scope, sanction, semi-detailed, authorization, preliminary)	–10% to +20% before contingency Typical contingency = 8–12%	Engineering 10–40% complete; prelimary layouts and diagrams; equipment list and specifications; partial soils data	Appropriation or funding; design development; cost control; detailed feasibility	Mixed parametric and unit: battery limit, cascading; parametric unit cost models; some unit costs
Class II (also detailed, control, or forced detail, definitive)	–5% to +15% before contingency Typical contingency = 5–10%	Engineering 30–60% complete; final layouts and diagrams; final equipment list and quotes; preliminary design drawings; complete soils data	Check or comparison; bid or tender (soft $); change order; detail cost control	Unit cost or line item with minor parametric application
Class I (also full detail, release, fallout, tender, firm price, bottoms-up, final price, detailed)	–5% to +5% before contingency Typical contingency = 3–5%	Engineering > 90% complete; design essentially complete; approved for construction; full quantity take-off	Bid or tender (lump sum or hard $), change order, material procurement	Unit cost or line item

Figure 1 Process industry estimate categorizations.

of the units of the item being estimated (12 m^3). The second example would be called stochastic "parametric estimating" because the parameter in the CER is a measure of *something other than the units of the item being measured* and thus the name simply remains "parametric." In the later case, the relationship between the parameter and the final cost is statistically significant, but still subject to conjecture. These differences are important to understand because the nature and form of the algorithm has implications for both the type of estimate input information required as well as the accuracy of the estimate output.

Algorithms are generally applied in a sequential series of steps to estimate various elements of the total estimate. In detail unit cost estimating, the steps are usually: 1) estimate the direct field cost, 2) the field indirect cost, 3) the office costs, and finally, 4) the profit and contingency. Parametric methods are less rigid, but tend to follow a systems approach, estimating the bottom line costs of various components of an engineered system that build up to a system total. In either method, there are various adjustments made throughout the estimate steps to assure that the final outcome reflects all of the estimate basis criteria identified.

Basic Algorithm Adjustments

In practice, CERs are rarely as simple as those in the previous examples. One reason is that the base CER needs to be adjusted mathematically to produce the most accurate results possible using all known information from the estimate basis. The base CERs as shown in the previous examples will be inadequate because:

1. *Factors* as drawn from project history or a standard database almost always reflect conditions from past experience that do not match those in the current estimate situation. The conditions that may vary from the database basis include:

   Escalation/inflation (Chapter 9)
   Labor rates (Chapter 6)
   Material markups (Chapter 5)
   Environmental impacts (Chapter 11)
   Taxes, duties, fees, etc. (Chapter 23)
   Exchange rates (Chapter 10)
   Labor productivity (Chapter 7)
   Location factors (Chapter 10)

2. *Parameters* or measures used reflect idealized models that do not precisely match actual technical or programmatic conditions. The conditions that may vary from the measurement basis include:

   - Waste and spoilage allowance (Chapter 5)
   - Accuracy of measurement (take-off) allowance (Chapter 5)
   - Specification, function, or content differences (Chapter 4)

Using one of the previous examples as a starting point, the following shows how some of these adjustments might be applied to a simple unit cost CER:

$$
\begin{aligned}
\$\text{ of Concrete} &= 500\$/\text{m}^3 \times 12\,\text{m}^3 \ \$ \text{ per cubic meter} \\
&\times 1.10 \text{ (inflation from database basis year)} \\
&\times 1.05 \text{ (for high local labor and material costs)} \\
&\times 1.10 \text{ (to allow for high degree of waste expected on job)} \\
&= \$7{,}623
\end{aligned}
$$

The adjustments can be made to entire line items in the estimate (as above), to a single cost resource such as labor or material, or to the total bottom line of the entire estimate as best fits the situation. For more discussion of the development and use of these adjustment factors see the chapters referenced in the list above.

Algorithm Presentation, Curves, and Graphics

While the estimating algorithms are discussed and defined below in their mathematical forms, it is often advantageous to convert the mathematics to a graphical presentation for ease of use and understanding. Values of the algorithm factors and parameters within a reasonable range can be entered into the algorithm and the results can be plotted on a graph or curve, or displayed in tabular format (see Figure 2).

C. Specific Algorithm/CER Types:

The following sections describe specific algorithm types starting with the basic deterministic methods used in later phases of the project cycle progressing to the complex stochastic parametric approaches used in the front end of projects (refer to the project cycle described in Chapter 1). The defining characteristics of each method are highlighted for comparison.

Detail Unit Cost or Line-Item Estimating (Bottoms Up)

Description. As was stated previously, unit cost estimating is given its name because the parameter in the CER is a direct or definitive measure of the *units* of the item being estimated. This is the universal technique for detail estimates based upon *take-offs* or *quantity surveys*. (Also see discussion on Gross Unit Cost Factors later in this section.)

Explanation. As shown in the example to follow, the engineer will use a unit cost CER several times for each item in an estimate—once to determine labor hours and cost, and once to determine material costs. Together, the labor and material costs, adjusted for basis, will equal the total cost for the *line-item.*

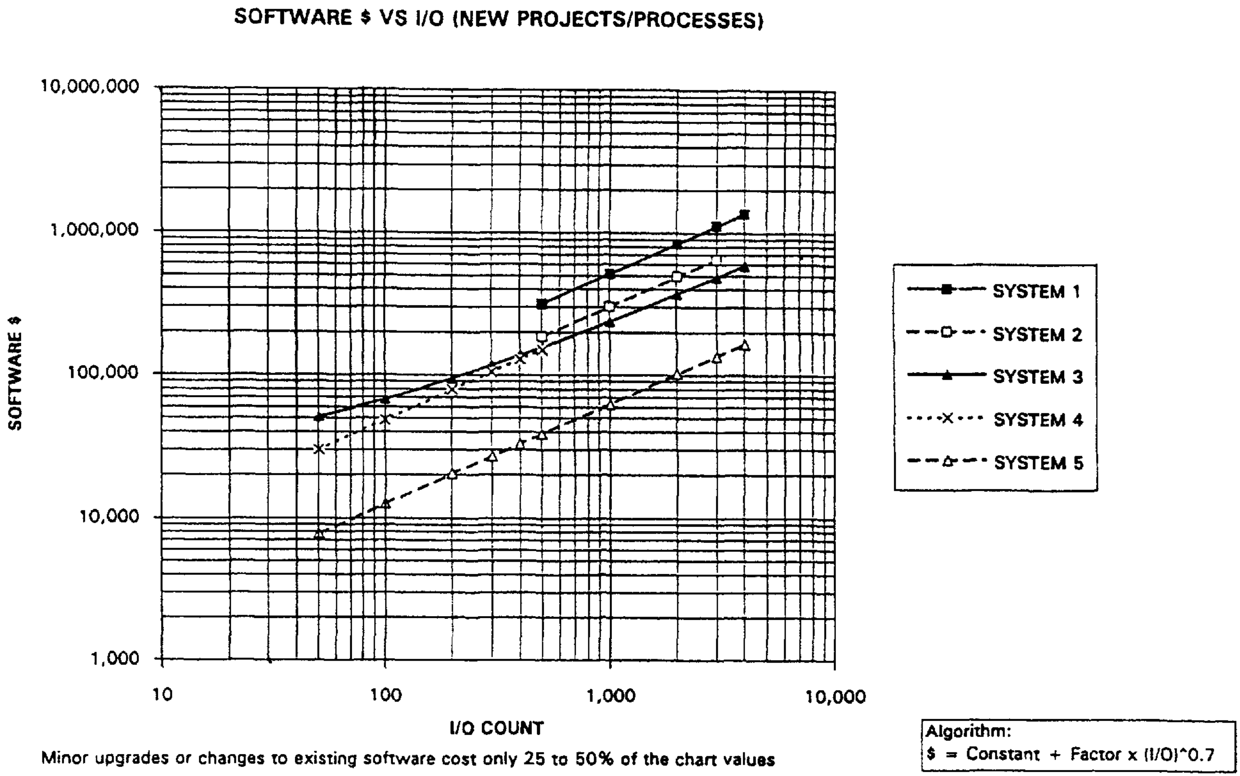

Figure 2 A typical cost curve (of a complex parametric model).

The term line-item refers to the fact that on manual estimating worksheets, the labor hours, labor cost, and material cost for an item are all calculated on a single line of the worksheet as shown in Figure 3. (See also the discussion of forms and tools later in this chapter.)

Estimating Process Phase: Most commonly applied just prior to construction execution, but it can be used at earlier phases if the detailed input information needed for unit pricing is *forced*, assumed, or otherwise known. Detail engineering and design work is generally greater than 30% complete, and most typically exceeds 60%.

End Uses. Primarily for detail project cost control budgets, *hard dollar* bid estimates by contractors, and change order estimates.

Information Required. A more or less detailed take-off or quantity survey of the items included in the project scope, and a project execution plan. A take-off usually requires completed detail design drawings and specifications or equivalent information.

Accuracy Range. +15/–10% to +5/–5% range before application of contingency (i.e., 90% confidence that actual result will fall within these bounds for the stated scope.)

Type, Source, and Reference. Deterministic. Has been in use as long as cost estimates have been prepared. Its use is described in any good cost estimating text [2–4] and it is applied in virtually all general purpose estimating software programs.

Limitations. As the name implies, this method requires that the details of the project design be known or assumable using take-off from drawings, etc. Application is relatively time consuming (less so if automated with a computer aided engineering or design (CAE/CAD) system or *digitized take-off*.)

Benefits. Good accuracy and subsequently the best basis for cost control. Easily applied in manual form, or in computerized spreadsheets, databases, and other application programs. Can be semi-automated in conjunction with a CAD system and coordinated with material procurement efforts.

Example. for a concrete foundation (excluding excavation):

Given: A material quantity parameter and unit cost factors including:

Quantity	=	12 m^3 based on take-off from drawings
Labor factor	=	10 hr/m^3 from database reference
Labor unit rate	=	$15/labor hour (all-in) from database reference
Material unit cost	=	$100/$m^3$ from database reference

Cost estimating worksheet											
Project:					Estimate #:			Page #:			
					Estimated by:			Date:			
Area/unit:					Checked by:			Date:			
		Quantity		Material		Labor					
Item number	Description	Quantity	Units	Unit price	Amount	Unit hrs	Total hrs	Rate	Amount	S/C	Total
Enter cost code here	Enter text here	A		B	M	C	D	E	L	S	= M+L+S
					= A×B		= A×C		= D×E		

Note: The letters designate values to be entered and calculations to be performed.

Figure 3 Cost estimating worksheet.

Labor \$ = 10 hrs/m^3 × \$15/hr × 12 m^3 = \$1,800

Material \$ = \$100/m^3 × 12 m^3 = \$1,200

Total direct \$ = Labor \$ + Material \$ = \$1,800 + \$1,200 = \$3,000

an allowance for indirect costs would then be applied to this figure.

Illustration. Figure 3 shows a line from a typical manual estimating form with equations highlighted.

Unit Cost Assemblies and Unit or Fixed Cost Models

Description. A single unit cost line item as discussed above may encompass more than one detailed item component. If the unit is a grouping or assemblage of associated discrete items, it is called a *unit cost assembly*, or *assembly* for short. If the unit is a more comprehensive grouping that encompasses a system of items or assemblies, it is called a *unit cost model.* A unit cost model differs from an assembly only in degree of scope. This aggregation of units into assemblies and models can save a lot of estimating time with little or no loss of accuracy when the groupings of items are repetitive. With computerized cost estimating systems, these assemblages can be prebuilt, saved in an electronic database, then later applied as a single line item without further consideration of the constituent parts. If desired, at estimate completion the assembly line item can be exploded back into its constituent parts in the estimate report so that proper subtotals of detail trade work can be obtained (see code of account and tools discussions.)

Explanation. For instance, an *all-in*, cast-in-place concrete *assembly* unit will typically include all associated form work, reinforcing, pouring, and finishing, which are all discrete, but related, unit cost elements that could be estimated separately if desired. (*all-in* indicates that the assembly includes all relevant components). A typical *unit cost model* might be a concrete roadway system which may include concrete as above, as well as definitive quantities of excavation, grading, backfill, guard rails, barriers, lighting, etc. The assembly and model are still deterministic if the amount of their constituent components is reasonably constant or definitive for all occurrences of the given item type.

Supporting Details. Discussions for detail unit cost estimating apply. Assemblies look like and can be used like any other unit cost line item (see Figure 4).

Item number	Description	Quantity		Material		Labor				Total
		Quantity	Units	Unit price	Amount	Unit hrs	Total hrs	Rate	Amount	
08.01-322-0050	Dual process connection (D/P)	1	ea	107.00	107.00	12.60	12.60	14.00	176.40	283.40
	Includes 1/2" tubing and fittings between process block valvesand instrument up to 10 ft from process stainless steel for chemical									

These detail items are contained in the assembly above: they can be reported at a detail level if desired

08.01-219-0002	1/2 in. stainless steel tubing	20	LF	1.85	37.00	0.31	6.20	14.00	86.80	123.80
08.01-410-0032	3-way valve manifold	1	ea	20.00	20.00	1.40	1.40	14.00	19.60	39.60
08.01-210-0001	Miscellaneous fittings	10	ea	5.00	50.00	0.50	5.00	14.00	70.00	120.00
	Total assembly	1	ea		107.00		12.60			283.40

Figure 4 A unit cost assembly: it can be treated as an independent line item.

Equipment Factored Battery Limit, Cascading Factors per Unit

Description. In this method a series of algorithms are used to estimate the direct cost of each discipline account contained in a limited area of a plant immediately surrounding and encompassing a piece of process equipment (i.e., a "battery" of equipment and material within a space "limit"). All discipline costs are factored from the cost of the equipment item within that battery limit area. The discipline item categories include the equipment, its piping, concrete, electrical, and other services either supporting it or connecting it to the off-site facilities. Some refer to this method as one of *cascading factors* based on its sequential application of CERs as described below.

Explanation. An estimate has four basic steps: 1) determine purchase costs for each piece of equipment, 2) factor each discipline material account from the equipment cost, 3) factor discipline labor hours from each discipline material cost—then multiply by labor rate, 4) to the sum of all the previous costs, add allowances for *indirects* (field indirects, home office costs and fees) and the non-battery limit *off-site* facilities. These off-sites must be estimated separately. Factors for off-sites have been documented by Miller [20]. Also, there are a number of adjustments to the factors that must be made to account for different metallurgies or service duties. The description of these adjustments are beyond the scope of this text and the reader is referred to the cited references. In general, *capacity factoring* (see later discussion) can be used to obtain the cost of common equipment types, but budget quotations are recommended for larger, custom units.

Estimating Process Phase: After initial engineering deliverables (see information required) are complete, but before detailed engineering and design work has begun in earnest. Engineering and design are generally only 10–20% complete at this stage.

End Uses. Primarily for early or intermediate project funding by owner, or *soft dollar* bid estimates by contractors.

Information Required. Preliminary plant layouts, final equipment list, preliminary equipment data/spec sheets, and in-house pricing on all process equipment. Also requires a project execution plan, process flow diagrams, preliminary electrical one-line diagrams, process control philosophy, and similar preliminary information.

Accuracy Range. +30/–15% to +15/–10% range before application of contingency (i.e., 90% confidence that actual result will fall within these bounds for the stated scope).

Type, Source, and References: Stochastic. First used in the 1960s as an expansion on the battery limit, single factor methods described by Hand [5, 6]. Discussed extensively by Guthrie [7, 8] and updated by Klumpar and Stoltz [9] and Peters and Timmerhaus [21]. Miller defines factors for off-sites [20].

Limitations. The method is not useful for projects that don't involve the installation of complete units of process or similar industrial equipment. It is limited to proven technology. It also does not provide for the cost of off-sites. Little commercial software available.

Benefits. Good accuracy for repetitive facilities. Discipline breakout permits preliminary project planning and cost control to be performed.

Example. For a major pump battery limit installation:

Given: An equipment cost parameter and discipline unit cost factors including:

Pump equipment material costs	=	\$10,000 (per quote, in-house pricing, or *capacity* factored estimate)
Discipline material unit cost factor	=	\$20 pipe/\$100 equipment (from reference database for piping for a pump)
Discipline labor factor	=	3 hrs/\$100 piping (from reference database for piping)
Discipline labor unit rate	=	\$15 per labor hour

Similar factors for other disciplines such as concrete, electrical, etc.

Indirect cost factor = 1.35 (indirect field cost, home office costs, fees)

Equipment material \$ = \$10,000 (given)

Equipment labor \$ = 0.2hr/\$100 equipment × \$10,000 equipment × \$15/hr
= \$300

Piping material \$ = \$20 piping/\$100 equipment × \$10,000 equipment
= \$2,000

Piping labor \$ = 3 hr/\$100 piping × \$2,000 piping × \$40/hr
= \$2,400

Other discipline material \$ = \$*n*/\$100 equipment × \$10,000 equip =

and so on for all other discipline accounts.

Total battery limit direct \$ = Equipment material and labor \$ + Piping material and labor \$ + other discipline \$

= $20,000 (estimate)

Total battery limit $= $20,000 × 1.35 (indirects) = $27,000

Non-Battery limit $ = add off-sites based on other unit pricing or parametric techniques

Illustration. Figure 5 displays a sample report from a computerized battery limit equipment estimating system developed and used by a major U.S. manufacturing firm. Actual factor values are too extensive for this text.

Equipment Factored Battery Limit, Single Factors per Piece (Hand Factors)

Description. A simple method in which the cost of each piece of process equipment is multiplied by a single corresponding factor to derive its total direct battery limit costs excluding off-sites. If the discipline detail of cascading factors is not needed, this method is reasonably accurate and is preferred over Lang factors (see later discussion).

Explanation. An estimate has three basic steps: 1) determine purchase costs for each piece of equipment, 2) factor total battery limit costs from the equipment cost (includes indirects), 3) to the sum of all the battery limit costs, add allowances for the *off-site* facilities. Note that like any equipment factored method, it depends on having known equipment costs.

Estimating Process Phase: During development of initial engineering deliverables. Engineering and design are generally only 5–10% complete at this stage.

End Uses. Primarily for business planning, feasibility studies, and alternative screening estimates.

Information Required. Basic project scope description with a block flow diagram and preliminary equipment list with in-house pricing.

Accuracy Range. +50/–30% to +30/–15% range before application of contingency (i.e., 90% confidence that actual result will fall within these bounds for the stated scope.)

Type, Source, and References. Stochastic. Method detailed by Hand in the 1950s [5, 6] and later expanded on by Guthrie [7, 8] and Cran [10]. This method is a natural precursor to battery limit, cascading factors estimating.

Limitations. Provides no discipline detail. Assumes a non-existent "normal" piece of equipment. The method is not very useful for projects that don't involve the installation of complete units of process or similar industrial equipment. It is limited to proven technology. Works best when factors are

Estimate identification: ABCD1234 Tag no.: 0001 Ed. desc.: pump

Cat. no.: Pump-M	Cat. desc.: Pump, motor driven	Size range: 3
Area/unit:	Qty: 1	Equipment cost: $14,500

Base and adjusted material factors in $ material per $100 of equipment cost

Discipline	Base factor	Material multiplier	Adjustment factor		Code	Metallurgy description	Cost factor
Concrete	4.0	1.00	4.0				
Steel	3.0	1.00	3.0	——>	CS	Carbon steel	1.0
Piping	45.0	1.00	45.0	——>	SS	Stainless steel	5.0
Electrical	28.0	1.00	28.0				
Instrumentation	1.0	1.00	1.0				
Painting	0.7	1.00	0.7				
Insulation	3.0	1.00	3.0				
Equipment	——	——	——	——>	SS	Stainless steel	5.0

Base and adjusted labor factors in MHS per $100 of associated material costs

Discipline	Base factor	Labor multiplier	Adjustment factor	Labor rate
Concrete	7.9	1.00	7.9	46.10
Steel	3.9	1.00	3.9	46.10
Piping	3.3	1.00	3.3	46.10
Electrical	5.2	1.00	5.2	46.10
Instrumentation	4.2	1.00	4.2	46.10
Painting	21.0	1.00	21.0	46.10
Insulation	6.8	1.00	6.8	46.10
Equipment	0.5	1.00	0.5	46.10

Equipment duty factor: 1.00 Ratio equipment/pipe increase in value: 0.75
Productivity factor: 1.40 Metallurgy labor factor: 1.35

Figure 5 A battery limit, cascading factor estimate report.

Factor Summary

	Material $	Labor MH/$100	Labor MHS	Labor $	Total $
Concrete	1.07	10.21	0.11	5.07	6.14
Steel	0.80	5.04	0.04	1.86	2.66
Piping	60.00	1.15	0.69	31.86	91.86
Electrical	7.47	6.72	0.50	23.15	30.62
Instrumentation	0.67	7.33	0.05	2.31	2.98
Painting	0.10	27.15	0.03	1.39	1.49
Insulation	1.20	11.87	0.14	6.57	7.77
Equipment	100.00	0.17	0.17	7.95	107.95
Totals	171.31		1.74	80.16	251.47

Material factor: 1.72 Labor factor: 0.80 Overall factor: 2.52

All-in cost summary for 1 equipment item

	Labor MHS	Labor $	Material $	Total $
Concrete	16.0	740	160	900
Steel	5.8	270	120	390
Piping	100.2	4,620	8,700	13,320
Electrical	72.8	3,360	1,080	4,440
Instrumentation	7.3	330	100	430
Painting	4.4	200	10	210
Insulation	20.7	950	170	1,120
Equipment	25.0	1,150	14,500	15,650
Totals	252.0	11,620	24,840	36,460

Figure 5 (Cont.)

derived from company specific cost data. Hard to apply basis adjustment factors for different material specifications.

Benefits. Can produce estimates quickly with a minimum of reference materials. Factors are easy to develop if historical data is available.

Example. For a chemical plant project:

Given: Equipment cost parameters and their corresponding factors as follows:
Equipment material costs; A = \$100,000, B = \$50,000, etc.
Equipment cost factors (including indirects); for A = 2.5, for B = 4.0, etc.

Total battery limit \$ = \$100,000 × 2.5 + \$50,000 × 4.0 = \$450,000 (including indirects)

Non-Battery limit \$ = off-sites based on other unit pricing or parametric techniques

Illustrations. Table 1 contains equipment factors compiled from the various reference sources and the author's experience. Note that these factors exclude contingency but include indirect costs (field indirects, home office costs, and fees of about 40% of directs), and instruments are treated separately like a piece of equipment. Off-site costs must be added. Also, note the degree

Table 1 Battery Limit Factors per Unit of Equipment

Process with *Significant Piping* (Carbon Steel Basis)	
Large columns/trays, pressurized vessels/horizontal-fired heaters, boilers	3.0
Large compressors, crystallizers, tanks, filters	3.6
Reactors, heat exchangers, instruments, large pumps, small compressors	4.2
Small columns/shells, pressure vessels/vertical small pumps	4.8
Average Process Equipment with Significant Piping	3.6
Process with *minimal piping* (carbon steel basis)	
Field assembled hoppers, bins, stacks, agitators	2.2
Crushers, classifiers, mills, large fans and blowers, screens, conveyors	2.6
Hydraulic presses, feeders, extruder, small fans and blowers	3.1
Dryers, ejectors/eductors	3.6
Average Process Equipment with Minimal Piping	2.6
Light industrial or modules with *minimal piping*	
Minimal field assembly, skid mount, standard designs	1.6
Some field assembly, modified-standard designs	2.1
More field assembly and interface, custom designs	2.5
Average light industrial equipment with minimal piping	2.1

of rounding properly reflects the uncertainty in published lists. Factors tend to be *one step lower in value (higher on the chart)* for equipment with expensive trim and internals, and for very large sizes. Figure 6 illustrates an estimate worksheet using Hand factors.

Equipment Factored—Battery Limit, Single Factor per Total Equipment (Lang Factor)

Description. This method is similar to the Hand factor except that a single factor is multiplied by the sum total cost of the plant's purchased equipment. There is little case for use of Lang factors considering that if one has a priced equipment list, the Hand factors provide more accurate results with very little extra effort.

Explanation. An estimate has four basic steps: 1) determine purchase costs for each piece of equipment and sum them up, 2) factor total battery limit plant costs (excludes contingency but includes indirects) from the sum of the equipment cost, 3) add allowances for the non-battery limit *off-site* facilities. (Note: Lang's original factors included at least some off-sites). Note that like any equipment factored method, it depends on having known equipment costs.

Estimating Process Phase: During development of initial engineering deliverables. Engineering and design are generally only 5–10% complete at this stage.

End Uses. Primarily for business planning, feasibility studies, and alternative screening estimates.

Information Required. Basic project scope description with a block flow diagram and preliminary equipment list with in-house pricing.

Accuracy Range. +50/–30% range more or less before application of contingency (i.e., 90% confidence that actual result will fall within these bounds for the stated scope).

Type, Source, and References: Stochastic. First described by Lang [11] in the 1940s as a way to factor total plant field costs from total equipment costs. Cran [10] provides a thorough analysis of Lang, Hand, and Guthrie factors. Peters and Timmerhaus [21] have provided factors as well.

Limitations. Factors assume that plants conform to a *nonexistent norm* and are thus highly uncertain. In addition, method has similar limitations to Hand factors only to a greater degree. Also, the Lang factor may or may not, depending on how it is presented, account for off-sites whose scope is much less predictable from plant-to-plant than battery limit costs.

Project *Example process plant*
Location *Anywhere*
Description *Equipment factored*
Single factors per equipment piece

Account number	Description	*Factor*	×	*Equipment $*	S/C $	Total $
	Compressor	3.6	×	45,000	=	162,000
	Pump 1	4.2	×	20,000	=	84,000
	Pump 2	4.2	×	15,000	=	63,000
	Heat exchanger 1	4.2	×	12,000	=	50,400
	Heat exchanger 2	4.2	×	10,000	=	42,000
	Column XYZ	3.0	×	210,000	=	630,000
	Vessel ABC	4.8	×	58,000	=	278,400
	Instruments	4.2	×	45,000	=	189,000
	Allowance for off-sites (see back-up)					95,000
	Direct field costs					
	Field staff and expenses					
	Temporary construction facilities					
	Miscellaneous services and supplies					
	Construction equipment					
	Small tools					
	Field burden					
	Field overhead					

	Indirect field costs					
	Total field costs					
	Project management and administration					
	Engineering and design					Includes indirects
	Procurement					
	Contracts					
	Office expense					
	Office burden					
	Office overhead					
	Total office costs					
	Total field and office costs					1,593,800
	Taxes					
	Escalation					
	Reserves					
	Contingency	20%				318,800
	Total project					1,912,600

Figure 6 Cost estimating summary sheet (hard factors).

Table 2 Typical Equipment Factors for Entire Plants (excludes contingency)

Fluid process plants with significant piping		Solid process plants with minimal piping		Light industrial plants with minimal piping	
Low	2.8	Low	2.2	Low	1.6
Mean	3.8	Mean	2.8	Mean	2.2
High	4.8	High	3.8	High	2.8

Benefits. Can produce estimates quickly with a minimum of reference materials. Factors are easy to remember for quickie estimates.

Example. For a chemical plant project of type *X*:

Given: Total equipment cost parameter and battery limits cost factor as follows:

Plant equipment material costs	=	$1,000,000 (per in-house pricing or *capacity factored* estimate)
Plant cost factor	=	3.8 for plant type × (from reference database)
Total battery limit $	=	$1,000,000 × 3.8 = $3,800,000
Non-Battery limit $	=	off-sites based on other unit pricing or parametric techniques

Illustrations. Table 2 provides typical factors for various plant types. Because published factors of this sort are highly uncertain, all that can be said with confidence is that published overall factors for large plants tend to fall in the table ranges including indirect costs but excluding contingency (application is similar to the Hand factors in Figure 6):

Cost Capacity or Exponential Factored

Description. A simple method based on the concept of economies of scale which holds that while costs tend to increase with an increase in size or capacity of an item, they generally do not increase linearly. The method can be applied to entire plants, pieces of equipment, or discipline costs such as piping and electrical. The method is often used to derive equipment cost for use in equipment factored estimates.

Explanation. The method consists of four steps: 1) obtain the cost and scaling parameter (capacity) of a similar item to the one being estimated, 2) normalize that known cost to the proper basis, 3) calculate a scale factor—this is a ratio of the scaling parameter values (estimate item over known item) taken to a fractional exponential power, 4) multiply the cost of a known item by the scale factor. The method is often called the *six-tenths rule* because studies have shown that the capacity factor exponent of 0.6 works fairly well with many, but not all, items. A capacity factor exponent can be calculated from the known costs and capacities of two items (*a* and *b*) using the following calculation:

$$\text{exponent} = \frac{\log[\text{cost}\, b/\text{cost}\, a]}{\log[\text{capacity}\, b/\text{capacity}\, a]}$$

Estimating Process Phase: During development of initial engineering deliverables. Engineering and design are generally less than 5% complete at this stage.

End Uses. Primarily for screening estimates of projects, or to obtain equipment pricing for use in equipment factoring methods.

Information Required. Basic project scope description with production capacities identified. A preliminary block flow diagram showing overall or block production capacities is desirable. Cost and capacity of a comparable item and an exponent value are required.

Accuracy Range. +50/–30% range before application of contingency (i.e., 90% confidence that actual result will fall within these bounds for the stated scope.)

Type, Source, and References: Stochastic. Source unknown, but use for total plant costs was confirmed by Chilton (exponents are sometimes referred to as *Chilton Factors*) [12]. A more detailed approach at the commodity and resource level was reported by Lunde [13]. Many general estimating texts include tables of exponent factors.

Limitations. Requires that the estimated and reference base item be reasonably equivalent in scope (with the exception of capacity). It is limited to proven technology, as pilot plants do not often scale as predicted. Also, the costs of many items scale in a step function rather than a smooth progression causing wide discrepancies in published data. Works best when company specific exponents are determined.

Benefits. Can produce estimates quickly. Can be used to estimate the cost of any plant, production unit, or item whose costs are statistically related to a capacity or other size scaling parameter value. The exponents are not hard to develop.

Example. For a chemical plant B of type X:

Table 3 Typical Cost Capacity Exponents

0.4–0.5	Smaller ranges of simple equipment with a fairly constant number and complexity of parts such as agitators and small pumps. Also, items for which capacity scale increases in three dimensions (i.e., volume) such as boilers or evaporators.
0.5–0.7	Average process plant.
0.7–0.9	Larger ranges of complex equipment whose number and complexity of parts increase with size such as compressors and hydraulic presses. Also, items for which capacity scale increases in two dimensions (i.e.., area or cross-section) such as conveyors, stacks, piping, or air coolers.

Given: Cost of comparable plant A parameter, and capacities of plants A and B as follows:
Cost of Plant A = $10,000,000 (adjusted to current year $)
Capacity of Plant A = 10,000 units/day
Planned capacity of Plant B = 20,000 units/day
e (exponent) = 0.6 (from reference tables for plant of this type)
Cost Plant B = cost factor × cost of Plant A
where the cost factor = (capacity of plant B/capacity of plant A)^e
= $(20{,}000/10{,}000)^{0.6} \times \$10{,}000{,}000$
= $15,200,000

Illustrations. Table 3 provides typical capacity exponents for various classes of equipment, and commodities. Figure 7 illustrates these factors in use. There is little consistency in published tables, but the following categorizations seem to apply (0.6 is still a good average for most uses):

Parametric Unit Cost Models

Description. This is a hybrid combination of unit cost modeling and complex parametric cost modeling. As was previously defined, a *unit cost model* consists of a predefined estimate of a system with a known set of constituent line items, with each line item having an algorithm with *fixed* design parameters and cost factors. A *parametric unit cost model* has *variable* parameters and/or factors in the algorithms of the cost model's constituent line items. They are made variable by interjecting into the model one or more mathematical expressions that translate a change in the overall model's design parameters to changes in the parameters and/or factors of each of the model's constituent line-item algorithms. As a variation to this approach, the mathematical expression is replaced by a *computer aided engineering* (CAE) application that generates the necessary parameters and/or factors for the base model. The method builds a sorely needed bridge between nuts-and-bolts unit cost estimating and esoteric parametric analysis. The ability of these systems to produce detailed, take-off type output provides a "comfort factor" that, rightly or wrongly, limits the use of less approachable parametric techniques in everyday engineering practice. This method is most heavily used in trade specific or general commercial building construction and chemical plant applications. The models and parametric relationships are prebuilt in some systems and left to the user in others.

Explanation. As an example of a parametric unit cost model, consider a roadway which includes a defined combination of grading, aggregate base, concrete surfacing, and guardrail line items. The unit cost factor of the overall roadway model might be expressed as $\$n/m^2$ of roadway for a given design loading parameter of 12 kg/cm^2. Unfortunately, the cost model is *fixed* because it only applies to a loading of 12 kg/cm^2. Rather than creating a series of additional fixed models for loadings of say 8, 10, 14, and 16 kg/sq. cm, a mathematical relationship may be developed that modifies the thickness parameters of the original unit cost model's aggregate base and concrete surfacing items depending on the change in loading (say 1 cm thickness change in the concrete surfacing with each 1 kg loading change.) Once the relationship is developed, the engineer can use a single algorithm to estimate the cost of any similar road, but with different loading conditions, without having to directly redesign or reestimate the component parts. Like any unit cost model, the parametric version can still be exploded into its constituent, but now modified, line items for estimate reporting purposes.

Estimating Process Phase: Can be applied at any phase from development of initial engineering deliverables through detailed engineering and design. Engineering and design may be from 5% to 60% complete.

End Uses. Primarily for intermediate project funding by owner, cost control budgeting, or *soft dollar* bid estimates by contractors. The use for *hard dollar* bids is limited by how definitive the model's parametric relationships are.

Information Required. From as little as basic project scope description with production item capacities identified, through preliminary design drawings. Scope of models must be close to the project scope.

Accuracy Range. +50/–30% to +15/–10% range before application of contingency depending upon relevancy of models (i.e., 90% confidence that actual result will fall within these bounds for the stated scope.)

Project *Example process plant*
Location *Anywhere*
Description *Cost capacity factored*

Approved date 07/01/96

Account number	Description	Hr	Labor $	Material $	S/C $	Total $
	Plant A = 40,000 BPD					
	Direct field costs 1990			12,000,000		
	Escalation			1,200,000		
	DFC 1996 BASIS			13,200,000		
	Plant B = 60,000 BPD				0.60	
	Plant A DFC =		13,200,000 ×	$\frac{60,000}{40,000}$	=	16,840,000
	Includes offsites (excludes indirects)					
	Direct field costs					16,840,000
	Field staff and expenses					
	Temporary construction facilities					
	Miscellaneous services and supplies					
	Construction equipment					
	Small tools					
	Field burden					
	Field overhead					

	Indirect field costs					× 1.5
	Total field costs					
	Project management and administration					
	Engineering and design					
	Procurement					
	Contracts					
	Office expense					
	Office burden					
	Office overhead					
	Total office costs					
	Total field and office costs					25,260,000
	Taxes					
	Escalation					
	Reserves					
	Contingency	20%				5,050,000
	Total project					30,310,000

Figure 7 Estimate worksheet using capacity factors.

Type, Source, and References: Deterministic or Stochastic. The base unit cost model is deterministic as previously described, but the overlaying relationships may be either a definitive CAE application or a conjectural parametric algorithm (see complex parametric models). The first major applications were for government facility applications and chemical process plants in the 1970s.

Limitations. Requires that unit cost models or assemblies be created, and that the model constituents be reasonably equivalent in scope to the project being estimated. Models require large databases. It is generally limited to proven technology and designs. Parametric relationships are like a "black box" that performs modifications to an estimate out of sight of the user. The user must understand the basis and limits of the relationship to avoid misapplication. For instance, the relationship may only be statistically valid for a specific limited range of input parameter values. The detail in the output can lull the user into overrating the estimate's accuracy.

Benefits. Can produce estimates relatively quickly. Can produce output with a take-off level of detail from limited input information; however, in many cases the take-off is actually not of high enough quality for material procurement or hard dollar bidding, which limits its value.

Example. For a concrete roadway:

Given: A unit cost model of the roadway with a modifying parametric algorithm: One all-in, line-item algorithm (concrete) of many in the given model is:

$ of concrete = $500 per cubic meter × (*N*) cubic meters

Where the corresponding parametric algorithm for quantity parameter *N* is:

(N) = (road width in meters) × (road length in meters) × (road loading in kg/cm^2) × (1 cm/kg)/(100 cm/m)

and the following road design parameters are given:

Road width = 10 m

Road length = 100 m

Road loading = 12 kg/cm^2

$\$ \text{ of concrete} = \$500 \times [(10) \times (100) \times (12) \times (1)/(100)]$

$= \$60{,}000$

plus remaining algorithms of all other constituent items of the model.

Complex Parametric Cost Models—Analytical or Statistical Models or CERs

Description. *A complex parametric cost model* differs from the preceding methods in that it has no predefined form except that it consists of mathematical expressions (usually statistically based) that incorporate one or more technical, programmatic, functional, or other parameters related to the item being estimated. As used by most engineers, these models are simply algorithms resulting from basic statistical regression analysis. They can however be much more complex, yielding more output information than just costs. Some practitioners refer to themselves as *parametric analysts* as opposed to cost estimators to reflect the larger scope of these *analytical models*. These models are often tied to a *systems engineering* process that involves the evaluation of system functions and requirements. Because most complex parametric models are highly stochastic, their use for project controls is generally limited to preliminary funding—their value derives mainly from their utility for strategic analytical studies such as simulation, optimization, cost of quality evaluations, robust design, and life cycle cost analysis. There are a few commercial estimating packages of this type, but their use has been limited primarily to research, government, aerospace, and software development applications due to their cost and the expertise required. However, developing regression models based on historical project information is fairly straightforward and is becoming a common practice with cost estimators (see data development section). Note: some texts limit the use of the expression "CER" to this type of relationship.

Explanation. In the most common case using a simple regression model, the method has three steps: 1) determine the parameter values needed by the parametric model, 2) enter those values into the algorithm (also see later regression and simulation discussions), 3) make adjustments to the resulting costs as needed.

Estimating Process Phase: During research and development through development of initial engineering deliverables (see information required). Engineering and design are generally 1–10% complete at this stage.

End Uses. Primarily for analytical evaluations such as process optimization and program life cycle cost, and screening estimates of projects. Can sometimes be used for early project funding.

Information Required. Basic project scope description with selected parameters identified depending on the algorithm's needs. Typically the models relate cost to production capacities, size, weight, flows, process material and heat balances, equipment piece counts, and other basic process design factors.

More complex programs deal with high level functional, system, and programmatic requirement input.

Accuracy Range. +100/–50% to +30/–15% range before application of contingency depending on quality of the parametric model (i.e., 90% confidence that actual result will fall within these bounds for the stated scope.)

Type, Source, and References: Stochastic. Early efforts began with defense applications in the 1950s by the Rand Corporation, but most developments have occurred since the 1970s. A good overview is contained in works by Stewart and Wyskida [4] and Gallagher [14].

Limitations. Requires that the scope basis of the parametric model be reasonably equivalent in scope to the project item being estimated. Parametric relationships are a *black-box* methodology—the user must understand the basis and limits of the relationships to avoid misapplication. The mathematical or statistical relationship are often highly constrained to limited ranges of input parameter values. The output is generally at a very summary level or bottom line, providing little detail with which to gauge appropriateness, therefore risk analysis is an especially important adjunct to parametric modeling.

Benefits. Can produce estimates quickly. Is amenable to simulation, optimization, life cycle cost analysis, designing to cost, value engineering, etc. It is the only technique routinely applied to research, new technology, and pilot plants because algorithms can be developed using primary inputs such as process material properties, flows, energy and heat balances, programmatic factors, technology and work assessment, and risk evaluation criteria.

Example. Simple Regression Based: For the cost of software application development for a programmable logic controller (PLC) of a given type.

Given: A regression model, approximate input/output (I/O) count, and a technology assessment factor:
Model: software \$ = [\$25,000 + \$1,700 × (I/O point count)$^{0.7}$] × (complexity factor)
Approximate I/O count = 130 addressed points
Complexity factor = 1.2 (from a predefined complexity assessment table)

$$\$\ \text{software} = [\$25{,}000 + \$1{,}700 \times (130)^{0.7}] \times 1.2$$

$$= \$92{,}000$$

Illustration. Figure 2 provides a graphical illustration of the algorithm in the above example.

Other Variations on Basic Methods: Ratio Factoring

Description. This method estimates the cost of one item or resource by simply multiplying the known cost of another related item by a given *ratio factor*. The factor is a predetermined, dimensionless ratio of the cost of the unknown resource to the cost of the known one. The known cost is already derived from one of the major algorithms above, by quotation, or some other means. The ratio is determined from analysis of historical data, or obtained from published references, or some other means. The method is stochastic if the ratios are derived through regression or other analysis—in that case it is really a simple form of a *complex parametric cost model*. It is deterministic if the ratios are definitive relationships such as the case with taxation and labor regulatory burden rates. Uses of this method include estimating project indirect costs from direct costs, home office costs from field costs, contingency from estimate total costs, and so on. It is similar to algorithm *adjustment factors* in that both use dimensionless factors against a known cost resource, but adjustments are intended to modify a given cost resource and not to derive the cost of another.

Explanation. The method has two steps: 1) determine the reference base cost that the ratio factor will be applied against, 2) multiply the base cost times the ratio factor.

Estimating Process Phase: Stochastic forms are used in early estimating phases and deterministic forms are used in any phase.

End Uses. Depends upon the use of the algorithm from which the known costs were estimated. The method is an extension of other primary, base methods. Ratio factors are also used as the primary benchmark measures for project cost and estimate performance evaluation.

Information Required. Known cost of an item or resource against which the ratio will be applied, and a known ratio factor applicable to the project scope and basis information given.

Accuracy Range. Can be no better than the accuracy of the base cost against which the ratio is applied.

Type, Source, and References. Stochastic or Deterministic. As with unit cost estimating has been used as long as estimates have been prepared. Refer to standard estimating texts [2–4].

Limitations. Ratio factors must be known and must be applicable to the items and projects against which they are applied. A ratio factor can not be used as the sole method of preparing a project estimate—it always requires a base cost to work from.

Benefits. Can produce estimates quickly. It is broadly applicable in many estimating situations.

Example. For the preliminary cost of Engineering on a chemical process plant.

Given: Costs of the base plant and an engineering ratio factor:
Total field costs (TFC) of a project = $2,500,000
Engineering ratio factor (Eng$/TFC$) = 0.21 or 21% (from a reference table)

$$\$\text{ Engineering} = \$2{,}500{,}000 \times 0.21$$
$$= \$525{,}000$$

Illustration. Figure 8 illustrates the use of ratio factors in an estimate summary worksheet.

Other Variations on Basic Methods: Gross or Broad Unit Cost Factored, Units of Use, or Rule of Thumb

Definition. At face value this method looks just like a detail unit costing CER with a cost factor times a unit of measure parameter. The difference is that the cost factor and unit of measure represent a summary level, gross assemblage of items of *indeterminate* content. No detail as to content of the assembly unit is given in this case. For instance, an office building gross unit cost factor of $\$900/m^2$ looks like a detail unit cost factor, but a square meter of building floor space may incorporate hundreds of indeterminate detail building items. A gross unit cost factor is stochastic and is usually derived from statistical analysis of historical project cost data. As such, it is really a simple form of a *complex parametric cost model.* If it is backed up by nothing more than judgment or an educated guess, it is often called a *wag, swag, rule-of-thumb*, or *ballpark estimate*. It has also been called a *unit of use* method.

Explanation. The method has two steps: 1) determine the unit quantity against which the factor will be applied, 2) multiply the unit quantity times the gross unit cost factor.

Estimating Process Phase. During research and development through development of initial engineering deliverables. Engineering and design are generally less than 5% complete at this stage.

End Uses. Primarily for screening estimates of projects.

Information Required. Basic project scope description with gross units of measure of the estimate item. Requires a predefined gross unit cost factor.

Accuracy Range. +100/–50% to +50/–30% range before application of contingency (i.e., 90% confidence that actual result will fall within these bounds for the stated scope.)

Type, Source, and References: Stochastic. As with unit cost estimating has been used as long as estimates have been prepared. Refer to standard estimating texts [2–4]. Same as complex parametric modeling if regression analysis is used for derivation.

Limitations. Requires that the scope basis of the gross unit cost factor be roughly equivalent in scope to the project item being estimated. The factor is a *black-box* methodology—the user must understand the basis and limits of the relationship to avoid misapplication. The mathematical or statistical relationship is often highly constrained to limited ranges of input parameter values. The output is generally at a very summary level or bottom line, providing little detail with which to gauge appropriateness.

Benefits. Can produce estimates quickly. Factors are easy to remember.

Example. For the cost of an office building.

Given: A gross quantity measurement and a corresponding gross unit cost factor:
Gross unit cost factor = \$900 per m^2
Total building floor area = 6,000 m^2

$$\text{Total building } \$ = \$900/\text{m}^2 \times 6{,}000\text{m}^2$$
$$= \$5{,}400{,}000$$

D. Variations on Form and Application of Algorithms

Algorithm Combinations

Many estimates utilize more than one of the above methods for different parts of the estimate (i.e., battery limit factored for onsites + forced detail unit costs for off-sites). Others use hybrid algorithm forms such as *parametric unit cost models* (unit cost model + parametric model). These combinations are dictated by the desire to utilize all of the basis information available in order to achieve the best accuracy possible. Any one method may neglect certain input information that is at hand, or it may need input information that can best be derived from another method. The term *semidetailed* is often applied to estimates that combine detailed unit cost methods with parametric methods.

Project *Example process plant*
Location *Anywhere*
Description *Summary sheet using ratio factoring*

Approved date 07/01/96

Account number	Description	Hrs	Labor $	Material $	S/C $	Total $
	Direct field costs from battery limit estimate (see back-up)					
	Concrete	16	240	160		400
	Steel	8	120	120		240
	Piping	104	1,560	8,700		10,260
	Electrical	72	1,080	1,100		2,180
	Instrumentation	8	120	100		220
	Painting	4	60	10		70
	Insulation	20	300	170		470
	Equipment	30	450	14,500		14,950
	Off-sites allowance					3,500
	Direct field costs	262	3,930	24,860		32,300
	Field staff and expenses					
	Temporary construction facilities					
	Miscellaneous services and supplies					
	Construction equipment					× .25
	Small tools					
	Field burden					
	Field overhead					

	Indirect field costs					8,100
	Total field costs					40,400
	Project management and administration					
	Engineering and design					
	Procurement					
	Contracts					× .20
	Office expense					
	Office burden					
	Office overhead					
	Total office costs					8,100
	Total field and office costs					48,500
	Taxes	6%				1,500
	Esacalation					
	Reserves					
	Contingency	20%				9,700
	Total project					59,700

Figure 8 Ratio factoring in an estimate summary worksheet.

Simulation

Simulation is not a parametric estimating algorithm in itself, but a way to apply a given estimating method in order to determine the probability distribution of potential estimate outcomes. Simulation generally involves specialized computer programs that replace the fixed, discrete factor and/or parameter values of an algorithm with probabilistic distributions of possible factor or parameter values. This creates a *simulation model*. Using Monte Carlo or other statistical sampling techniques, the simulation model is recalculated multiple times, each trial with a different set of input factors and parameters selected from the probability distributions used. The output is a distribution of trial outcomes with measurable statistical properties.

The primary uses of simulation for cost estimating is the evaluation of risk and return (see Chapters 12, 13, 14). This includes analysis of project risk and contingency (see Chapter 12), profitability analysis (Chapter 13) and investment decision making (see Chapter 14). It is also useful in life cycle cost estimating during value engineering (see Chapter 19).

Optimization

Another technique often applied to algorithms is *what-if analysis, optimization*, or *goal seeking*. With these techniques the user evaluates multiple combinations of possible factor and parameter values in order to find one or more combinations that will produce a desired cost result. This outcome may be a minimum, maximum, or other target value. These techniques are valuable in value engineering (see Chapter 19) or *design to cost* because it allows you to find design parameters that yield a desired cost outcome. It can also be used in the evaluation of risk and return as was discussed with simulation. In these methods, a table of possible factor and parameter values is set up and a computer program recalculates the estimating algorithm using each set of input values from the table. The recalculation continues until it finds all the solutions that meet your criteria [4].

III. THE COST ESTIMATING DATABASE

Each of the algorithm types discussed above employs one or more *cost factors* whose values are assumed to be known. For consistent application, these known cost factors should be kept in a standard reference database by the estimating organization. The database may be in hard copy or electronic form, and the data may be obtained from third parties or created in-house. More than one database may be maintained because different types of algorithms require different types of cost factors. Table 4 shows the types of cost factors to be found in a database as needed by the various algorithm types.

Table 4 Types and Sources of Data

Algorithm type		Data source[a]			
#	Type	1	2	3	Basic data fields needed in cost estimating databases
1.1	Detailed unit cost	X			Labor hour factors, material unit costs, S/C, and other unit costs, labor rates
1.2	Unit cost assemblies and models	X	X		Same as above: compiled into assemblies
2.1	Equipment factored: cascading		X	X	Battery limit material and labor cost ratio factors by discipline and equipment type, labor rates
2.2	Equipment factored: per unit			X	Battery limit cost factors by equipment type
2.3	Equipment factored: total plant			X	Battery limit cost factors by plant type
3.1	Capacity factored			X	Exponents by plant, equipment, discipline, or resource type as desired, historical cost database
4.1	Parametric unit cost model		X	X	Same as unit cost models, plus corresponding established parametric algorithms as appropriate
5.1	Complex parametric models			X	Established parametric algorithms as appropriate
6.1	Ratio factoring	X	X	X	Ratio factors by appropirate cost tyupe (some factors are given or required by third parties)
6.2	Gross unit costs			X	Gross unit cost factors by appropriate cost type
	Adjustment factors as used by various algorithms	X		X	Labor productivity, location factors, exchange rates, mark-ups, complexity factors, etc.

[a] Data source refers to the primary or most typical source of the data in the database as described below:
1 = Published reference manuals (contractors may obtain from first hand historical cost records)
2 = Evaluation of unit cost models developed from engineering standard designs
3 = Regression analysis of historical cost data

In practice, obtaining factors and parameters applicable to a given project situation is often the most difficult task in the estimating process. For common, highly repetitive projects such as commercial building construction, the problem is minimized because there is a wealth of published data relevant to that type of project. As projects become more unique or technologically complex, engineers will find themselves falling back on their own resources to find data to use in the estimating process. Another problem with any cost data is *obsolescence*. This is particularly true for material prices (i.e., recall lumber price increases in the early 1990s). Labor factors also change with changes in the technology of an item or in a trade practice (i.e., continual evolution of instrumentation from pneumatic to electronic, and central control to distributed).

Data scarcity, obsolescence, and the need for consistency all mandate that a reference estimating database with a known basis be created and maintained. As was stated in the introduction, *an effective methodology consists of a standard set of cost estimating practices, resources, and tools that are consistently applied in all estimates.*

The database can be obtained from a third party and/or created in-house as needed. However, no matter how obtained, the database must be more than a random collection of data points—it must have *internal consistency of content.* For instance, picture a database of piping cost factors with piping labor hours for 2 in. diameter pipe from source A being *too high*, 3–4 in. from source B being *too low*, and so on (with high and low referring to applicability to the norm for your site). With such a database it will be impractical to determine a site *labor productivity adjustment factor* for piping (a factor that corrects your base data for a discipline to match site conditions), because each project has a different mix of pipe sizes and it will be too hard to sort it all out unless you record labor costs for each pipe size increment.

Another consideration is that an estimating database is a *point of reference* only; it will *NOT* match the conditions present on all your projects. A common misconception is that a cost database should accurately reflect, in verbatim/absolute terms, the cost factors prevalent for a site. This leads to never ending modification of, or shopping around for, databases in an attempt to make it match experience without further adjustment. With a database that keeps changing, it then becomes impossible to maintain consistency and determine logical adjustment factors. It is preferable to settle on a reasonable standard database(s) and invest your resources in identifying appropriate adjustment factors. If the data is internally consistent within a discipline or other grouping as was described, no matter how far off the mark in absolute terms, the estimator will then be able to apply project specific adjustment factors to make the data relevant.

The remainder of this section will outline how to build such a database including how to obtain or create data, modify it to suit the needs of a methodology, and how to structure, store, and maintain it for efficient, effective use.

A. Available Data Resources

Unit Cost Factors

There are a large number of commercial cost data resources, which the engineer can obtain, in printed, xbase, or spreadsheet form. These resources can generally be categorized according to the cost factor types they provide and the trade disciplines they cover. For instance, many sources provide only labor factors in terms of labor hours per unit of measure, some concentrate on trade material prices that require frequent updating, and others attempt to provide both labor and material costs. In terms of trade discipline coverage, some sources concentrate on a single trade such as electrical or equipment rental cost factors, while others cover all trades. The most common sources in broad general construction usage that include both labor and material information and are updated annually are R. S. Means [15] and Richardson's Engineering Services [16] manuals.

Other Cost Factors

Cost factors used in stochastic methods such as *battery limit equipment factoring* and *capacity factoring* are much harder to find in published sources than are detail unit cost factors. This is because the market is limited, the data tends to be costly to develop, and the historical basis of the cost is often proprietary. Most published references are contained in professional journal articles or texts such as AACE's Cost Engineering Notebook [5, 6, 9] that have been referenced in the previous discussions of each estimating methodology. Gross Unit Cost Factors (or rule-of-thumb or unit of use) for building construction can however be found in several published database sources.

Adjustment Factors

As previously discussed, adjustment factors include labor productivities, material markups, escalation, labor rates and similar modifying terms. All of these factors tend to be highly specific to a given location, site conditions, and other project characteristics. Labor wage rates are the easiest to find as many sources publish prevailing rates by location (including the Means and Richardson's sources mentioned earlier). Many of the database suppliers also provide tables of adjustment factors for labor and material pricing for various localities and other conditions. Most other factors will require the engineer to research and analyze their local conditions.

Cost Models and Assemblies

Many cost estimating computer programs that use *parametric unit cost modeling* techniques include prebuilt unit cost models to work with, but the systems and data are largely proprietary. It is expected that as more general estimating software packages employ parametric unit cost modeling in addition to object oriented operating systems, there will be more third-party and other cost models made available. Cost *assemblies* can be found in some of the database publications for building and commercial construction such as R. S. Means and Richardson's. *Complex parametric cost models* are largely proprietary and limited to use in the few commercial systems available.

B. Creating Data Resources

If you have niche project types that don't fit neatly into the categories of basic commercial building, light industrial, or commodity chemical process construction, then you will have to develop some in-house estimating data to supplement your estimating methodology. You may also find that published references for stochastic methods don't apply to your projects. The following provides some guidelines for data development. Please note that obtaining feedback on the quality of custom data is especially critical to improving the quality of the estimating database.

Detail Unit Cost Factors

Having determined that there is no published data that meets your needs, the following alternative steps can be used to fill the void (the following is intended for engineers who do not have access to detailed construction trade labor and material cost records such as contractors would have at their disposal to support hard dollar bid estimates):

1. If there is a published reference that has similar, but not quite identical items *(i.e., a reference has lots of 600V wire, but not 300V wire)*:

a) Material Unit Costs: Determine a material markup to the available published reference that gets prices within shooting distance of your purchasing experience for the new type of item (i.e., say 300V is about 95% of 600V). Generally, this markup will remain constant over time—maintaining your custom database only requires you to obtain the most current copy of the published reference.

b) Labor factors. Determine a labor adjustment factor from a logical evaluation of the relative size, weight, complexity, and installation steps of new item compared to the reference (i.e., 600V and 300V insulation are similar and have essentially identical installation steps).

2. If there is no published reference that has similar items (i.e., you cannot find a published source for actuated process control valve pricing):

a) Material Unit Costs: Select a single vendor source to contact (a single vendor should have internal consistency). Obtain budget quotes for the range of items desired. Compare the budget quote to actual purchasing experience for that type of item (usually better discounts on a real purchase.) Determine a discount to the budget quote. Generally, this discount will remain constant over time for a given vendor—maintaining your custom database requires that you recontact the same vendor periodically to obtain the most current budget quote.

b) Labor Factors: Base the labor requirements on historical records if you have them. If not, find a published reference with items of a similar size, weight, complexity, and installation steps, etc. and make a relative evaluation compared to your items. Obtain feedback to assure consistency.

Other Cost Factors

The development of stochastic cost factors is generally beyond the scope of this text. However, the following is a brief discussion of the most common techniques.

Regression Analysis. Regression analysis is a mathematical technique used to determine a relationship between the values of a single dependent variable and the values of one or more independent variables. The resulting relationship takes the general form of:

$$Y = \text{constant} + [\text{coefficient}(a) \times A] + [\text{coefficient}(b) \times (B)] + \cdots$$

The method also provides statistical parameters (standard error, r squared, etc.) that indicate how successfully the relationship models the observed values [17]. This is very useful for creating *complex parametric cost models* and *gross unit costs*. If Y is the cost, and A and B are design parameter values, the regression output is then a complex parametric cost model.

The analysis procedure generally consists of performing trial and error regression analysis of historical costs vs. the various values of one or more design parameters (these parameter values may be taken to an exponential value). The trial and error outcomes are evaluated to select a model that provides the best statistical measures possible (r squared, standard error, etc.). For example, the cost of various size pumps can be regressed against their liter per minute pumping capacity rate taken to an exponential power. Most spreadsheet software now includes tools for performing basic regression analysis.

Take-off Analysis of Simple Unit Cost Models. This is most useful for *battery limit equipment factored estimating*. With this approach, simple unit cost models (prebuilt estimates) of the battery limit facility are used as the basis of data analysis. Engineering provides model specifications and a typical P&ID for the capacity, metallurgies, and pressures to be considered for a given equipment type. From this design data, a unit cost model is created. The model is then iteratively reestimated to determine the battery limit cost factors for each set of expected design parameters.

Factors

As previously discussed, adjustment factors include labor productivities, material markups, escalation, labor rates and similar modifying terms. All of these factors tend to be highly specific to a given algorithm, location, site conditions, and other project characteristics. Development of these factors is left to other chapters of this text.

C. Data Sources

In addition to published manuals, text, and journals, there are many professional organizations involved with cost estimating that can help. There are also scores of project management, engineering, construction, architecture, and other associations with interest in cost issues. Many of those associations provide or participate in on-line forums, bulletin boards, and other venues accessible to the public through direct dial-up, commercial on-line services, or the Internet.

D. Data Resources

A truth about estimating is that *cost estimates and estimating data are always wrong*! This is a hard truth for many to accept but, the fact is that the probability of the actual cost of an item of any significance exactly equaling the estimating database value is infinitesimal. This is particularly true for generic cost data in many published references. Estimating data is "wrong" primarily because its basis is usually different from the basis of the project estimate. Note that it is OK and normal for the reference basis to be different from your experience, so long as you know what that reference basis is.

Data Basis

The basis is the defining set of characteristics that qualifies what the data represents. The basis tells where the data is or isn't applicable. These basis characteristics for data in a cost estimating database can be grouped as follows:

Time period—For what time period is the data applicable? (i.e., cost reflects market conditions in mid-1996)

Content—What are the specifications of the item represented by the reference data? (i.e., piping is carbon steel, standard weight)

Physical environment—What physical conditions are assumed by the data? (i.e., assumes all work at a height less than 10 ft, U.S. Gulf Coast)
Nonphysical environment—What nonphysical conditions are assumed by the data? (i.e., work is performed during a standard 40-hr work week, day shift)

Knowing these facts about the data, the engineer can then apply appropriate *adjustment factors* to make the data match the basis conditions of a particular estimate. Unfortunately, published data does not always provide detailed basis information for their data and one must assume that it reflects "normal or prevailing conditions and practice."

When creating a database it is essential that the engineer *normalize* logical groupings of the data to a standard basis and document what that basis is.

Normalizing and Documenting Data

As was stated, it is essential for a database to be internally consistent. Having 12 gauge wire in 1993 dollars and 16 gauge in 1996 dollars, or 2 in. pipe dollars based on schedule 40 weight and 3 in. based on schedule 80 would be ludicrous. *Normalization* is simply the process of reducing all the data in a grouping to a common or *normal* basis regarding each of the characteristics previously identified.

It is not necessary to normalize entire databases to a single basis in all respects. For instance, piping labor could be normalized to represent the labor required to work at ground level, while electrical labor could be normalized to represent the work at up to 5 meters elevation if these are prevailing, reasonable assumptions for each distinct grouping of items. Having normalized the data to an established basis, each basis characteristic of the data must be *documented* for reference by the user.

IV. MANAGING DATA RESOURCES

A. Data Organization and Cost Coding

Having collected or created the desired data resources, it is necessary to organize it in a logical fashion. The organization involves the assignment of a set of alphanumeric cost codes to each cost factor in the database. In order to facilitate information management, the cost codes need to address a large number of business and system data categorization needs in the following areas:

- Address project management needs
- Address business and financial needs
- Address technical and procurement needs

As many of the needs vary from one firm to the next, establishing a standard cost coding system is rarely a matter of taking one off the shelf.

Project Management Needs and Work Breakdown Structure

Modern project management requires that each project task be identified in a logical, hierarchical coding scheme called a *Work Breakdown Structure* (WBS). The hierarchy allows the cost of the tasks to be rolled up and reported at various levels of detail. A detailed discussion of WBS coding is beyond this text, but a typical code structure for a large chemical process project may look like this:

Program/project identification—(XYZ Division, Chemical Plant A)
Organization(s) responsible—(administration, engineering, construction, etc.)
Trade/discipline responsibility or *prime*—(piping, equipment, etc.)
Detail item identity or content, or *subprime*—(pumps, shop fabrication, piping, etc.)
Project area—(south area, phase I)
Project unit or system—(distillation unit, DU-1)
Various cost resources—(direct/indirect; office/field; labor/material)

Each task characteristic above will be given a code designation of one or more alphanumeric characters. The total WBS code may include 40 or 50 characters. Estimating databases however only need to specify a few of the elements above. This selected subset of codes is usually referred to as the *cost code* and it is predefined for each cost item in the database. These primarily include the trade/discipline (prime account) and the detail item content (subprime account) identifiers.

There are no universally accepted standard WBS codes for all projects. However, for the trade/discipline or prime account code that applies to an estimating database, there are two published standards that are used for almost all building construction and general contracting work, and a third unofficial standard that is frequently used for heavy industrial and chemical process projects.

The two published coding systems have been established by the Construction Specifications Institute for standardizing the organization of specifications. These are called the MASTERFORMAT and UNIFORMAT codes. The MASTERFORMAT is used for project controls during project execution and the UNIFORMAT is used for front-end project analysis. The MASTERFORMAT breaks the work down into 16 trade related divisions commonly dealt with by a general contractor. These divisions are dominated by an emphasis on building architectural items as can be seen in Table 5 (note: another 3 digits providing a lower level of detail is not shown here.)

Table 5 CSI MASTERFORMAT Division Codes

01.	General requirements	09.	Finishes
02.	Site work	10.	Specialties
03.	Concrete	11.	Equipment
04.	Masonry	12.	Furnishings
05.	Metals	13.	Special construction
06.	Wood and plastics	14.	Conveying systems
07.	Thermal and moisture protection	15.	Mechanical
08.	Doors and windows	16.	Electrical

The MASTERFORMAT is hard to use for estimating with parametric cost models which are based on overall design parameters of composite building systems as opposed to individual trade detail. For instance, in early project phases it is desirable to estimate the cost of exterior wall with one parametric model, but the MASTERFORMAT splits the wall between masonry, wood, thermal and moisture protection, and other accounts. To address this problem, a system-oriented standard was established. It is called the UNIFORMAT (Table 6) which has the following 12 system division designations:

As a project progresses from the definition phase to the execution phase, system estimates done with the UNIFORMAT can be related to detail estimates done with the MASTERFORMAT because they share internal logic at the detail item level.

For heavy industrial and chemical process projects, the CSI codes are seldom used for cost estimating or control. Industrial projects have little or no use for the architectural codes which dominate the CSI standards. Instead, they need additional coding detail for the equipment, piping, instrumentation, and other trades which dominate this kind of project. Therefore, for industrial projects, most engineers use some variation of the coding scheme in Table 7.

Notice that all building work is lumped into a single account to reflect the fact that the work is usually minimal and major engineer/procure/construct

Table 6 CSI UNIFORMAT Division Codes

01.	Foundations	07.	Conveying
02.	Substructure	08.	Mechanical
03.	Superstructure	09.	Electrical
04.	Exterior closure	10.	General conditions
05.	Roofing	11.	Special construction
06.	Interior construction	12.	Site Work

Table 7 Typical Industrial Process Division Codes

Site/civil
Concrete/foundations
Structural/steel
Buildings/architectural (typically subcontracted—includes all building trades)
Ductwork (for industries where process air is a large factor)
Equipment
Piping
Electrical
Instrumentation/process control
Painting/coatings
Insulation

(E/P/C) firms tend to subcontract this work out. It is likely however that the building subcontractor will use the MASTERFORMAT for their internal control purposes.

One of the three trade/discipline structures identified above will be the primary, fixed, predetermined identification codes found in any given reference estimating database. They are usually supplemented with several tiers of item detail describing the item content. For instance, piping may be further broken down to welded, flanged, socketweld, screwed, and clamp. The other organization and system codes are project specific and are assigned to estimate items during the estimating process. Below is an illustration of a cost code in an estimating database reference and the related code carried into a project specific WBS cost control code.

Estimating database item code: 05.30.110

where 05 = Equipment
30 = Thermal process
1xx = Heat exchanger
x10 = Shell and tube

Project WBS task control code: XY219.A3.52.*531*.1

where .*531*. relates to estimate coding and other characters identify the project, area/unit, organization, cost type, etc.

Project Business Needs and Financial Coding Structures

For owner firms, project cost control efforts must interface with the firm's accounting and finance process. For instance, actual costs on a project are obtained from the firm's accounting system, and project costs are capitalized, expensed, or otherwise booked in the financial systems. As these systems tend to use large, legacy computer programs with fixed data structures, the engineer is often constrained in the number of fields and digits that can be used in a WBS cost control coding scheme. In order to report costs to various organizations and authorities, the business system requirements will often add several tiers of coding to the WBS hierarchy. For instance, for tax purposes, every material item may have to be coded as taxable or nontaxable, and capital or expense. These financial code identifications are not predetermined for items in a reference database, but are applied to estimate cost resources during the estimating process.

Technical and Procurement Needs and Asset Identification

With the increasing integration of computer aided design (CAD) and cost estimating, there is a corresponding increase in the complexity of cost coding. This is due to the need for cost estimating unit cost data to be correlated with standard data structures used in the CAD system. For instance, every pipeline in the CAD system will be tagged with a standard specification ID number that needs to be tied to line items in the cost estimating database. Purchase requisition and purchase order numbers may be identified during estimating as well. These technical code identifications are not predetermined for items in a reference database, but are applied to estimate cost resources during the estimating process.

B. Data Storage, Maintenance, and Use

Storage

Having tagged a code number on every unit cost line item or cost factor in the database, it is necessary to store it, make it accessible to users and estimating systems, and maintain it. In general, the cost estimating database will always be recorded in a hard copy reference manual(s) with all basis documentation included. Depending upon the estimating methodology and systems in use, it will also be maintained in electronic form, either in flat-file spreadsheet or relational database formats. Many third party databases are available either in hard copy or electronic form.

Access

The local or wide area networking of personal computers has greatly aided the access and sharing of data in electronic format (LANs or WANs). Estimating systems on a network usually allow for *user created items* to be entered into a database by any user on the network. User items are usually highlighted as such to identify them as unverified and unnormalized. The advantages of having user items accessible is that it quickly shows where the standard database needs improvement, and it makes new information available immediately to other users.

E-mail and on-line computer services have also made electronic bidding and data exchange a common practice. Data and reports can now be sent instantly to anywhere in the world over the Internet, commercial services, or direct dial modem connection.

Maintenance

Data in the database must be adjusted periodically for time related impacts such as obsolescence and escalation. Material prices and labor rates are the most volatile cost factors to consider while labor hour data should remain fairly static. In times of low inflation rates, it is usually not necessary or desirable to update the reference database every year. Adjustment factors can take care of small changes. A reasonable cycle for updating a database is every 2–4 years.

Creating, maintaining, and updating a database is one of the most time consuming tasks in the estimating process. It is not unusual for a dedicated cost estimating department to spend 10–15% of their labor in methods and data development and maintenance, even when a standard methodology and reference database already exists. This could be higher if the department is involved in all project phases and must develop parametric estimating methods and data. It would be lower if the department's work was limited to a single project phase and their projects were repetitive, commercial work.

Usage

There is rarely a question anymore that cost estimating will involve the use of computers. But even with the increased number and power of commercial software packages, spreadsheets are still the bread and butter of many estimators. This is due to the fact that no one commercial system can handle all methodologies, nor can they create every conceivable report. For this reason, many systems allow their data to be imported from or exported to spreadsheet software packages. Spreadsheets are particularly useful for performing regression analysis, risk simulation and analysis, preparing graphics, and other special chores.

With the advent of object oriented programming software, it is now possible for estimators to have more than one software application in use that communicate with each other as if the systems were one. For instance, the estimator can enter data in an estimating application which in turn is feeding data to a spreadsheet for concurrent statistical analysis.

C. Cost Feedback

Continuous improvement of the estimating process depends upon obtaining and incorporating feedback of actual cost results and project experience.

Feedback from actual projects is necessary for database calibration and it is necessary for creating new data points. Also, as was discussed, complex parametric cost modeling and other stochastic methods are usually dependent upon the evaluation of historical data. Feedback is usually obtained after projects are complete from *project close-out records*. Real time feedback has little use in periodic database evaluations or methods development.

Project Close-Out Records

The contents of the project close-out record file should include basic summary cost and schedule results as well as some metrics of cost related technical descriptors of the project scope and project deliverables. Project close-out records for project controls purposes (as opposed to technical records) provide a number of things including:

Feedback for estimating database calibration
Data for development of estimating algorithms and methods
"Go-by" information to help plan future projects of a similar nature
Performance measures for the project process
Performance measures and planning information for management

Often, the department that performs estimating functions is charged with holding and evaluating these records given their interests in the subject matter and their existing staffing for data development and maintenance. The project manager or the individual who performed cost control functions on the project is usually responsible for gathering and preparing the close-out record file. The file may be kept in hard copy or electronic form. Table 8 is an index of a typical close-out report:

Feedback for Estimating Database Calibration

The primary means of calibrating the estimating database is *actual-to-estimate cost comparison or evaluation*. Comparing actual to estimated costs requires that the basis of both costs be the same. If project changes were not controlled and the estimate was not maintained with cost coded change estimates, then comparison will be impossible.

Calibration is done for two purposes: 1) to determine appropriate, site specific adjustment factors to apply to the reference database, and 2) to determine if the individual unit costs in the database are internally consistent (i.e., adjustment factors work equally well for all costs of a given type). Comparisons can be made at any level of detail at which actual project costs were reliably captured. For most, calibration is done at the division or prime account level as shown in the previously identified cost coding systems. The calibration is usually done periodically, using the average results of a large number of projects to avoid discrepancies that might exist on anyone project.

Table 8 Project Close-out Report Index

1. Table of contents
2. Project summary
   a. Project narrative appraisal (lessons learned)
   b. Cost ratio summary reports
   c. Project fact sheet
   d. Project labor analysis
   e. Summary description of facilities
3. Scope documents
   a. Requirements document
   b. Conceptual design proposal
   c. Project organization chart
   d. Approved preliminary and final funding documents
   e. Final acceptance notice
4. Schedule
   a. Final statused master summary schedule
   b. Special/unique control level or detail schedules
   c. Engineering and design progress report
5. Project estimate and WBS
   a. Project estimate(s)
   b. Project WBS/code of accounts
6. Cost and performance
   a. Final cost control report
   b. Final trend and change order log
   c. Cost or cash flow curve(s)/expenditure plan
   d. Performance curves (hrs/progress/performance)
7. Contracts
   a. Contract bid summaries
   b. Subcontract plan
   c. Unit price and other detail cost submittals
8. Technical
   a. Plot or site plan, and block flow diagram (reduced size)
   b. Drawing list (may be part of engineering design progress report)

A simple example of how to determine an adjustment factor (in this case labor productivity) for a given reference database follows:

1. Piping labor hours from actual project budgets = 100,000
2. Average productivity adjustment used to derive those budgets = 1.20
3. Unadjusted piping labor hours from estimates = 100,000/1.20 = 83,300
4. Actual piping labor hours = 110,000

5. New labor productivity adjustment factor = 110,000/83,300 = 1.32 (Note: hour totals and factors are for a group of projects with a similar basis.)

Assuring that all unit costs for a group of line items in the database are internally consistent follows a similar approach, except, the adjustments for every line item or small group of line items are determined as opposed to an entire division. If the adjustment for any one item falls significantly out of line with the rest, then a database correction is called for that item.

Data for Development of Estimating Algorithms and Methods

As was discussed, complex parametric cost models can be created from historical cost data using *regression analysis*. The actual costs are regressed against various selected design parameters or other project metrics. Historical data is commonly used to determine gross unit cost factors such as engineering costs as a percentage of total project costs, etc.

Go-By Information for Planning Future Projects

The material in a project close-out report can serve as a skeleton outline for controls tools and reports for future projects of a similar scope. Having this information available can significantly speed up the learning curve on new projects. If a project's estimating data was stored electronically, it can be loaded up in an estimating system for use on the next job. Another important close-out report document is the project narrative, providing lessons learned information.

Performance Measures

Project metrics such as the cost of preparing an estimate can be derived from the historical data. These metrics can be used as estimating tools or for tracking performance trends. In a similar vein, performance trends for the various organizations and functions involved with projects can be analyzed, if the cost control coding captured that kind of detail. If the code of accounts used is consistent with the code used by outside firms, then these metrics are excellent tools for benchmarking your performance against the outside. Table 9 gives an example of the kinds of metrics that can be obtained from historical data.

V. COST ESTIMATING TOOLS

Cost estimating tools include the forms, hardware, and software used to execute the estimating methodology. The tools are where the algorithms and data come together to yield the final estimating product. They also include

Table 9 Project Performance Metrics and Benchmarks

End product/use	Common relationships	Example calculations	Units
Rough order-of-magnitude cost estimating relationships (CERs)	Cost-cost	DFL $/DFM $ Total $/equipment $	%
Uses:	Labor-cost	DFL-hrs/equipment $ HO $ /HO-hrs,	hr/$
Management performance/quality review			
Client performance/quality review	Cost-labor	DFL $/DFL-hrs HO $/HO-hrs,	$/hr
Estimating tools			
Estimated database calibration	Cost-deliverable or output	Total concrete $/total CY Total $/output capacity	$/unit
Capital management forecasting			
	Labor-labor	Process engineering hrs/total engineering hrs HO-hrs/DFL-hrs,	%
	Labor-deliverable	DFL-hrs/piece of equipment Engineering hrs/drawing	hrs/unit
Rough order-of-magnitude schedule relationships (cycle time analysis)	Time-cost	Construction days/TFC $ Engineering/design days/HOC $	day/$
Uses:	Time-deliverable or output	Debug days/number equipment pieces Engineering-design days/number drawings	day/unit
Management performance/quality review			
Client performance/quality review	Time-labor	Constrution days/DFL-hrs Engineering-design days/HO-hrs	day/hrs
Planning tools			
	Time-time	Front end days/total days Engineering-design days/construction days	%
Detailed estimating database feedback (productivity and rates)	Actual-to-budget-to-estimate labor-labor	Actual-hrs/unadjusted estimated hrs	%
Uses:	Same as ROM estimating, but mostly cost and labor/deliverable		$/unit hrs/unit
Estimated database calibration			

Performance and quality measurement (indices and benchmarks)	Labor efficiency labor-labor	Actual-hrs/budget-hrs	%
Uses:	Rework cost-cost or time-time	Rework $/total $ Rework days/total days,	%
Management performance/quality review Client performance/quality review Estimating tools	Change management cost-cost or time-time	Non-scope change $/total $ Scope change days/total days,	%
Capital management forecasting Project planning tools	Capacity achieved output-output	Actual units/nameplate units	%
	Indices any ratio-process measure	Rework %/number new process steps	%
	Same as ROM estimate and schedule cost, labor, time/deliverable	Engineering hrs per drawing	x/unit
Workload forecasting factors (CERs) *Uses:*	Labor-cost	Engineering-hrs/sum of project $ construction-hrs/sum of project $	hrs/$
Capital management forecasting	Labor-labor	Electrical DFL-hrs/construction-hrs design-drafting hrs/HO-hrs	%
Risk assessment factors (indices and benchmarks)	Technical process measures any ratio-process measure	Rework %/number new process steps	%
	Execution strategy measures any ratio-strategy measure	Change %/%DFL in shutdown	%
Uses: Management performance/quality review	Location measures any ratio-location measure	Productivity factor/location change %/per location	%
Client performance/quality review Project planning tools Estimating tools	Project process measures any ratio-process measure	Change %/integrated team index	%
	Organizational/client measures any ratio-client measure	Change %/for selected client	%

Table excludes complex algorithms developed by off-line statistical analysis, modeling, etc.
DFL = direct field labor; TFC = total field costs; HO = home office (engineering, administration); DFM = direct field material; HOC = home office costs.

the linkages to other project process tools such as CAD that support the estimating process. Estimating tools fall into the two broad classes of manual forms and computer software. The continual proliferation of software products precludes listing them here, but sources can be found describing them in more detail [18]. The following discussions cover general considerations for the selection and use of the major categories of tools and describes their relationship to the various algorithm types.

A. Manual Forms

Forms for Unit Cost Applications

Manual estimating forms and worksheets are still used for smaller estimates where large database searches and fast recalculation are less valuable. The forms used are often tailored to a specific firm's needs, but typically, they look something like the illustration previously shown in Figure 3.

The quantity parameters are usually obtained from take-off measurements from design drawings. The labor cost factors are obtained from a cost estimating database. Material unit costs are obtained from the database or from quotations. The item costs are calculated and summed across to a line item total. Line item totals are summed for the page or to whatever subtotal is desired. Then the pages are summed to a total to which general requirements are added and other adjustments are made. As these forms can easily be duplicated in a spreadsheet that can be run from a laptop computer, manual forms are used less and less. In large manual estimates, any change to an item can lead to a cascade of erasures and recalculation—a problem that does not occur with spreadsheet software.

Forms for Ratio Factoring Applications

Having prepared the direct unit cost detail (or some other method) on manual backup sheets as above, it is common to tabulate those direct costs on a summary sheet and then use ratio factoring to derive the indirect costs and project bottom line. Figure 8, previously shown, provided an illustration of this type of summary tabulation sheet.

B. Spreadsheet Software

Spreadsheets for Unit Cost Applications

Used in the simplest way, a spreadsheet simply duplicates the manual forms discussed above. A basic spreadsheet is nothing more than a two-dimensional series of columns and rows with "cells" being the place where they intersect. The user can enter data, formulas, or text in the cells, duplicating the appearance and functions of the manual estimating sheet. Most spreadsheet software also allow a "third dimension," which is like stacking individual work sheets on top of one another, to be added. Each sheet may represent individual project units that can be added vertically through the worksheets to derive the project total.

One the most useful functions for semi-automating a basic unit cost spreadsheet application is the *look-up* function. This function provides some relational database-like functionality to basic spreadsheets. It does this by looking up and retrieving the cell contents from a preestablished spreadsheet *look-up table* (like a database). It looks for the proper cell in the table based on rules established in the look-up function as well as the value entered in a designated entry reference cell. For instance, the cost code "401" could be entered in the "Item Number" reference cell of the estimate worksheet illustrated in Figure 3. In the "Description" cell, a look-up function could be entered that takes the value 401, goes to a look-up table elsewhere on the spreadsheet, and returns with the title "buildings, prefab." The look-up table was prebuilt to associate that title with the standard code 401. In a similar fashion, all the unit cost factors applicable to cost item 401 could be found and returned to the work area of the spreadsheet automatically. There are many other uses of this function that make it worth learning.

Spreadsheets for Other Applications

Taken to its extreme, a spreadsheet can be programed to create an entire semi-automated estimating system if desired. This is done by including complex functions in the cells and/or by adding macros. Macros are essentially computer programs that automate spreadsheet operation. With special analytical functions, graphics capabilities, and some relational database features added, there is very little that spreadsheet software cannot do if taken to the limit. Spreadsheets have some limitations in size due to their reliance on random access memory (RAM), but for many applications this is not a problem.

A spreadsheet can be used to automate any of the methods described in this chapter. Their basic use is intuitive as it somewhat parallels the way work is done on paper. They can also be used for regression analysis, risk analysis, decision analysis, simulation, optimization, and other analytical functions. Some of these special functions are built in and others can be obtained as add-on software. For these reasons, spreadsheets will probably remain the most common software tool used by engineers for estimates.

C. Relational Database Software

This type of software stores its data in a relational structure of fields and rows. These fields and rows are not unlike a spreadsheet's columns and rows, except all the pieces of field data across a row are tied together or related.

Only data can be entered and stored in the "cells"—all functions and calculations must be performed as special commands or batch programs that exist independently of the database but work upon it as called on. Database software has the advantage of being able to store, access, and manipulate a large amount of data very rapidly (data is not kept in RAM), but it is less intuitively functional than a spreadsheet. Because the user must program the functionality into the system, its direct use has been limited to more advanced users. However, easier user interfaces and application development tools are reducing this problem.

The primary use of databases for most engineers will be to store cost estimating data, whether it be the reference cost estimating database or project historical cost data.

It should be noted that essentially all commercial estimating software packages employ database functionality in their systems. Custom databases developed by the engineer can be accessed by these commercial systems. The reference electronic databases of these systems and their output are generally stored in xBase structure ("x" indicating various proprietary database formats) that can be accessed and used by an engineer using a standard xBase software package independent of the estimating system.

D. Commercial Estimating Software

Commercial Software for Unit Cost Estimating

There are a large number of excellent general estimating packages on the market [18]. Most of the systems operate in the same general way and all can use one or more of the major commercial electronic estimating cost database products that are available. Most import and export data in xBase format and many employ object oriented programming to ease interface with other computer systems used by the engineer. Most systems allow the user to create and store unit cost assemblies. Extensive cost coding capability is a desirable feature that most share. Parametric unit cost modeling capability is becoming a standard feature as well. Given the similarities between packages, many users select a system based on how it interfaces with other systems at their firm such as general office packages (word processors, spreadsheets, databases, and presentations), planning and scheduling, job cost accounting, bidding, CAD, etc.

In addition to the general packages, which can be used generically for any cost estimate, there are many discipline specific packages (i.e., piping, hvac, electrical, etc.). These packages are tailored to general and specialty contractors who need a high level of detail in their estimates to support hard dollar bidding. These packages are often bundled with customized *digitizing* tools, data, and software to allow the contractor to perform rapid, thorough take-offs from request-for-bid drawings.

Commercial Software for Parametric Unit Cost Modeling

As was mentioned many general estimating packages now permit parametric unit cost models to be created. However, these general packages do not usually come with a set of prebuilt models to use. For those who wish to avoid model building there are commercial systems available with hundreds of prebuilt models of buildings or chemical process plants. The use of these packages is somewhat limited by the scope of the models they offer, but if those models fit your needs, they are superb products.

Commercial Software for Complex Parametric Cost Modeling and Other

There are a handful of packages that specialize in complex parametric cost modeling. Due to complexity and cost, their use has been somewhat limited to research, aerospace, energy, software and hardware development, and other technologically complex, large, and risky ventures.

Commercial Software for Combined CAE and Cost Modeling

Some systems have overlaid a computer aided engineering and/or design (CAE/CAD) system onto a parametric unit cost modeling system. The CAE/CAD or other system design module feeds the cost models with the technical parameters needed to produce a cost estimate. Many systems of this sort are available for specific trades such as HVAC and piping. A number of packages used by larger owner and architect/engineer firms are designed for estimating entire buildings and chemical plant projects.

Commercial Expert Systems for Cost Estimating

Some estimating software packages are billed as expert systems, but most often, they are really just combined CAE/cost models as described above. They take the user from basic project requirements and specifications directly to a cost estimate, with a minimal amount of user input. These systems are expert in the sense that the user does not have to perform the intermediate calculations which have been predefined, but they do not contain the heuristic rules and such that would remove the requirement that the user have a high level of knowledge of both the engineered process and the cost models involved. Some of the complex parametric cost modeling systems do have expert system capabilities built in but their use is limited in general industry.

Custom Cost Estimating Applications Development

As was mentioned, spreadsheet, database, and other software packages have become increasingly easy to use as tools for programming custom applications. Spreadsheet and database tools can be compiled to create independent, executable programs. In addition, object oriented programming has made possible the creation of custom modules that can be added on to commercial estimating tools. As on-line computer services expand, the use of shareware for special applications is likely to grow. Given the prevalence of excellent products however, engineers are advised to seek commercially available packages for general unit cost estimating that can be used as platforms for such add-ons and enhancements as the need arises.

E. Estimating Related Tools

As has been stated previously, there are many tools such as planning and scheduling, CAE/CAD/CAM, job cost accounting, finance, procurement, and other software tools that either provide data for the estimate or use its output. The engineer must determine how the tools for a chosen estimating methodology will interface with these products. Questions to address include: will their interface be automatic or manual? are the database files compatible? will they all accept the same cost code structure? can they operate on the same LAN and operating systems?, etc.

F. Project History Analysis

As was discussed, feedback on estimating and project process performance is essential to quality and continuous improvement. Unfortunately, there are not many commercial software products available specifically for this function. The engineer should create a system or methodology for collecting historical project and cost data, and analyzing that data using the resources at hand. The type of data to collect covers more than the usual job cost accounting figures. Relational database applications are preferred given the large amounts of data that may accumulate. Table 9 shown previously highlights some of the measures to be collected and analyzed. Figure 9 illustrates how a historical cost evaluation system would integrate with a project management information system.

G. Other Tools and Sources

There are hundreds of niche products, tools, and utilities being created that are not readily available through normal commercial channels. In particular, engineers are encouraged to contact their professional associations, and to search the Internet, commercial on-line services, and other on-line sources

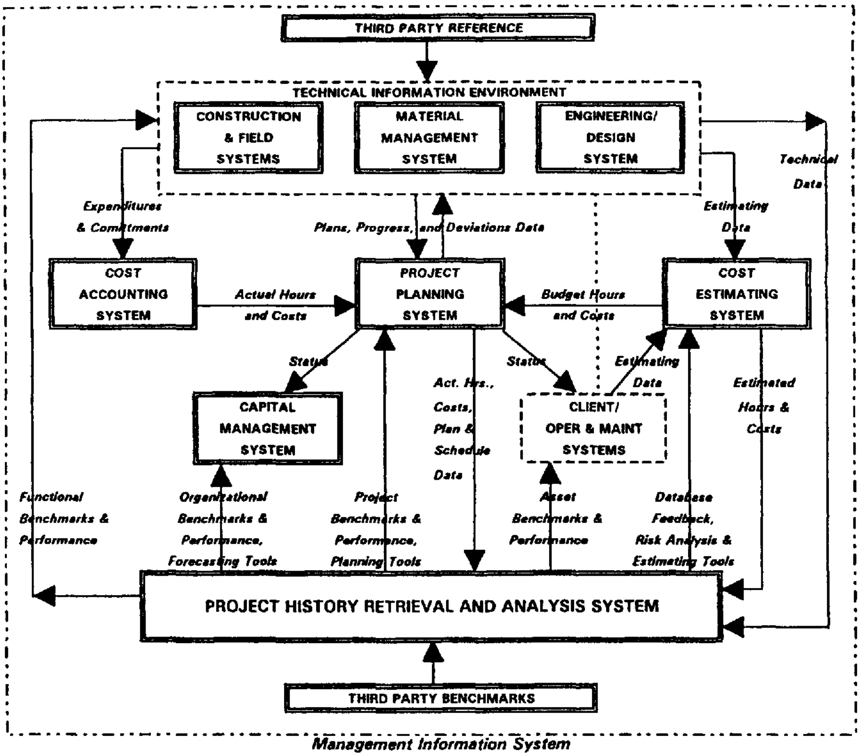

Figure 9 Historical data in a project information flow diagram.

for the vast amounts of freeware, shareware, and other software products that can be found there.

VI. PROCEDURES

Having selected the appropriate algorithms or techniques, and having obtained or created the necessary data resources and estimating tools to apply them, it is necessary to organize and plan an approach to make the estimating methodology work efficiently.

A. Organization Considerations

Given the possible variety of organization sizes, scope of involvement with projects, expertise of employees, and other variables, it is impossible to generalize in regards to organizing for estimating. There are some general principles that should be considered:

Cost estimating is a profession. While all engineers do some estimating, it is not reasonable to expect a typical professional engineer to also be fully proficient in cost estimating. Consider establishing a dedicated estimating department or supplement the engineering department with cost estimating professionals. In construction or hard dollar estimating, knowledge of construction trade practices is essential.

The cost estimating process is a continuous cycle. A proper methodology starts from a project's first conception and follows through the feedback cycle. Different estimating methods are applied at different phases of the cycle. For consistency and control, it is important that one estimator or team follow the project estimate through from beginning to end. Avoid the "over-the-wall" approach where estimates pass from one place to another until nobody remembers what the number represents or how it came about.

There is no such thing as "estimating in a can." Do not expect to find off-the-shelf data and tools that are 100% comprehensive and accurate for your situation right from the box. Allow 10 to 15% of your estimating budget for database and tool development and maintenance. Remember that estimates and estimating data are always wrong, and time must be spent in finding out how wrong.

Estimating is a part of the project team. A project cost estimate is not an incidental byproduct that falls out of design. As the basis of the project schedule and budget (or bid), the quality of a cost estimate can make or break a project. A proper estimating methodology improves the quality of a design right at the start.

B. The Cost of Estimating

As with the organization, it is difficult to generalize on what an estimate ought to cost to prepare. Figure 10 shows one example of the cost of estimate preparation as a function of the total cost of the project being estimated and the accuracy range of the estimate. These values represent an owner firm with a dedicated estimating department with established methods, data, and tools working primarily on manufacturing and chemical plant projects. Each firm's experience will differ somewhat from this graph (pilot plant work may be many times greater than the chart); however the general form of the estimating algorithm as follows is believed to be broadly applicable [12].

$$\text{Estimating Costs} = K \times (\text{Project Costs})^{E}, \text{ where } E = 0.35 \text{ to } 0.4$$

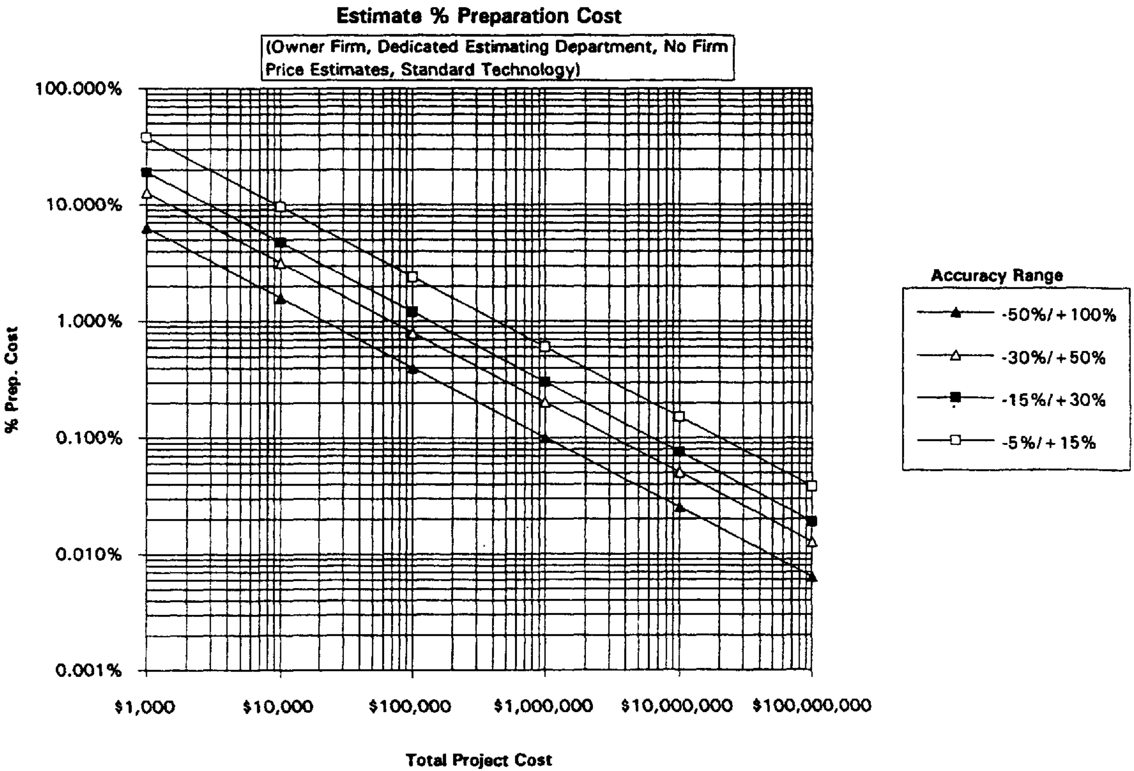

Figure 10 Typical estimate preparation costs.

With modifications of the constant and exponent, the chart in Figure 10 can be made to work in various situations.

C. Putting It All Together

Having all the parts of the methodology in place, and an organization to execute it, it is necessary to document the process that has been established. A procedures manual covering the estimating process in general (per Chapter 1) and the methodologies in particular, is a valuable tool in maintaining continuity and consistency in practice over time. Established procedures also aid in continuous improvement evaluations of the estimating process.

Subsequent chapters in this Part provide more detail on the various cost factors and adjustment factors outlined in the estimating methodologies described here. These include labor and material factors, equipment costs (which are of primary concern for industrial and chemical projects), and the more critical adjustments for labor productivity, escalation, and location.

VII. GLOSSARY

Accuracy Range The high and low percentage or absolute cost value range by which a project's actual cost may vary from a stated point value with a stated level of confidence.

Adjusting Factor An estimating algorithm independent variable that is applied against a cost resource to adjust the result (i.e., adjustment corrects the result to reflect the given estimate basis conditions—often a dimensionless value) (also see Cost Resource, Cost Factor, and Cost Parameter) (also, see Productivity, Escalation, Markup, Location Factor).

Algorithm In estimating terms, a mathematical routine that transforms project, technical, and programmatic descriptive information into cost terms (also see CER).

All-in A descriptive term generally applied to an Assembly or Unit Cost Model to indicate that the assembly line item contains the cost of all of the detail items customarily associated with such an assemblage.

Analytical Model (or Statistical Model) Alternate terms for a Complex Parametric Model. Analytical models may imply that the model is performing more functions than just traditional cost estimating (also see Complex Parametric Cost Model).

Assembly (or Unit Cost Assembly) A Unit Cost that encompasses more than one detailed item component. A grouping or assemblage of associated discrete detailed items (also see Unit Cost Model, and All-in).

Basis of Data The basis is the defining set of characteristics that qualifies what the data in a cost estimating database represents. The characteristics define the data's basis in time, content, physical environment, and nonphysical environmental conditions (also see Normalize, Cost Estimating Database).

Battery Limit A limited area of a plant immediately surrounding and encompassing a piece of process equipment (i.e., a "battery" of equipment and material within a space "limit").

Battery Limit Estimate An estimate whose result reflects all of the cost for equipment and materials within a battery limit. Excludes off-site items. May or may not include indirect costs. Usually applies with Equipment Factored Estimates (also see Battery Limit, Equipment Factored, Off-sites, Indirect Costs).

Benchmark For reengineering and continuous improvement it is necessary to know how your process performance measures compare to the process measures of third parties. Performance measures selected as goals are called benchmarks (i.e., best-in-class, or industry average.) (also see Performance Measures).

Black Box A term used to describe estimating systems that produce estimate results directly from factor and parameter input without the user being involved in the intermediate calculation process. Estimate accuracy from a black box system is partly dependent upon the users understanding of how the systems algorithms function (garbage in, garbage out).

CAE/CAD Computer Aided Engineering or Design

Calibration The process of adjusting cost estimating database values to make them internally consistent within groupings, and to assure that all the database values accurately reflect the stated reference basis of the database (also see Basis of Data, Normalize).

Capacity (or Exponential) Factored Estimate An estimate whereby the cost of an item with a known capacity parameter is factored from the cost of a comparable item with a different capacity. The capacity cost factor used is a ratio of the new item's capacity over the historical item's capacity all taken to an exponential power (also see Six-Tenths Rule and Chilton Factor).

Cascading Factors A form of a Battery Limit Equipment Factored Estimate where a sequential series of cost factors are applied in the estimating algorithm to derive various lower level discipline and resource cost details from a base equipment material cost.

Chilton Factors Exponents used in capacity cost factored estimates. C.H. Chilton documented the applicability of capacity factors to entire plant costs (also see Capacity Factored Estimate, Six-Tenths Rule).

Complex Parametric Cost Model A stochastic estimating algorithm that has no predefined form except that it consists of mathematical expressions (usually statistically based) that incorporate one or more technical, programmatic, functional, or other parameters related to the item being estimated. As used by most engineers, these models are simply algorithms resulting from regres-

sion analysis. Some use the terms CER or Parametric Cost Model to refer to this form of algorithm (also see Regression Analysis, CER).
Contingency see Chapter 1
Cost Code An alphanumeric code applied to an estimate item that identifies its discipline and summary content category (other categorizations may also be included). Used to organize estimating data for storage, use, reporting and subsequent project cost control (also see Discipline, Work Breakdown Structure).
Cost Curve A graphical representation of an estimating algorithm.
Cost Estimating Database A hard copy or electronic reference source of standard cost factors with a known basis for use in estimating algorithms (also see Basis of Data).
Cost Estimating Relationship or CER An estimating algorithm. Often used when describing parametric estimating algorithms (also see Algorithm).
Cost Factor An estimating algorithm dependent variable that when applied against an independent parameter, results in a cost resource measure (i.e., often has units of cost resource value/parameter value) (also see Cost Resource and Cost Parameter).
Cost Parameter An estimating algorithm independent variable that is a numerical representation of an item's technical, programmatic, or other noncost basis characteristics (i.e., measure of quantity, size, weight, throughput, inputs, etc.) (also see Cost Resource and Cost Factor).
Cost Resource An estimate result usually measured in units of currency or time in hours (i.e., cost resource = cost factor × cost parameter).
Design-to-Cost A design methodology related to optimization that starts with a desired cost outcome and then seeks to determine a design(s) that will yield the desired cost while still meeting stated performance requirements. Parametric Cost Modeling is ideal for these studies (also see Optimization, Complex Parametric Cost Models, Parametric Unit Cost Models).
Deterministic An algorithm that is based on conclusive, definitive cost relationships between cost factors and parameters. Opposite of Stochastic (Generally applies to unit cost estimating relationships—see Unit Cost Estimate).
Digitize/Digitizer The act of performing a take-off using electronic devices that translate measurement data to a digital format. The device for performing such a take-off is often referred to as a digitizer (also see take-off).
Directs see Chapter 1
Discipline (or Trade) Refers to the customary divisions of work types in an engineering or construction project. The primary characteristic of an item (prime account) conveyed by a cost code (i.e., mechanical, electrical, and process disciplines in engineering, or piping, steel, and electrical disciplines in field construction) (also see Cost Code, WBS).
Equipment Factored Estimate An estimate whereby the cost is derived by multiplying the known material cost of the process equipment by a factor.

The result of the factoring may be the cost of the entire plant or an individual cost resource depending on how used (also see Battery Limit Estimate, Equipment List, Cascading Factors, Hand Factors, Lang Factors).

Equipment List A listing of all the process equipment to be included in the estimate. May include major electrical equipment. As used in an estimate it should include the equipment tag number, description, capacity/size parameter, and price.

Forced Detail Take-off like units of quantity derived from experience-based assumptions or extrapolations as opposed to actual measurements or scaling from drawings.

Gross Unit Cost Factor A stochastic estimating method similar to detail Unit Cost Estimating except the cost factor and unit of measure parameter represent a summary level, gross assemblage of items of indeterminate content (also see Complex Parametric Cost Models, Regression Analysis, Unit Cost Estimate).

Hand Factors A specific type of cost factor documented by W.E. Hand for use in battery limit equipment factored estimates. A Hand Factor is multiplied by the price of each discrete process equipment item to derive the battery limit cost for that item (also see Battery Limit Estimate, Equipment Factored Estimate, Lang Factor).

Hard Dollar Estimate An estimate used as the basis of a contract bid where the contract price is not subject to change for a given scope (also, see lump sum, fixed price, fall-out, tender, firm price, or final price).

Hybrid Algorithm A term describing specialized algorithms that combine the application of various common methods.

Indirects see Chapter 1

LAN/WAN Local and Wide Area Networks. These are methods of connecting personal computers into a shared operating environment.

Lang Factors A specific type of cost factor documented by H.J. Lang for use in equipment factored estimates. A Lang Factor is multiplied times the total price of an entire facilities process equipment to derive the facilities total battery limit cost (also see Battery Limit Estimate, Equipment Factored Estimate, Lang Factor).

Life Cycle Cost Estimate A cost estimate of all costs (research, design, construction, operation, decommissioning, etc.) for a system that occur through its life cycle.

Line Item Estimate A Unit Cost Estimate where the labor, material, subcontract, and other direct costs for a given item appear on a single line of an estimating worksheet.

MASTERFORMAT A standard cost coding structure which divides general contracting work into meaningful, *discipline* oriented divisions for specification, estimating, and control. Divisions parallel the way commercial building work is specified and contracted. Established by the Construction Specifications Institute (also see Cost Code, WBS, UNIFORMAT).

Methodology In estimating terms, a standard set of cost estimating practices, resources, and tools that are consistently applied in all estimates.

Normalize The process of adjusting or calibrating cost data to make it reflect a given basis of data (also see Basis of Data, Calibration).

Object Oriented Programming Software programming that yields an application that can be linked with and embedded in another application programed to work in the same computer system operating environment. The linked and embedded application is referred to as an object in graphical operating environments such as Microsoft Windows™. The two linked applications can run simultaneously and cooperatively.

Off-sites All plant items not included in a battery limit. Normally includes site development, services, utility and product supply and distribution facilities such as offices, electrical power switchgear, main piping headers, etc. (also see Battery Limit).

Optimization A way to apply a given estimating algorithm in order to determine the best combination(s) of parameters to yield a desired outcome or range of outcomes. Also called goal seeking or what-if analysis.

Parametric Estimate An estimating algorithm in which the parameter or independent variable is stochastic (i.e., parameter is usually an indirect or conjectural measure of an item that is something other than the units of quantity) (also see Unit Cost Estimate).

Parametric Unit Cost Model This is a hybrid combination of a Unit Cost Model algorithm and a Complex Parametric Cost Model. Typically, the parametric model is used to modify the unit quantities of the detail unit cost items in an existing unit cost model or assembly.

Performance Measure For quality management and continuous improvement it is necessary to measure the outcome of a process. In the estimating process, these measures usually take the form of ratio cost factors expressed as a measured cost resource value over a known parameter value (i.e., engineering hours/equivalent drawing count, such as 32 hrs/drawing) (also see Ratio Cost Factors, Adjustment Factors, Benchmarks).

Point Estimate The end result or bottom line of an estimate stated as a single value without an expression of confidence or accuracy range.

Productivity, Escalation, Markup, Location Factors See other chapters.

Quantity Survey See Take-off

Ratio Cost Factor A cost factor used in estimates whereby the cost of one item or resource is derived by multiplying the known cost of another related item by this factor. The factor is a predetermined, dimensionless ratio of the cost of the unknown resource to the cost of the known one. It is similar to algorithm adjustment factors in that both use dimensionless factors against a known cost resource, but adjustments are intended to modify a given cost resource and not to derive the cost of another (also see Performance Measure, Adjustment Factor).

Regression Analysis A statistical technique (least squares method) used to determine a relationship between the values of a single dependent variable and the values of one or more independent variables. In parametric cost estimating, the dependent variable is the cost output, and the independent variables are parameters. This is the primary technique used to derive parametric estimating algorithms.

Risk Analysis A systematic evaluation of the cost risk of a project. Usually involves the use of simulation techniques. Usually results in an estimate accuracy range with stated probabilistic characteristics (also see Simulation).

Semi-Detailed Estimate A term describing an estimate of intermediate accuracy range produced with a combination of unit cost and parametric algorithms.

Simulation A way to apply a given estimating algorithm in order to determine the probability distribution of potential estimate outcomes (also see Simulation Model, Risk Analysis).

Simulation Model Refers to an estimating cost model whose discrete factor, parameter, or other root values have been replaced with probability distributions of possible values. The model is then used in statistical simulation using sampling techniques such as Monte Carlo simulation.

Six-Tenths Rule In Capacity Factored Estimates it has been shown that a capacity factor exponent of 0.6 is widely applicable for many process plant components and plants as a whole (also see Capacity Factored Estimate, Chilton Factors).

Soft Dollar Estimate An estimate used as the basis of a contract bid where the contract price is subject to change for a given scope depending upon the occurrence of defined circumstances or conditions (also, see cost plus).

Stochastic An algorithm that is based on conjectural cost relationships between the factors and parameters. Usually derived through statistical analysis as opposed to engineering measures. Opposite of Deterministic (Generally applies to parametric cost estimating relationships—see Parametric Estimate).

Systems Engineering An engineering process that involves the methodical evaluation of system functions and requirements.

Take-off The act of obtaining the units of quantity parameter for an estimate by physically measuring or scaling the units from a design drawing or other deliverable. Also refers to the resulting list of quantity requirements (also see Quantity Survey, Digitize, and Forced Detail).

UNIFORMAT A standard cost coding structure that divides general contracting work into meaningful, *systems* oriented divisions for estimating and planning. Divisions parallel the way commercial building systems are designed and evaluated. Established by the Construction Specifications Institute (also see Cost Code, WBS, MASTERFORMAT).

Unit Cost Estimate An estimating algorithm in which the parameter or independent variable is deterministic (i.e., parameter is usually a direct or definitive measure of the units of quantity of the item being estimated) (also see Parametric Estimate).

Unit Cost Model A prebuilt unit detailed Unit Cost estimate containing a defined grouping, assemblage, or system of related unit cost items or assemblies. A unit cost model differs from an assembly only in degree of scope (also see Assembly).

User Item An item in an electronic cost estimating database that was entered by an estimating system user. The data may not be normalized.

Work Breakdown Structure (WBS) A logical, hierarchical alphanumeric coding scheme applied to project tasks and activities that allows the cost (and other information) of the tasks to be rolled up and reported at various levels of detail (also see Cost Code).

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3
Estimating Engineering Costs

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I. GENERAL

Projects are complex endeavors that require the services of engineers to plan, design, and manage these efforts. The need for a facility is first established in order to set the purpose and function of the project. Preliminary design efforts are undertaken by engineers in order to estimate the project's costs. Engineers assist in determining the economic worth of a prospective project.

The facilities to be constructed must be designed by engineers, in accordance to owner/client wishes along with the applicable codes and standards. Engineering services typically culminate in working drawings and specifications that depict the design intent of a facility to be constructed. The extent of different facilities, equipment, systems, and site improvements that make up a project must all be considered by an engineer in order to meet owner/client expectations.

Construction projects are typified by their complexity and diversity that is influenced by a considerable amount of variables and often unpredictable factors. Each project is executed by a team of resources that includes owner, craft workers, sureties, lending institutions, governmental bodies, insurance companies, equipment vendors, fabricators, material suppliers, and construction contractors. Team members all depend on an engineers' knowledge, judgment, his work output and direction.

Today's industry is being driven by the demand of a new global business environment on one hand and by profound changes shaped by information technology on the other. Information technology speeds the pace of many work activities and, at the same time reduces the need for human involvement. Large engineering construction companies, for example, used to be vast halls of closely packed drafting boards at which draftsman, designers, engineers and architects prepared drawings and made calculations of facilities to be constructed. Now those halls are smaller and furnished with computer work stations. The draftsman, designers and engineers are replaced with CAD (computer aided drafting) operators and engineers working with computer simulation models and artificial intelligence systems. These changes combine with the demand for being more competitive along with making improvements in quality, safety, and faster delivery time at a lower cost. All have definite influence on the services provided by engineering construction organizations.

The purpose of the chapter is to assist in developing cost estimates for engineering services. The term "engineering" encompasses all design professionals that are involved with providing services to design and assist with execution of a project. This chapter will provide an engineering contractor's perspective of fundamentals, principles and proven methods that are used in developing cost estimates.

II. ENGINEERING SERVICES

Engineering firms furnish a wide variety of services to owner/clients for the efficient and successful completion of their project. The most common use of professional engineering firms is to provide design services that result in producing all necessary documents required to construct a project. Other arrangements can be that an owner/client may contract with a single full services turnkey engineering construction firm for a project. In the drive to become more competitive owner organizations have reduced their in-house engineering capabilities and have outsourced for engineering services. These initiatives have included supplementing their needs with as-required consultants or design teams, to forming strategic alliances for obtaining a broad range of design, engineering, and related services. The advantage of these partnering arrangements is to establish a long-term trusting relationship that fosters team work and understanding, resulting in an overall lower cost to the owner.

The task of engineering covers a diverse spectrum of services that extend from project preplanning, consulting, research and development, field investigation, site selection, conceptual studies, optimization studies, preliminary design, detailed design, final design, engineering support during construction, commissioning/start-up assistance, to postproject support.

The approach most frequently used to accomplish complex projects in a cost effective manner is a Task Force concept of operation. This concept usually consists of an assembly of resources (people) at one office location for execution of work under guidance of a project manager. The primary feature from this type of operation is based on a team of people who are selected for their skills in various disciplines with the sole responsibility to perform work necessary for efficient and successful completion of a project.

Team size can expand and contract as work dictates during the life of a project. Task force starts with a few people in early stages, building to a peak during the period of major production efforts. Engineering projects range from a few people in a front end study to several hundred for a large design-construct project.

In order to remain competitive in the global economy, engineering firms have embarked on a variety of services execution paths that extend from teaming arrangements to work sharing with overseas engineering companies as a source of low cost services. With the evolution of information technology work, sharing is more feasible with basic engineering being accomplished in one location and detailed design efforts being done in a lower cost location.

III. COMPENSATION AND RESPONSIBILITY

Compensation for engineering design services is usually dependent on what sector of the industry is being served, and what type of services are being provided in conjunction with terms and conditions of the contractual agreement.

Owner/clients have many different options available to them as to how engineering design services can be obtained and paid for. The different methods that are most commonly used for construction projects are:

Cost Reimbursable Agreements
- All-in hourly or day rates
- Hourly rates plus expenses
- Actual salary cost with a multiplier for overhead and profit
- Actual salary and expenses at costs with a fixed fee to cover overhead and profit
- Actual salary and expenses at costs with a incentive fee based on sharing in cost savings
- Actual salary cost with a multiplier to cover overhead and all expenses

Fixed Price Agreements
- Lump sum bid
- Percentage of construction cost
- Unit prices per deliverables: (drawings, specifications, reports, etc.)

Some of these types of contractual agreements may be part of a turnkey bid for an entire project where the design engineering is only one portion of the services required for full execution.

IV. PROJECT PHASES

Today most owner/client organizations have recognized the merits of using preplanning before embarking upon capital expenditure programs. Owner/clients have learned how to minimize the capital at risk by staging a funding approval process. Funding approvals are usually tied to an individual project phase that reflects the amount of information available for a potential project as it proceeds through development. At each approval stage the owner/client has a quantification of funds at risk should he decide to terminate a project before being fully committed. The phasing of projects are typically in four distinct stages.

1. *Conception.* This phase usually involves conducting feasibility studies in conjunction with technical screening and economic evaluations. Owner/clients usually need assistance from engineering firms that have a particular technical expertise for these early studies.
2. *Inception and Development.* This phase, sometime called the Programming phase, is the start of definitive planning and proceeds into basic engineering for a selected concept identified in an earlier phase. An engineering contractor will most likely be engaged to support the basic engineering effort with estimating project costs in order to set a budget if the project goes ahead.
3. *Contracting.* This phase encompasses all the activities required to engage contractors to perform the services necessary to design, procure the materials and equipment, fabrication, transportation of materials, and field construction, to start up of the facilities.
4. *Execution.* This phase is typically subdivided further into Detailed design, Procurement, and Construction. Contracting may be to a major contractor that includes a full turnkey capability, to others that specialize in engineering and procurement only, or engineering support for the field construction effort. A large complex project may require a variety of engineering contractors that have a particular knowledge or special skill required for the successful execution of a project.

V. ESTIMATING METHODS

Estimating cost for engineering services is one of the more challenging activities for a project. In the early stages of a project, a need often arises for an appraisal of engineering and design costs; yet there is seldom enough project definition or technical information to use detailed estimating methods. A variety of estimating methods have been in use for arriving at engineering services costs. This section identifies each of these methods.

A. Historic Relationships

A common practice in determining engineering costs is based on a percentage value of the advertised overall project cost. Caution must be exercised for percentages can vary considerably. Some average percentage ranges for different types of facilities are as follows:

Office buildings and laboratories 3–13%
Electrical power generating plants, and cement plants 4–14%
Petrochemical plants and oil refinery process units 8–20%
Cross-country pipelines 1–5%
Offshore oil/gas production platforms and marine facilities 6–15%

Typically, the percentage is a lower value for a large expensive project. Projects that contain more technical elements and complexity will tend to have a higher percentage.

B. Statistical Correlations

This is a method commonly used in the industrial sector for determining engineering design estimates with the minimum of information. This method is based on two correlations:

1. Correlation between the number of major process equipment pieces and design engineering work hours
2. Correlation between the cost of engineering and design/drafting and the number of various types of engineering deliverables (e.g., number of drawings for a particular type and size of facility)

C. Level of Effort (LOE)

This is an estimating method frequently used when project scope is difficult to define in terms of deliverables. Engineering studies, or research and development projects usually employ the LOE estimating method. Estimates are prepared by identifying the resources that have a particular skill and knowledge required. A predetermined time schedule is resource loaded for the various required tasks in order to determine work-hours and the respective labor cost and expenses. This method is also used for estimating support activities such as management and administrative services.

D. Detailed

Probably the most widely use and most accurate estimating method for determining engineering office cost. This method is used to produce cost estimates for each work activity and deliverable.

VI. ESTIMATING PROCEDURE

The procedures typically used in developing detailed cost estimates are outlined in Example "A"—Engineering Estimating Sheet, "B"—Drawing List, and "C"—Staffing Plan. Example estimate forms are provided to assist in understanding the procedures and techniques presented.

A. Detailed Engineering Office Estimating

Definition of the project work scope for a typical industrial plant usually begins with process flow diagrams, and proceeds with development of equipment specifications and early layouts of a plot plan. Each engineering discipline will prepare their respective definition of activities and list of deliverables (e.g., drawings, specifications, take-off and requisitions for materials/equipment etc.).

The nonengineering disciplines develop parameters needed for defining and assessing their activities and deliverables. For Procurement, the governing factors include equipment count, amount of bulk materials to purchase, subcontracting plan, worldwide versus local in-country buying, inspection, expediting requirements, logistic, shipping, delivery schedule, and client coordination of approval cycles.

Management and control functions of a project are outlined to include a scope for developing a project execution plan. This plan encompasses: safety, quality, environmental, cost estimates, schedules, project kickoff and alignment, status reporting, documentation, computer, communication needs, and teaming partners for the project.

Project Business Services includes contractual conditions, funding basis, progress billing requirements, vendor invoice payment requirements, accounting and payroll requirements.

Project Management and Control work-hour requirements will depend upon the size and complexity of the task force organization required to manage and control. Does the project require considerable interfacing with a client representative, is staffing required to be in the field or in office locations for

Example A Engineering estimating sheet.

Client: XYZ Interest Inc. Project No.1234567
Project: Oil/Gas Plant
Area: Outside battery limits Date: 9/28/96

Cost code	Description	Labor rate/ work-hr ($)	Work-hr	Total cost ($)
10.00	*Project engineering*			
10.10	Project management	38.00	2,000	76,000
10.20	Project engineers	25.00	1,500	37,500
10.30	Project controls	22.00	1,500	33,000
10.40	Project accounting/finance	18.00	500	9,000
10.50	Secretarial/clerical support	16.00	2,000	32,000
20.00	*Engineering*			0
20.10	Process engineering	35.00	300	10,500
20.20	Marine engineering	0.00	0	0
20.30	Mine engineering	0.00	0	0
20.40	Environmental engineering	34.00	150	5,100
20.50	Special technical consultants	36.00	100	3,600
30.00	*Design engineering*			0
30.10	Civil	16.00	3,500	56,000
30.20	Structural	17.00	1,500	25,500
30.30	Architectural	18.00	500	9,000
30.40	Mechanical	19.00	1,200	22,800
30.50	Piping	17.00	9,700	164,900
30.60	Electrical	18.00	2,900	52,200
30.70	Instrumentation	20.00	6,700	134,000
30.80	Technical document control	12.00	2,000	24,000
40.00	*Procurement/contracts*			0
40.10	Procurement/contracts management	25.00	1,000	25,000
40.20	Buyers	18.00	2,000	36,000
40.30	Subcontract administration	20.00	500	10,000
40.40	Expediting/traffic	17.00	1,500	25,500
50.00	*Other services*			0
50.10	Business services	10.00	200	2,000
50.20	Human resources	15.00	0	0
50.30	Support services	8.00	300	2,400
	Total labor cost	19.16	41,550	796,000

Example A (Continued)

Cost code	Description	Labor rate/ work-hr ($)	Work-hr	Total cost ($)
60.00	*Expenses*			
60.10	Reproduction/copying	0.75	41,550	31,163
60.20	Communications	0.50	41,550	S20,775
60.30	Travel	1.50	41,550	62,325
60.40	Computer costs	2.00	41,550	83,100
	Total expenses	4.75		197,363
	Total labor and expenses			993,363
70.00	*Indirect cost*			
70.10	Payroll burdens/fringes	35%	796,000	278,600
70.20	Office overhead costs	55%	796,000	437,800
70.30	Insurance and Tax	0.50%	796,000	3,980
	Total indirect cost			720,380
	Total direct and indirect costs			1,713,743
	Contingency and escalation	4%	1,713,743	68,550
	Fee	23%	1,782,292	417,948
	Grand total (selling price)			2,200,240
	Unit values			
	Price per workhour			52.95
	Workhours per drawing	1,100 drawings		37.77
	Price per drawing	1.100 drawings		2,000.22

Example B Drawing list.

	Client: XYZ Interest Inc. Project: Oil/gas plant Area: Outside battery limits	Project No: 1234567

Cost code	Description	Number of drawings
30.10	*Civil*	
	Excavation/ponds and drainage plans	
	Equipment foundations	50
	Steelworks and supports foundations	5
	Area paving	4
	Miscellaneous concrete, supports, etc.	6
30.20	*Structural*	
	Structural steel, plans and elevations	16
	Ladders and platforms, miscellaneous supports	20
	Grating drawings	10
30.30	*Buildings*	
	Building arrangement plans and elevations	5
	Architectural details	2
30.50	*Piping*	
	Piping arrangements plans and elevations	30
	Piping isometrics and details	400
	Piping underground drawings	10
	Piping hangers/supports	5
30.60	*Electrical*	
	Electrical one-line drawings	4
	Substation layouts	15
	Electrical schematics	15
	Circuit schedules, connection diagrams	5
	Cable tray layouts/supports	17
	Lighting drawings	8
	Grounding drawings	8
	Underground electrical drawings	10
30.70	*Instrumentation*	
	Instrument location drawings	20
	Control cable schedules	22
	Control systems schematics	25
	Instrument loop diagrams	350
	Connection diagrams/junction boxes	15
20.10	*Process drawings*	
	Block flow digrams	4
	P&IDs	10
	Overall plot plans	3
	Total number of drawings	1,100

Example C Engineering Staffing Plan

Client: XYZ Interest Inc.
Project: Oil/gas plant
Area: Outside battery limits

Project No.1234567
Date: 9/28/96

Cost code	Description	Number of months 1	2	3	4	5	6	7	8	9	10	11	12	Man months	Work hrs
	Project engineering														
10.10	Project management	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.6	11.6	2,000
10.20	Project engineers	1.7	1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	8.7	1,500
10.30	Project controls	1.7	1.0	1.0	1.0	0.5	0.5	0 5	0.5	0.5	0.5	0.5	0.5	8.7	1,500
10.40	Project accounting/finance	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	2.9	500
10.50	Secretary/clerical support	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.6	11.6	2,000
20.00	*Engineering*														0.0
20.10	Process engineering	1.0	0.7											1.7	300
20.20	Marine engineering													0.0	0
20.30	Mine engineering													0.0	0
20.40	Environmental engineering	0.5	0.4											0.9	150
20.50	Special technical consultants	0.6												0.6	100

30.00	*Design engineering*													0.0	
30.10	Civil	3.0	5.0	5.0	5.0	2.2								20.2	3,500
30.20	Structural	0.0	1.0	3.0	3.0	1.7								8.7	1,500
30.30	Architectural		0.0	1.0	1.0	0.9								2.9	500
30.40	Mechanical	1.1	1.2	1.2	1.2	1.2	1.0							6.9	1,200
30.50	Piping	2.1	3.0	4.0	6.0	7.0	8.0	8.0	7.0	5.0	4.0	1.0	1.0	56.1	9,700
30.60	Electrical	1.0	0.2	0.2	0.2	0.2	1.0	1.0	1.0	5.0	4.0	2.0	1.0	16.8	2,900
30.70	Instrumentation	0.7	1.0	1.0	1.0	1.0	3.0	3.0	4.0	8.0	8.0	6.0	2.0	38.7	6,700
30.80	Technical document control					0.6	1.0	1.0	1.0	2.0	2.0	2.0	2.0	11.6	2,000
40.00	*Procurement/contracts*													0.0	
40.10	Procurement/contracts management	1.0	1.0	1.0	1.0	0.5	0.5	0.2	0.2	0.1	0.1	0.1	0.1	5.8	1,000
40.20	Buyers		2.0	3.0	3.0	2.0	1.0	0.6						11.6	2,000
40.30	Subcontract administration		1.0	1.0	0.5	0.4								2.9	500
40.40	Expediting/traffic							1.0	1.0	2.0	2.0	2.0	0.7	8.7	1,500
50.00	*Other services*													0.0	
50.10	Business services	0.1	0.1	0.1	0 1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.2	200
50.20	Human resources													0.0	0
50.30	Support services	0.5	0.1	0.1	0 1	0 1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	1.7	300
	Total staffing level	17.4	20.9	24.8	26.3	21.1	18.9	18.2	17.6	25.5	23.5	16.5	9.8	240.2	41,550

execution of work? These requirements are to be reflected in a project Organization Breakdown Structure (OBS) and serve as a basis in arriving at estimated work hours for project management and control.

Work hour requirements are developed by each discipline through separate assessment-of-task activities that produce deliverables and level-of-effort activities as related to the project schedule.

Upon completion of work-hour estimates by each discipline, the estimator compiles and reviews the work hour data as compared with past similar projects. The appropriate labor rates are applied to each discipline and classifications to arrive at bare labor costs. These costs are then escalated to account for inflation (see Chapter 9).

B. Office Expenses

Certain office expense are estimated based on historical averages of costs per work hour, while others are developed with a more detailed estimating approach.

In the absence of suitable recent comparable cost experience, the estimator will rely on historical data. This data is usually based on actual cost of the different expenses and categorized by various types of engineering jobs from preproject front end studies to full detailed engineering, and procurement services.

A common estimating approach for expenses is to address each major cost element of expense as follows:

1. *Reprographic Printing and Copying Costs.* This cost element normally includes special binders, book covers, paper stock, video tapes and photographs for progress reports or studies in addition to any outside services for printing or other related services. These costs are best estimated from historical information that is based on cost per total engineering office work hours.

Another method is to quantify the amount of printing and copying based on number of pages, i.e., the amount of drawings and text sheets estimated for the project times a representative unit cost per sheet. The best source of cost data is a recent project that is comparable in size and scope.

2. *Model Costs.* Some projects still require a plastic model of the facility even though this can be done with three-dimensional CAD. These costs are estimated by the model maker or personnel responsible for construction of the model.

In large organizations a design discipline, usually the Piping Design Group, is responsible for the construction of a model. Their work hours are typically in the design engineering estimate. If this effort must be contracted out, quotations on work hours and labor costs must be obtained. Costs for the materials to construct a model plus costs for creating and shipping the completed model to the client are to be included with the estimate. Again, checking against like costs for past comparable projects is advisable.

3. *Computer Costs.* The many possible configurations of computer applications and programs are almost endless. Computer charges can vary greatly depending on project requirements for hardware, firmware, software, and communications costs and their respective charge basis.

In order for companies to be competitive and remain abreast of technology advancements, organizations are finding that leasing from a computer specialty firm is often cost effective in meeting the changing demands of a project. Advantages are: it provides a firm basis for charging and estimating these costs for a project in addition to having the benefit of productivity gains in using the most current computer systems that are faster, cheaper, better. An estimate for computer costs must begin with identification of the equipment and software to be used, including network, remote terminals, communications needs, and the basis for usage and costs. The development of an overall project system configuration plan is to include all offices, and job site locations required.

Once the system configuration is defined, each user discipline can estimate their anticipated usage, based on programs to be used, CAD drawings to be produced, frequency of reporting and level of detail required. Computer usage estimates are usually estimated in terms of screen-hours for the different user disciplines. Unit costs are applied to these screen-hour estimates in order to arrive at a total estimated cost. In today's business environment it is not uncommon for screen-hours to run about seventy to eighty-five percent (70% to 85%) of total engineering office work hours.

There are other ways for determining computer costs; some firms have established an all-in rate per work hour to cover their cost recoveries for all expenses associated with computer operations and usage. This approach is used by firms that own their computer systems where equipment updating is a gradual process and costs for new technology is not dramatic. Historic cost from past projects is also used as a basis for estimating computer expenses, either as a unit cost per work hour or as a percent of labor costs.

The estimator summarizes costs gathered for all computer related use anticipated for the project. He or she reviews these costs as they relate to total estimated work hours for an office to perform comparison analysis with similar recent projects and make appropriate estimate adjustments.

4. *Travel Expense.* Includes travel air fares, costs of lodging, meals, ground transportation and subsistence expenses. Other costs typically include mileage allowance for use of a personal car, telephone, communications hook-up for computer, or any outside business services to be used during a business trip.

The estimator gathers information from each discipline that defines anticipated travel, including number of trips, destination, time duration and number of individuals that will be traveling. From this information the estimator summarizes the travel requirements and applies the appropriate unit costs for air fares per policy (coach, business class, or first class), hotel rates, meals, laundry, telephone and ground transportation (rental car, taxies, train, etc.) and other anticipated expenses. Upon development of these estimates an appropriate allowance is added to cover the undefined trips and travel costs elements. Again, total travel expenses are compared with like cost from recent jobs, and adjusted to review cost per total office work hour for the project.

5. *Communications.* This cost element typically includes long distance telephone charges, facsimiles, satellite hookup, telegraph, special conference calls, postage, courier package services, and air freight for shipping drawings and other urgent documents. Local telephone charges and communications equipment rental costs are usually not charged to a project unless at a special request by the client.

Communication costs are normally correlated to total project office work hours and estimated accordingly. With the ever-changing technology of telecommunications their costs can vary considerably, depending on capabilities of equipment, and systems used, along with the extent of use and hookup charges for connection to remote locations or other central units.

For a project anticipating the use of advanced telecommunications systems an estimate of these costs with a defined system, hardware, or service is required. From this estimate conventional communication costs can be adjusted to reflect the use of the more advanced system. Again this is usually expressed in costs per total project office work hour.

6. *Royalties and Outside Engineering Expenses.* This category includes costs of royalty, licensing, and technology secrecy agreements fees. Additionally, it covers charges for engineering services contracted to outside firms or special consultants required on the project. These costs are best developed specifically for each case from information provided by those firms or individuals considered to provide the services or charging technology fees required.

C. Office Payroll Burdens and Benefits (PRB&B)

These costs usually fall into two categories (1) Payroll Burdens and (2) Employee Benefits. Payroll Burdens consist of costs that are normally required by law or compulsory insurance in order to conduct or protect a business within a country and state where the work is being executed by personnel that are at locations considered heir principal place of work. Employee Benefits typically include costs for vacation or time off and certain forms of insurance as a fringe benefits, and or profit sharing, pension, retirement savings (401k) investment programs, and education reimbursement, etc.

These benefit programs normally consist of group insurance coverage (major medical, etc.) arranged between the company and an insurance carrier where certain benefits are made available to all employees or only to a specified class or category of company personnel. A list of elements that are normally considered under this category are:

Payroll burdens	Employee benefits
Worker's compensation insurance	Vacation or time off with pay
Comprehensive general liability insurance	Group insurance
	Profit sharing program
State unemployment insurance	Pension or retirement savings programs
Federal unemployment insurance	
Social Security (FICA)	

Payroll burdens and benefits are arrived at by calculating a percentage rate for these cost, applied to total bare labor costs. Other methods of arriving at PRB&B can be on a unit rate per work hour basis. There is not a standard percentage rate for these costs. Each company's particular way of doing business and location has its own unique set of cost elements. However, in order to be consistent and simplify the estimating process, some companies (particularly large ones) have elected to use overall average PRB&B costs, irrespective of office, to be used throughout the organization within a given country.

D. Office Overhead Cost

This usually includes general business expenses such as office rent, office insurance, heat, electricity, office supplies, furniture, telephone communications, legal expenses, sales, marketing, bid preparation estimating expenses, donations, advertising, travel, associations dues, and salaries of the management, executives, and office employees necessary in the operation of the company. The total cost of overhead is usually expressed as a percentage that is applied to bare labor plus burdens and benefits costs, although each company may have their own method of applying these costs. Overhead costs are based on the company's annual business volume which represents the inescapable cost of doing business that must be included with each estimate for a project.

Overhead costs are incurred in support of the overall company projects that generally cannot be charged to any one specific project. It is for this reason that these costs are considered as being acceptable and are to be included with each project estimate.

E. Fee or Markup

The final action required in preparing an engineering services cost estimate is an application of fees expected for services. Typically, a fee is determined as a percentage of the cost. Usually, fees are an expected profit to be earned for the engineering services provided for a project, although some firms include certain costs within a fee. Fees for engineering services can and do fluctuate and are sensitive to a wide variety of considerations including competitive market forces, type of contract, complexity of the project, technology, and unique skills required. Usually, larger fees are for work that involve high levels of technology or special unique knowledge and skills; more common types of engineering attract lower fees. Of course, the law of supply and demand comes into play when setting fees.

VII. SUMMARY

Estimates for engineering reflect more than cost, they are a plan for executing work. Preparation methods that embrace a disciplined and consistent approach result in benefits to both the contractor and client. These benefits are lower bidding cost, improved work proficiency, accuracy, and capacity to produce estimates with confidence. Use of these methods culminate in faster estimates, with improved quality.

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4
Estimating Engineered Equipment Costs

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Equipment costs are also critical to estimating as many estimates, particularly those that use factors, are based on equipment costs.

I. DEFINITION OF TERMS

Before describing any one of these estimating methods, it is worthwhile to define some of the commonly used terms in estimating [1].

Battery Limit Comprises one or more geographic boundaries, imaginary or real, enclosing a plant or unit being engineered and/or erected, established for the purpose of providing a means of specifically identifying certain portions of the plant, related groups of equipment, or associated facilities. It generally refers to the processing area and includes all the process equipment, and excludes such other facilities as storage, utilities, administration buildings, or auxiliary facilities. The scope included within a battery limit must be well-defined so that all personnel will clearly understand it.

Bid Security Security is provided in connection with the submittal of a bid to guarantee that the bidder, if awarded or offered the contract, will execute the contract and perform the work. The requirements for the bid security are usually designated in a specific section of the bidding documents. The bid security is payable to the owner (usually around 5% of the total bid price) in the form of either a certified or bank check or a bid bond issued by a surety satisfactory to the owner. The bid security of the successful bidder is usually retained until the bidder has executed the agreement and furnished the required contract security, whereupon the bid security is returned. Bid security of the other bidders is returned after the bid opening.

Bulk Material Material bought in lots. These items can be purchased from a standard catalog description and are bought in quantity for distribution as required. Examples are pipe (nonspooled), conduit, fittings, and wire, etc.

Consumables Supplies and materials used up during construction. Includes utilities, fuels and lubricants, welding supplies, worker's supplies, medical supplies, etc.

Code of Accounts A systematic numeric method of identifying various categories of costs incurred in the progress of a job; the segregation of engineering, procurement, fabrication, construction, and associated project costs into elements for accounting purposes.

Contingency An amount added to an estimate to allow for changes that experience shows will likely be required. May be derived either through statistical analysis of past project costs or by applying experience from similar projects. Usually excludes changes in scope or unforeseeable major events such as strikes, earthquakes, etc. Contingency funds that are included within the project total estimated cost, shall be considered part of that cost and not as an "extra."

Contracts Legal agreements between two or more parties, that may be of the following types:

1. In cost plus contracts the contractor agrees to furnish to the client services and material at actual cost, plus an agreed upon fee for these services. This type of contract is employed most often when the scope of services to be provided is not well defined.
2. Fixed Price or Lump Sum types of contracts are ones wherein a contractor agrees to furnish services and material at a specified price, possibly with a mutually agreed upon escalation clause. This type of contract is most often employed when the scope of services to be provided is well defined.

Direct Costs In construction, cost of installed equipment, material, and labor directly involved in the physical construction of the permanent facility. In manufacturing, service and other nonconstruction industries, the portion of operating costs that is generally assignable to a specific product or process area.

Escalation The provision in actual or estimated costs for an increase in the cost of equipment, material, labor, etc., over that specified in the purchase order or contract due to continuing price level changes over time.

Early Work Schedule Predicated on the parameters established by the proposal schedule and any negotiated changes, the early work schedule defines reportable pieces of work within major areas. The format is developed into a logic network including engineering drawings and equipment deliveries and can be displayed as a time-phased network. It is compared to the budgeted cost of work scheduled (planned) to obtain schedule performance and it is compared to the actual cost of work performed to obtain cost performance.

Fringe Benefits Employee welfare benefits; i.e., expenses of employment such as holidays, sick leave, health and welfare benefits, retirement fund, training, supplemental union benefits, etc.

Indirect Costs In construction, all costs which do not become a final part of the installation, but which are required for the orderly completion of the installation and may include, but are not limited to, field administration, direct supervision, capital tools, start-up costs, contractor's fees, insurance, taxes, etc. In manufacturing, costs not directly assignable to the end product or process, such as overhead and general purpose labor, or costs of outside operations, such as transportation and distribution. Indirect manufacturing cost sometimes includes insurance, property taxes, maintenance, depreciation, packaging, warehousing, and loading. In government contracts, indirect cost is often calculated as a fixed percent of direct payroll cost.

Letter of Credit A vehicle that is used in lieu of "retention" and is purchased by the contractor from a bank for a predetermined amount of credit that the owner may draw against in the event of default in acceptance criteria by the contractor.

Off-sites General facilities outside the battery limits of process units, such as field storage, service facilities, utilities, and administration buildings.

Schedule The plan for completion of a project based on a logical arrangement of activities, resources available, imposed dates, or funding budgets.

Scope Change A deviation from the project scope originally agreed to in the contract. A scope change can consist of an activity either added to or deleted from the original scope. A contract change order is needed to alter the project scope.

Shop Planning The coordination of material handling, material availability, the setup and tooling availability so that a job can be done on a particular machine.

Slack Time The difference in calendar time between the scheduled due date for a job and the estimated completion date. If a job is to be completed ahead of schedule, it is said to have slack time; if it is likely to be completed behind schedule, it is said to have negative slack time. Slack time can be used to calculate job priorities using methods such as the critical ratio. In the critical path method, total slack is the amount of time a job may be delayed in starting without necessarily delaying the project completion time.

Terms of Payment Defines a specific time schedule for payment of goods and services and usually forms the basis for any contract price adjustments on those contracts that are subject to escalation.

II. SOURCES OF EQUIPMENT COST ESTIMATING DATA

There are two main facets of the Equipment Cost estimating process: the procedure and the cost database.

Equipment cost data is the foundation of the capital cost estimation. It is essential to know:

The source of the data
The date of the data
The basis of the data
The potential errors in the cost data
The range over which the cost data apply

There are three main sources of equipment estimating data: vendor contacts, open literature, and computerized estimating systems. There is a great deal of literature available and there are many computerized estimating systems available in the marketplace. Computerized systems have also done an important job of opening the estimating process to more people. This is possible because the estimating procedure has been established by the system vendor and the cost data base is regularly updated by the vendor.

III. SOURCES OF VENDOR DATA

The most obvious source of equipment cost data is vendor quotes. One can usually phone a vendor and get a telephone quote. But to do this, one has to know who to call. Therefore it is important to maintain a file of vendors. Two annuals that list vendor addresses and telephone numbers by product line are the *Thomas Register*—a set of books listing vendors alphabetically, by trademark and by product line, and the *Chemical Engineering Equipment Buyer's Guide*—published by *Chemical Engineering* magazine.

IV. SOURCES OF EQUIPMENT COST DATA

There are a number of outside sources for cost data. The following are some of the most common ones:

Richardson The Richardson Engineering Service [4] consists of four volumes that include process equipment costs, construction costs, labor, materials, field engineering, etc. The volumes are revised yearly and there are quarterly updates. Size limitations on some of the major equipment might present a problem. However, the data is as up-to-date as can be expected without direct quotes.

Conceptual Cost Estimating [2] This book, published by Gulf Publishing, gives cost/size curves for a large number of major equipment items and materials plus information on other categories of project cost.

Guthrie Guthrie has published considerable data relative to estimating capital investment costs for process plants. He starts with a base purchased cost for a category of equipment, gives various adjustment factors (for example; material adjustments, pressure adjustments, etc.), adds bulk materials, labor and indirects, and arrives at a total installed equipment cost for that equipment category.

PDQ$ This is a time-share computer system so a modem is required to access their database. It is a fast system for obtaining the cost of many types of major equipment.

Questimate It is a PC based estimating program from Icarus Corp. to estimate equipment cost along with the total cost for the project in petrochemical related industry. Minimal information is required for pricing the cost of equipment from questimate.

V. SOURCES OF DATA ON SCALING FACTORS

It is often necessary to scale costs for a given size to other sizes. Scale factors for major equipment can often be obtained from the sources listed above. However two additional sources of scale factors, along with a discussion of their use, can be found in *Chemical Engineers Handbook*, edited by R. H. Perry and C. H. Chilton and *Plant Design and Economics for Chemical Engineers*, edited by M. S. Peters and K. D. Timmerhouse.

The following general comments should be noted regarding the use of scale factors.

1. Cost-capacity data are reasonably accurate over a limited range (say ten fold).
2. Many equipment items are manufactured in discrete sizes so that there is no continuum. Equipment sizes often increase by step functions.
3. In scaling costs, no consideration is given to technological advances and "learning curve" in both equipment and process design.

VI. SOURCES OF DATA ON COST INDICES

Cost indices are a measure of cost escalation and are used to project cost data from one time basis to another. Through the proper use of cost indices, an estimator may take equipment cost data based on a variety of dates and project the cost forward in time. Some useful cost indices are:

Engineering News Record (ENR) Index This is the oldest index in current use. It is published in the *Engineering News Record* magazine. It is weighted towards the general construction industry. It does not include a productivity factor and therefore tends to increase at a more rapid rate than other indices.

Marshall and Swift This index traces equipment costs and installation labor in selected process industries and in related industries. It therefore reflects changes in installed equipment costs. It is published in *Chemical Engineering* Magazine.

Chemical Engineering Plant Cost Index This is a special purpose index published in *Chemical Engineering* magazine and weighted by the chemical process industry cost experience for equipment, machinery and supports, construction labor, buildings, and engineering and supervision. It incorporates about a 2.5% per year productivity improvement to its labor and engineering components. It is designed to reflect trends in plant costs in the chemical process industry.

Nelson Refinery Construction Index This index is heavily weighted towards the refinery and petrochemical segments of the Consumer Price Index. This index does not include a productivity factor. It is an inflation index that shows the relative cost of duplicating an installation without respect to mechanical or process design, construction techniques, size, or changes in technology.

There are many other indices published. For example, the Bureau Of Labor Statistics publishes information on material and labor indices for a number of various industries. This data appears in the monthly labor review. The four factors which could most affect costs projected by the use of indices are:

1. Technological developments
2. Changes in productivity
3. Process improvements
4. Equipment design changes

The term "inflation" implies that there is a tendency for all prices in the economy to be rising. The term "escalation" on the other hand is an all inclusive term which reflects price increases due to any of a number of reasons, such as; inflation, supply and demand conditions, or environmental issues.

VII. EQUIPMENT COST

Once the equipment list is finalized, one can start the process of determining the cost of each item by any one of the previously listed methods. However in general all equipment should be priced in conjunction with the use of Richardson's *Process Plant Construction Estimating Standards*, Vol. 4, previous project equipment costs, vendor quotations, or any one of the commercially available computerized estimating programs. Only minimal information is required to make use of any one of these sources. We will provide a few examples to show how some of these resources could be used in estimating the equipment cost.

Richardson's *Process Plant Construction Estimating Standards* [4], Vol. 4 is quite comprehensive in different types of equipment for all types of industries and is set up to present average equipment costs along with man-hours for equipment installation or total erected costs of equipment. Sales taxes are not included. F.O.B. points of equipment are indicated. Man-hours shown are for direct labor only. To these man-hours we should apply a composite crew man-hour rate determined from the actual site conditions. Typical examples follow.

Questimate (one of the many computerized PC based cost estimating programs) from Icarus Corporation on the other hand generates a total cost estimate including equipment pricing from minimal information input. Questimate pricing in the database is revised at least twice a year to provide the most up-to-date information. Equipment cost compares well with Richardson or preliminary vendor quotes. In order to illustrate the use of Questimate program we have set up each example for each type of equipment with a blank output sheet from the program along with a worked out example based on minimal available data. We have limited the output to highlight the cost of equipment rather than the total direct cost of the project. Two other programs worth mentioning are MC2 or Richardson's computerized version of their estimating manuals.

In addition to the equipment pricing, when the equipment is received at the job site, it will be necessary to unload, inspect, transport to the point of installation, install and perform the cleanup work. Installation man-hours for horizontal and vertical vessels can be estimated based on total vessel weight and the use of a mobile crane with the use of Richardson's applicable account number. The other computerized programs in the market place would also provide this information rather easily. Pricing of the instrumentation is not included in equipment pricing; this should be added to the total estimated cost of the project separately. Although, this chapter is focused on estimating the cost of equipment, it is appropriate to show the overall cost of a project based on equipment cost.

Once the cost of each piece of equipment has been established, the next step is to apply installation factors to each item to determine the total installed cost for all equipment. The installation factors are determined from Table 1. These factors were developed from previous historical data along with input from estimators and project engineers. The example reflects the use of installation factors for exchangers, drums, towers, and pumps. In addition to the total installed equipment cost, suggested general guidelines covering all other

Table 1 Total Installed Cost Installation Factors for Major Equipment (All Factors Based on Carbon Steel Material)

Air cooler	1.7	Agitator	1.1
Blower	1.1	Boiler (packaged)	0.9
Bullets (pressured)	0.9	Centrifuge	1.5
Compressor	1.2	Cooling tower	0.6
Cyclone	1.5	Drums (horizontal)	1.6
Drums (vertical)	2.4	Dryer	1.6
Dust collector	1.9	Evaporator	2.2
Exchanger	1.85	Filter (rotary)	1.6
Furnace (packaged)	1.2	Hopper (bolted)	1.5
Pump (API w/motor)	1.4	Pump (chemical w/motor)	1.85
Refrigeration unit	1.4	Reactor	2.1
Screw conveyor	1.4	Sphere	0.9
Stack	0.8	Strainer	1.5
Tank	0.9	Tower	2.0
Transformer	0.6	Weigh scale	1.1

Factors include field labor, piping, foundations, site preparation, electrical, etc., and exclude instruments, engineering, all indirects and main electric substation, etc.

elements of an estimate are described. Example A illustrates how each element is developed relative to equipment cost or material and labor costs.

REFERENCES

1. *Standard Cost Engineering Terminology*, AACE Practice and Standard No. 105–90, AACE, Inc., Morgantown, WV, 1990.
2. *Conceptual Cost Estimating*, Gulf Publishing, Houston, TX.
3. Clark, F. D. and Lorenzoni, A. B., *Applied Cost Engineering*, Marcel Dekker, New York, 1985.
4. *Process Plant Construction Estimating Standards* (published annually), Richardson Engineering Services, Mesa, AZ.
5. Humphreys, K. K. and English, L. M., *Project and Cost Engineers Handbook*, Marcel Dekker, New York, 1993.
6. Humphreys, K. K. and Wellman, P., *Basic Cost Engineering*, Marcel Dekker, New York, 1987.
7. *Means Labor Rates for the Construction Industry* (published annually), R. S. Means Co., Kingston, MA.
8. *Means Mechanical and Electrical Cost Data* (published annually), R. S. Means, Kingston, MA.

Example A Factored Estimating of Total Project Cost ($000) (based on equipment cost)

Description	Equipment ($)	Factor[b]	Material and labor ($)[c]
Exchangers (1)[a]	47	1.85	87
Drums (2)	46	2.40	110
Towers (w/trays and internals)	653	2.00	1,306
Pumps (6)	103	1.40	144
(Equipment cost from Questimate)			
Total	849		1,647
(Material and labor split = 60/40 = 988M/659M)			
Instrumentation			255
Material (30% of equipment) or (849 × 30%)			
Installation (45% of instrument material) or (255 × 45%)			115
Subtotal	849		2,017
Sales tax at 7% (depends on location)			
(Equipment and materials = 849M + 988M + 255M) × 7%			146
Indirects on labor at 115% (659M + 115M) × 115%			890
Contractor engineering			
(20% of direct cost) or (E + M&L) × 20% = ($849 + 2,017) × 20%			573
Pre-engineering (when necessary)			60
Owner engineering (2 man-years)			230
Subtotal			4,765
Contingency (10%)			477
Grand total			5,242

Other items to be considered

- Spare parts (5% of equipment)
- Freight (3% of equipment for domestic or 5 to 10% for overseas)
- Environmental permits (fee varies each location)
- Labor productivity (varies for each location)
- Escalation (based on project completion date)
- Hazardous and operability reviews (HAZOP): allowance

[a] Numbers in the parenthesis indicate number of pieces of equipment.
[b] Installation factors are from Table 1.
[c] Material and labor is calculated by multiplying equipment cost with appropriate installation factor.

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5
Estimating Bulk Material Costs

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I. INTRODUCTION

The estimating of bulk material costs is an area of project management that is important to project success. It is an area that is more difficult to define, expensive to quantify, and the unit costs can vary widely. There are a number of techniques that we will outline to assist in the process of defining and costing bulk material costs.

II. DEFINITION OF BULK MATERIALS

Bulk materials are those finished and semifinished materials that are prepared and installed in volume or pieces. The main characteristic of bulk materials is they are not engineered specifically for the project [1]. The design and engineering of bulk materials is guided by industry agreements on product purity or performance and also by organizations that establish standards such as the American Society of Testing Materials (ASTM). Most bulk materials are manufactured in quantity and are readily available through local preparers or distributors.

Some characteristics of bulk materials include large areas (e.g., roofing), significant volumes (e.g., soils), and long lengths (e.g., piping). Most bulk materials have no moving parts. Finally bulks can be viewed as everything except equipment and delivered/erected items.

An additional point of definition is the difference between direct and indirect materials. In this chapter we will discuss direct bulk materials as generally recognized by medium to large industrial process companies. Direct materials are those materials that are installed and form a permanent part of the facility.

Some estimating techniques will include temporary materials which are removed and do not form part of the permanent facility (Forms for concrete placement are a good example.). We generally exclude indirect materials used to maintain construction and construction forces. Temporary material warehouses and construction offices are examples of these.

A. Types of Estimates and Bulk Materials

There are three broad types of estimates. The first is *conceptual*: This type of estimate is completed at the earliest stage of a project. It is also called a budget or screening estimate. It is most often performed by owners, operators or developers. Its purpose is to establish an approximate investment level. This information may in turn be used to calculate a rate of return or an expense budget. A clear objective in this type of estimate is to determine if the project should progress to the next stage of analysis or be dropped. Estimates at this stage of a project can assist in choosing a process or a location. *Bulk materials are estimated using summary techniques such as curves or factored estimating.*

The second type of estimate is *preliminary*. It is completed after a preliminary design is completed. Some groups call this the basic design. The main project characteristics are chosen during this phase. This estimate is performed by owners, operators, and developers but may involve management contractors and sometimes general contractors. The purpose is to more accurately establish the investment level. The preliminary estimate is used to establish the budget or a request for appropriation. The objective is to establish whether the project can proceed or needs to be scaled back to meet rate of return thresholds. *Bulk materials are estimated using summary techniques or quantities and unit rates.*

The *final* estimate is completed at the latest stage of project development. It represents the definitive design of the project from a detailed design group. All details of the project are designed or determined such that a general contractor or a vendor can provide a firm quotation for construction or supply. The purpose of the estimate is to establish a cost reference point or a quoted bid. The estimate is also called a control estimate because actual construction costs will be compared to it. The accuracy of most control estimates is 10%. *Most bulk quantity costs will be taken off from the detailed designs. Unit rates come from published sources or vendor quotations.*

B. Bulk Material Categories

Each of 11 categories will be discussed in detail.

Excavating, Backfilling, and Site Development

Definition: Includes all activities to prepare a site for construction. The equipment used in the excavating and backfilling is considered a direct project cost. Some types of civil projects such as road works would have separate accounts for equipment and classes of equipment. Site development can include clearing, grubbing, and site drainage work. Also included is foundation piling.

Sources of information:

Heavy Construction Cost Data, Means Annual Cost Guides
Heavy Construction Cost Guide, McMahon
Process Plant Construction Estimating Standards, Richardson
Site Work and Landscape Cost Data, Means Annual Cost Guides
(See the final section for publisher's of cost estimating and general technical books.)

Estimating techniques (These techniques are explained later in this chapter).

Curve or factoring
Unit prices and detailed quantities
Subcontract prices for piling

Concrete and Masonry

Definition: Concrete includes formed-in-place concrete and includes the forms, reinforcing, and concrete. Mud mats are also included. Concrete types include foundations, fireproofing and nonstructural such as curbs and sidewalks. Masonry includes hollow and solid types made of concrete, clay, and composites.

Sources of information:

Concrete Construction and Estimating, Craftsman
Concrete and Masonry Cost Data, Means
Process Plant Construction Estimating Standards, Richardson

Estimating techniques:

Factoring.
Unit prices and detailed quantities.

Structural Steel

Definition: This category includes main structural elements such as columns and beams. Other structural elements include joists, trusses, and girders. Secondary structural elements are platforms, floor decking, roof decking, and grating. In addition, piping will require structural steel supports, which may be made up on site.

Sources of information:

Assemblies Cost Data, Means
Building Construction Cost Data, Means
Process Plant Construction Estimating Standards, Richardson
Structural Steel Estimating, Means
Walker's Building Estimator's Reference Book, Walker

Estimating techniques:

Unit prices by weight and square footage.

Waterproofing

Definition: This category includes a variety of materials and techniques. It includes both above-ground and below-ground waterproofing materials. In the above-ground types we include building and structure skins such as roofing and siding. The roofing materials can be fabricated, sheet metal, and natural materials. The underground waterproofing in this category is limited to the sealing of structures and foundations. Included are various applied and sprayed-on materials.

Sources of information:

Building Construction Cost Data, Means
Building Estimator's Reference Book, Walker
Process Plant Construction Estimating Standards, Richardson

Estimating techniques:

Unit prices by square footage
Subcontract unit rates

Piping and Valves, Plumbing, Mechanical

Definition:

Piping system used for the movement of liquid, semiliquid and fluidized dry materials.

Piping tubular shapes of steel, alloys, aluminum, copper, and synthetic materials.

Fittings formed shapes which allow the pipe to be jointed together.
Valves devices which control the flow of material through a given piping system.
Plumbing class of piping system generally used in homes.
Mechanical air ducts for HVAC.

Piping, valves, and plumbing offer the widest variety of materials and techniques of installation. Recent advances in materials engineering have justified the use of a variety of synthetic materials in place of metallic piping systems.

Sources of information:

Cost Estimating Man-hour Manual for Pipelines and Marine Structures, Gulf Publishing
Estimating Piping Man-hour Manual, John S. Page, Gulf Publishing
Estimator's Man-hour Manual on HVAC and Plumbing, Gulf Publishing
Mechanical Cost Data, Means
Mechanical Estimating, Means
National Plumbing and HVAC Estimator, Craftsman
Plumbing Cost Data, Means
Plumbing Estimating, Means
Process Plant Construction Estimating Standards, Richardson
Walker's Building Estimator's Reference Book, Walker

Estimating techniques:

Curve and factoring
Costs per square foot
Unit prices and detailed quantities

Instruments

Definition: This category of bulk materials includes sensing elements, transmission, and control devices. Certain groups also include safety and relief valves. Included are fire safety sensing and control equipment. Instruments can be divided into two parts. The first part is local sensing and display of pressure, temperature, flow, or level (PTFL). The second part is the transmittal of the PTFL information (signal) to a location where it is used, analyzed, or stored. The signal can be used by a control valve to determine its setting. The signal can also be sent to a central control room where it is analyzed to make a process decision.

Sources of information:

Mechanical Cost Data, Means
Mechanical Estimating, Means
Process Plant Construction Estimating Standards, Richardson

Estimating techniques:

Curve or factoring
Unit prices and detailed quantities

Electrical

Definition: This category includes the distribution of electricity to the consuming equipment or device. We exclude power generation equipment. Some estimating techniques can include intermediate distribution such as substations. It is important to define the scope of work included in the electrical costs.

- Always included

Wire and cable	Ducts and accessories
Cable trays	Terminal blocks
Conduit and fittings	Lighting
Junction box	Heat tracing

- Sometimes included

Transformers	Motor control centers
Switchgear and boards	Ground fault protect
Circuit breakers	Motor starters

Sources of information:

Electrical Change Order Data, Means
Electrical Cost Data, Means
Electrical Estimating, Means
Estimator's Electrical Man-hour Manual, Gulf
National Electrical Estimator, Craftsman
Process Plant Construction Estimating Standards, Richardson

Estimating techniques:

Curve or factoring
Unit prices and detailed quantities

Insulation

Definition: This category includes the materials used to retain heat or cold and to protect personnel from hot surfaces. Insulation can include materials for walls, roofs, and foundations. The major application of insulation in non–building work is piping and equipment insulation. Common hot and cold insulation materials for pipe insulation include calcium silicate, polyurethane, and foamglass. Insulation work in the process industry is typically performed by specialty subcontractors.

Sources of information:

Building Construction Cost Data, Means
Process Plant Construction Est. Stds., Richardson
Walker's Insulation Techniques and Estimating Handbook, Walker

Estimating techniques

Curve or factoring
Square foot costs: curve or factoring
Unit prices and detailed quantities
Subcontractor unit rates by detailed quantities

Architectural Finishes

Definition: This category includes interior floor wall and ceiling finishes.

- Floor

Ceramic and quarry tile
Terrazzo
Hardwood
Carpeting
Linoleum

- Wall

Wallboard
Ceramic
Paneling
Wallpaper

- Ceiling

Acoustic tile
Suspended ceiling

Sources of information:

Building Construction Cost Data, Means
Facilities Construction Cost Data, Means
Interior Cost Data, Means
Interior Estimating, Means
National Construction Estimator, Craftsman
Process Plant Construction Estimating Standards, Richardson
Walker's Building Estimator's Reference, Book

Estimating techniques:

Factoring
Square foot costs
Unit prices and detailed quantities

Painting

Definition: This category includes coatings applied to a variety of surfaces to protect and maintain the building or equipment piece. It includes the following:

Building	Exteriors
Building	Moisture protection and decorative
Metallic pipes	Corrosion protection
Plastic pipe	UV protection
Equipment	Corrosion and chemical protection
Tanks	Corrosion and chemical protection

Sources of information:

Estimating Painting Costs, Craftsman
Interior Cost Data, Means
Interior Estimating, Means
National Painting Cost Estimator, Craftsman
Process Plant Construction Estimating Standards, Richardson.

Estimating techniques:

Factoring
Square foot costs
Unit rates from detailed quantities

Specialties

Definition: This category includes specialties that are usually installed by subcontractors such as structural fire protection, and landscaping.

Sources of information:

Site Work and Landscape Cost Data, Means
Landscape Estimating, Means
Process Plant Construction Estimating Standards, Richardson

Estimating techniques:

Factoring—% of total project cost
Square foot cost
Unit rates from detailed quantities

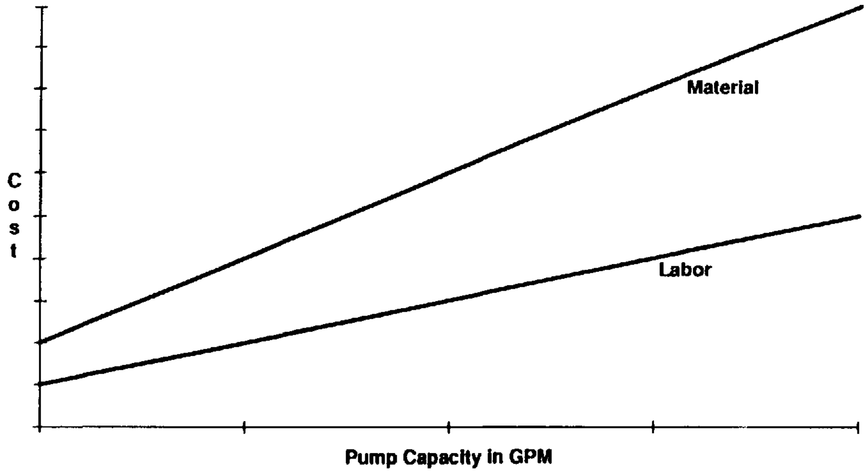

Figure 1 Cost of piping.

C. Estimating Techniques

Curve Estimate

A curve estimate is an estimate that uses the relationship between capacity and cost to determine the estimate. The cost can represent a process unit, part of a process unit, a piece of equipment or a bulk material cost. Figure 1 shows a curve for the cost of piping as it relates to pump capacity in gal/min (gpm). The relationship can be established from a number of data points. The curve should be specific about the basis of the pumps and piping. In our example we will assume a single-stage, heavy duty centrifugal pump. The pump and piping are conventional steels. The curve will give us base costs for piping material and piping labor. The labor basis should also be given. A common labor basis for the process industry is present day U.S. Gulf Coast. In 1994 this cost for a direct hire man-hour would be about $15 per man-hour.

Many applications call for materials other than steel and we will show a simple way of converting the costs from one material basis to another. In our example we will assume that the required piping for our pump is 304 stainless steel.

Table 1 shows material cost factors for our curve from carbon steel (CS) to other materials that cost less (e.g., PVC) to others that cost more (such as stainless steel). In our example the material cost factor for 304 SS would be 2.25. That is, 304 SS is 2.25 times the cost of CS. Table 2 shows labor conversion factors that are used in the same way. The labor cost factor for stainless steel is 1.10 times the cost of carbon steel. For example:

Table 1 Material Cost Factors

PVC	0.85
Carbon steel	1.00
Stainless steel, Type 304	2.25
Stainless steel, Type 316	3.90
Inconel	5.00

Step 1 Figure 1 pump GPM gives piping material cost
Step 2 Figure 1 Pump GPM gives piping labor cost
Step 3 Table 1 304 SS material cost factor = 2.25
Step 4 Table 2 SS labor cost factor = 1.10
Step 5 Material cost = piping material cost × 2.25
Step 6 Labor cost = piping labor cost × 1.10

Curve estimates are useful during the early part of project development, but have a high degree of variability when compared to estimates from a final design. However they are quick to use and require a minimum of design information. If the curves are derived from a large base of information their use can also be considered for preliminary estimates. Curve estimates are not recommended for final estimates if used for bidding and lump sum work. Curve estimates could be considered in reimbursable type contracts or where schedule demands do not allow for detailed design information to be used for a full quantity take off and detailed costing.

Factored Estimates (see also Chapter 4)

Factored estimates established a relationship between two cost elements. For estimating bulk material costs these elements are as follows:

First Cost Element (serves as the estimating basis for the second cost element)

Equipment
Structure
Facility

Table 2 Labor Cost Factors

PVC	0.90
Carbon steel	1.00
Stainless steel	1.10
Inconel	1.15

Bulk Material (e.g., Second) Cost Element

Site development
Excavations
Foundation
Structural steel
Piping
Mechanical
Instrumentation
Paint
Insulation
Others

These factored estimates, like curve estimates, require the tracking and collection of data from a group of projects. The technique is quick, easy to understand, and reasonably accurate. The following examples show a factored estimate for a drum and a pump.

Bulk material factors

	Pump	Drum
Equipment (base)	1.00	1.00
Excavation	0.25	0.15
Concrete	0.40	0.25
Piping	1.10	0.75
Instruments	0.95	0.70
Electric	0.40	NA
Insulation	0.35	0.40
Paint	0.05	0.05

These calculations were done as per the example below:

	Material and Labor Estimate ($000)	
Equipment (base)	$15.0	$25.0
Excavation	3.8	3.8
Concrete	6.0	6.3
Piping	16.5	18.8
Instruments	14.3	17.5
Electric	6.0	0
Insulation	5.3	10.0
Paint	0.8	1.3

Estimate = base equipment cost × bulk material factor
Pump piping = $15.0 × 1.10 = $16.5

Drum piping = $25.0 × 0.75 = $18.8

Quantity Take-off

The AACE International defines "take-off" as follows:

> . . . measuring and listing from drawings the quantities of materials required in order to price their cost of supply and installation in an estimate and to proceed with procurement of the materials [2].

Many industries have specific drawings and specifications which enable engineers and bidders to perform quantity take-offs. They vary from the building industry to the process industry and to specialty subcontract groups. There are two essential elements that must be identified in these documents: 1) Where is the bulk material located? (e.g., layouts, plot plans, equipment plans) and 2) What is the bulk material? (e.g., specifications, schedules, piping and instrument diagram; P&ID)

D. Where is the Bulk Material Located?

We will further explain the relationship between two of the documents listed above. In the process industry two important documents, which enable estimators to perform a take-off of piping, are the *plot plan* and a *Piping and Instrument Diagram* (P&ID). The plot plan shows the exact physical location of the equipment. The drawing is to scale and should be clearly noted. Side views or elevations are added to plot plans to show the vertical relationships between equipment in a structure. A key piece of information in the elevations is the relative height of an equipment piece from a reference point. The reference point is generally at grade and is frequently called the zero elevation because it is 0 ft 0 in. elevation regardless of the actual elevation of the site as measure by a topographic map. The elevation drawings should show the floor elevation and the elevation for each equipment piece. Pumps will generally be at grade level, vertical drums and towers should show the bottom tangent elevation. Horizontal drums should show the bottom vessel elevation.

We have just explained where equipment is located in the plot plan. What does this tell us where the bulk equipment is located? If we know exactly where the equipment is located the other documents will tell us what runs between them. Plot plans also show the piperacks and pipe-runs that the piping must follow in order to get from one equipment piece to another. An estimator should have specific documents which specify the pipe route.

E. Defining the Bulk Material?

We now establish exactly what the bulk material is by the P&ID and the job specifications. The P&ID diagramatically (i.e., nondimensionally) shows the primary and secondary piping between equipment pieces. Notes will show line numbers, pipe diameter, flange rating, and type of material. Also shown on the line note will be a corrosion allowance and if the pipe is insulated and steam traced. A common type of pipe line note is as follows:

PT1706 2" CS-2 IS3

PT1706	Pipe number (unique)
2"	2 in. diameter pipe
2	Corrosion allowance
IS	Insulated and steam traced
3	Insulation type

The P&ID will also show all valves and special accessories such as in line flame arrestors.

Quantity Take-off Tabulation

The quantities as calculated are then entered onto a tabulation form. Traditionally this was done on paper and it was structured such that summaries of the same or similar components could be tabulated for the purpose of material unit costing and labor installation man-hours. Much of this tabulation process has now been shifted to spreadsheets and estimating programs. These programs have helped the industry by increasing productivity of estimating and bidding groups. However there has been an additional burden to train people on the proper use of the estimating programs. Also, spreadsheets can sometimes be dangerous if undetected errors are present in formulas and macros.

F. Sources of Cost Data

We now need to add cost to the quantities of materials that have been taken off. The costs to be added are material unit costs and labor unit costs. We are then able to arrive at a total direct cost for a given line item. For each quantity such as a lineal foot of pipe or a gate valve we can get prices to buy the quantities and use standard or custom unit installation rates to calculate the cost to install it.

Material Unit Prices

In the preceding sections of this chapter we have given general and specific sources of information on material unit prices. Most bulk materials are readily available through these references. The job specification will determine the exact material required. One should be careful that the price reference matches the specification. Special materials will require the estimator to obtain telephone and sometimes written quotations. One should try to identify these special materials ahead of time to permit the vendors time to prepare their quotations.

Some estimating programs come with the unit prices as part of the program. This can be a great aid to groups that prepare many estimates quickly. However the prices tend to be averaged nationally and may have minor fluctuations with prices from a local distributor. One should take into account the frequency of the price updates in the program. These price updates can be quarterly or yearly.

The base source of material prices comes from purchase orders written by owners and contractors. Copies of these purchase orders are then analyzed, normalized, and then summarized in a form used by the estimator. Most of the time this format is material dollars per unit. Sometimes a material factor or index is calculated and published. In this chapter we will only cover material unit prices in dollars or currency units.

G. Labor Units and Labor Rates

The final element in the calculation of a bulk material cost is the labor required to install it and the cost of that labor. Many advances in materials research and technology has focused on reducing the labor required to install a material unit or on transferring it to a shop. The methodology to calculate labor rates and labor costs is very important to job success. Specific information as to the unit rates is readily available in the references quoted. Unusual site conditions should be addressed as adjustments to the unit rates or on an overall basis. Labor rates are well documented in the U.S. for construction trades. Also extensively published are the federal, state, and local taxes, and social benefits that apply to these labor rates. Again, specific site conditions should be reflected in the labor rates.

If the local labor supply is unable to meet the project requirements then financial incentive may have to be included for travel costs, living costs, and bonuses. The need for overtime and the associated costs premium will need to be identified and included in the labor rate calculations.

H. Cost Estimating Software

Some of the more widely distributed cost estimating software is listed below. These programs were selected because their sole or major function is to support the estimating function. Some programs are standalone, others are part of large project control programs that and control actual job costs and schedule progress. We make some general indication of the project or industry for which they are suitable.

- Rapid Access Cost Estimating (RACE) Spreadsheet System; Richardson Engineering Services, Inc.
- Bid Fax; North America MICA, Inc.; Distributor: WareCon Systems, Inc.; Rancho Santa Margarita, California; Bid Management System
- Composer Gold Cost Estimating Software; Building Systems Design, Atlanta, Georgia; General construction estimating
- Construction Reporting System (CRS); Tempest Company, Omaha, Nebraska; General and heavy construction estimating
- Hard Dollar Estimating Office System (EOS); Grantlun Corp., Tempe, AZ; Heavy and highway estimating
- Heavy Bid; Heavy Construction Systems Specialists, Inc. (HCSS), Houston, TX; Heavy and highway construction estimating
- MC^2; Management Computer Controls, Inc., Memphis, TN; General construction estimating
- Means Data; RS Means Co., Inc., Kingston, Mass; General construction estimating
- Paydirt Estimating System; Spectra-Physics Laserplane, Inc., Dayton, Ohio; Earthwork estimating
- Precision Estimating; Timberline Software Corp., Beaverton, OR; General and heavy construction estimating
- Questimate and Icarus 2000; Icarus Corporation, Rockville, MD; Plant and process industry estimating
- Rapid Access Cost Estimating; Richardson Engineering Services, Inc., Mesa, AZ; General and process industry estimating
- Success Estimating and Cost Management System; SoftCost, Inc., Atlanta, GA; General and process industry estimating
- Win Est, Estimating for Windows; Win Estimator, Inc., Kent, WA; General construction, mechanical and electrical estimating;

I. Cost Estimating Books

Cost Estimating
- Craftsman Book Co., Carlsbad, CA
- RS Means Company, Inc., Kingston, MA
- Richardson Engineering Services, Inc., Mesa, AZ
- Frank R. Walker Company, Lisle, IL
- Leonard McMahon Inc., Quincy, MA
- Marshall and Swift, Bridgewater, NJ

General Technical
- McGraw-Hill Inc., New York, NY
- Marcel Dekker, Inc., New York, NY

Prentice Hall Inc., Englewood Cliffs, NJ

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1. Clark, F. D. and Lorenzoni, A. B. *Applied Cost Engineering*, 2nd Ed., New York: Decker, 1985, p. 89.
2. AACE Recommended Practices and Standards, *Cost Engineering Notebook*, AACE, Inc., Morgantown, WV, 1990, p. 94.

6

Estimating Construction Labor and Indirect Costs

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I. OVERVIEW

The competitive nature of the construction industry demands continuous improvements in estimating accuracy, methods, and processes as they relate to *construction labor* and *construction indirect costs*. This is true for the engineering and construction firm bidding to perform the work scope, as well as owner firms or investors charged with allocating project funds in advance of any formal bidding process.

The estimating methods and processes utilized by the professional estimator or engineer charged with estimating construction labor and indirect costs must be capable of capturing changes in cost trends. These changes may result from new market developments and breakthroughs in construction technology. It is this type of change that most directly affects labor productivity, and hence construction costs. These same construction labor and indirect estimating methods must be sufficiently flexible to allow for the incorporation of site specific labor practices and productivity factors.

This chapter will focus on the fundamentals, principles and proven methods that are used in developing construction cost estimates. Information presented in this chapter can serve as a foundation for development of a company-specific estimating process for construction labor and indirect costs. It is also readily adapted for use on a specific project. This material will also provide individual users with a framework that permits them to introduce their own corporate experiences and historical cost data.

II. CONSTRUCTION LABOR ESTIMATES—A CHECKLIST OF KEY VARIABLES

Construction labor is one of the more difficult portions of a total project cost estimate. In order to prepare a construction labor estimate that is credible and has the desired level of accuracy, an organized approach is required. The key is to examine the variety of conditions that influence the construction labor work elements and hence their respective costs. Adequate investigation and understanding of these conditions is critical. It is equally important that the resulting estimate assumptions and qualifications be fully documented and reviewed with the appropriate levels of corporate management.

The spectrum of conditions directly affecting a project's construction labor productivity and direct costs includes:

A. Scope of Work.

Determining the clarity and level of scope definition at the time the estimate is prepared is critical to construction labor estimate accuracy. For example, *grass roots* facility locations (i.e., locations in which nothing has been built before—as disctinguished from "revamp" or "retrofit" projects that modify existing facilities) typically require significant surface and subsurface preparation. Difficulties may be encountered in "getting the project out of the ground."

Conversely, *existing* facilities may have numerous abandoned or poorly defined underground obstructions (e.g., pipelines or old foundations) requiring removal or rerouting. Significant unforeseen costs in direct craft labor and stand-by time for equipment may be encountered.

The estimator also must determine if costs associated with utility runs leading up to the new plant facility battery limits (e.g., water mains, telephone trunk lines, power company transmission lines, transformers, etc.) are to be included as part of the project's cost estimate or excluded as being the responsibility of other entities.

B. Quality Definition Requirements

Documenting the sources and accuracy of quantity information to be utilized in the estimate is also an essential ingredient to accuracy. Elements of the labor estimate for which definitive quantity data is missing or poorly defined should be highlighted for further refinement and possible special project contingency analysis.

C. Project Size, Complexity, and Layout

Consider possible impacts on individual craft manpower densities and the ability to position lifting equipment for maximum productivity. For example: Is the construction site located within an existing operating plant with limited direct access for placement of equipment and materials?

D. Project Execution Plan

Has a comprehensive Project Execution Plan been developed in advance of the estimate? If yes, what issues impacting on construction labor have been captured? What determinations have been made regarding the possible subcontracting of specific elements of work scope?

E. Design Technology

Does the project contain new or untested design technology that may adversely affect construction labor productivity? Is there a need for equipment manufacturers to provide specialized craft persons or supervision? Will certain construction or installation operations be performed for the first time?

F. Specifications

Do the construction specifications mandate the use of specialized craft skills or certifications that are scarce and/or require a premium hourly rate? Are project specifications sufficiently flexible to permit the use of the latest labor saving construction techniques?

G. Local Culture and Local Labor Laws.

Construction locations outside of the U.S. may be impacted by requirements as to the nationality and makeup of the construction work force. National policies may dictate the need for craft skills training of "local" workers and/or place strict limitations on the importation of skilled work crews from other countries.

Local culture may limit the use of labor saving construction equipment in favor of maximizing employment of unskilled workers, e.g., utilizing workers with hand tools for tasks such as site excavation and backfill.

It is important to note that national and local labor laws may impose requirements that directly affect the construction labor estimate such as: nonworking paid holidays, overtime pay schedules, worker severance payments, etc. These types of issues, if not addressed within the estimate, could trigger labor disputes and cost overruns late in the project.

H. Site Conditions

Do adverse site conditions (e.g., extreme heat, cold, dust, noise levels, exposure to hazardous environmental conditions) pose an unfavorable impact on worker productivity and indirect project costs? Will poor site conditions coupled with a requirement to wear specialized protective gear have a cumulative impact on craft productivity, absenteeism and/or turnover rates?

I. Location Considerations

1. Is the construction site sufficiently remote to require the selective payment of craft hourly premiums, travel time, or daily per diems? (Premium craft payments help ensure an adequate labor supply for critical crafts.)
2. Is the construction site located in latitudes that experience extreme weather conditions on frequent intervals or for long periods of time? How will this affect the craft productivity, absenteeism and/or turnover rates?
3. Is there a need to provide for crew rotations in the craft labor estimate, including payment of travel time?
4. Can the construction site be successfully "closed-in" or winterized so that indoor work can proceed during the winter months?
5. Should the project maximize the use of skid mounted or modularized construction techniques in order to minimize the overall site manpower requirements?
6. Is there a requirement to supply craft living quarters or camp with support staff (e.g., cooks, maintenance workers, medical staff, security?)

J. Availability of Local Craft Resources

Will other construction projects in the general vicinity be competing for limited local craft resources? What impact might this have on craft availability?

K. Currency Exchange Fluctuations/High Foreign Inflation Rates

Construction locations outside of the United States may be adversely impacted by payroll costs denominated in local currency. The project estimator should investigate this issue with corporate financial specialists. Estimate assumptions tied to a stable currency is typically the best practice.

L. Union or Open/Merit Shop Considerations

The use of union or nonunion work force can have a big impact on productivity and cost. This chapter makes no attempt to deal with the myriad issues and arguments relative to the use of union versus nonunion crafts. These types of specialized labor issues are best addressed in the estimate with the assistance of an experienced construction personnel specialist versed in union bargaining and craft labor issues.

Issues typically addressed in national and local bargaining agreements for unionized crafts may include

The ratio of journeymen to apprentices
The use of local hiring halls
Guaranteed work hours for foremen and general-foremen
Nonworking craft stewards
Selective hiring or termination of nonlocal personnel
Availability of craft change rooms

It is important to note that projects funded in part with U.S. Federal matching funds are normally subject to the Davis-Bacon Act. This Act mandates that all construction contractors (including open or merit shop employers) pay their hourly employees in accordance with a published prevailing local craft wage rate. Typically these Davis-Bacon rates are closely aligned with a local unionized pay scale.

The majority of these and other similar issues that impact on construction productivity and direct labor costs should be documented before making any type of comprehensive construction estimate.

Firms that routinely undertake construction work at sites removed from their immediate main office location have developed preneed *site survey checklists* that cover the checklist items noted above. These checklists are typically utilized by individual project construction investigative teams. The lead project estimator should be considered as a key team member when compiling the site survey checklist and investigating specific project site issues. In addition to construction labor related issues as outlined above, site investigation teams should address constructability issues such as:

Material staging and lay-down areas
Site access for movement of oversized loads (e.g., road conditions, bridge limits, rail, barge, etc.)
Identification of local material suppliers and specialty subcontractors

It is also helpful to capture existing site conditions with both still and video photography as an aid to estimate development.

III. CONSTRUCTION LABOR ESTIMATES—ORGANIZATION

Selecting how an estimate is to be organized and *what estimating methods* are to be used is normally based on the following key considerations:

Estimate accuracy required
Purpose of estimate
Information available for estimating
Time available for preparation

Planning is important. The estimator should use methods that will result in an estimate with the degree of accuracy matching the purpose of the estimate. Likewise the finished estimate must be in a form that is readily understood by the final "customer" (e.g., project management, owner firm, lending agency other team members) so they can use it effectively for decision-making or project control.

The critical nature of a labor cost estimate requires the estimator to seek out the most current and reliable information. There are varying degrees of detail with different levels of effort that directly correlate to the amount of risk exposure the estimate is intended to represent.

For example, a contractor preparing an estimate for conceptual design or economic studies usually will take a much different approach then when they are called upon to submit a firm price bid. Likewise estimates used for contract change order pricing will take a more detailed approach.

Estimates are normally organized to best reflect their intended purpose and the level of definition of the scope of work. Typically, this is done by using a variety of *logic structures* that help in organizing and presenting estimate data and information. Some estimating logic structures include:

Work breakdown structure (WBS): The WBS uses a hierarchal structure to identify systems, components and end-items; unique packages of work or particular services; and bid items for proposal estimates or change orders.

Cost breakdown structure (CBS): The CBS identifies cost elements and cost code of accounts similar to the Construction Specifications Institute (CSI), MasterFormat system.

Organizational breakdown structure (OBS): The OBS is used to identify different labor resources by department, craft, discipline, activity codes, teaming partners, and/or responsibility.

Other variables that may be used in estimate logic structures include: separate legal entities, contract funding agreements, geographical location, owner asset accounting breakdowns, and government regulatory items.

IV. CONSTRUCTION LABOR ESTIMATES—DIRECT AND INDIRECT COSTS

Selecting the correct approach for an individual estimate usually depends on the complexity of a project, the type of facility, and the work that is to be estimated. Most complex project estimates require a combination of more than one kind of estimating method or technique. Use of a single estimating method may be adequate for a small project.

In order to determine total labor requirements for a construction project, estimates are usually prepared by separating costs into direct and indirect cost elements, defined as follows:

Direct Construction Labor Cost This is the cost of work directly involved in the fabrication, handling, installation, and final testing of materials and equipment that is to become part of a permanent facility.

Indirect Construction Costs These are the costs associated with the support of direct construction required for orderly completion of the project. These costs usually include field administration, direct supervision, construction management, engineering staff, site support services, statutory labor burdens, benefits, insurance, and taxes. These costs typically are for work efforts that do not directly result in work products that become a part of the permanent facility.

Separating a project estimate into two major cost elements (i.e., direct and indirect) allows the estimator to select the most applicable estimating method and/or technique for each.

V. CONSTRUCTION LABOR ESTIMATES—METHODS

There is a wide variety of labor estimating methods. The method of choice for a given project will depend on the degree of scope definition, data availability, and project location.

The various labor estimating methods are described below, together with their most common applications.

A. Factored Estimating

This method is generally used to arrive at a preliminary cost estimate quickly, with a minimum of information. It is commonly used in industrial construction and for chemical or refining process plants. The principal of this estimating method is based on historical relationships and ratios of total direct cost to

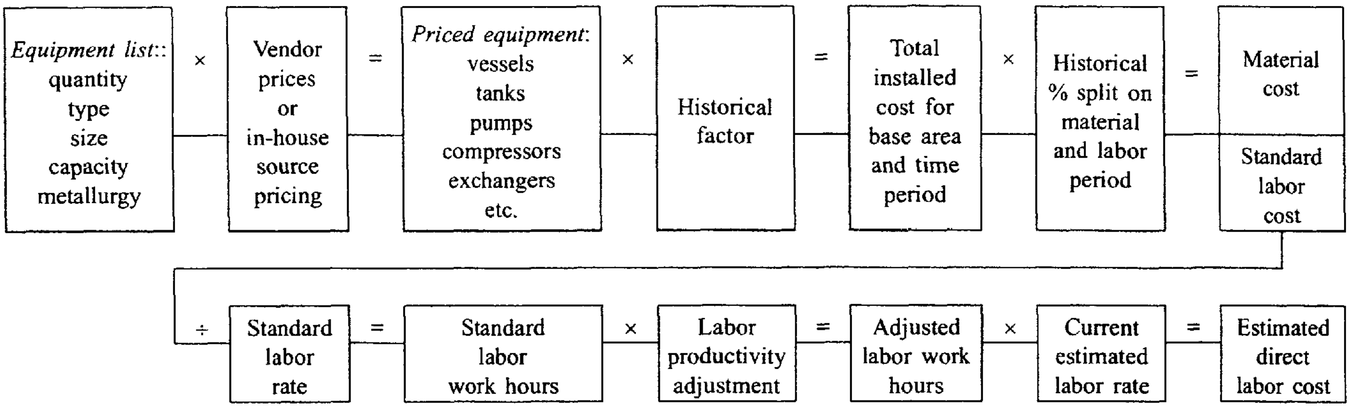

Figure 1 Factor estimating method, direct labor cost

the cost of individual items of equipment. The factor accounts for bulk materials (e.g., foundations, piping, electrical, etc.) and direct labor costs.

Typically this type of factored estimate is based on facility design information. Preliminary source information may include: process flow diagrams (PFDs), permanent equipment list, standard specifications and data sheets for each item of engineered process equipment.

Each piece of equipment is typically priced from preliminary vendor quotations or from other recent historical cost data sources. After compiling the cost of process equipment, historical factors and ratios are utilized to determine all the associated direct material cost required to fully install the equipment. (e.g., foundations, structural supports, piping, electrical, instrumentation, insulation, and painting)

This same method is also used to determine the direct labor work hours required for the installation of the equipment and associated bulk materials. If warranted, site location adjustments for labor productivity can be applied to portray the conditions envisioned for the project. Gross craft labor rates including allowances for statutory burdens and benefits are then applied to these labor work hours to arrive at a total labor estimate.

Figure 1 presents a typical factor estimating method with emphasis on direct labor cost elements. This method of factor labor estimating and the principles on which it is based may be used in many types of projects (e.g., mining, building construction, and systems-oriented construction.)

Estimators who may wish to use this type of factored estimate should begin the process by examining and analyizing a sample of cost data from recently completed projects in order to ascertain the reliability of factors and ratios being considered for use.

B. Quantity Take-Off Estimating

This is a widely used appropriate for all types of estimates, ranging from conceptual studies to definitive estimates used to support fixed priced bids.

Cost estimates based on the quantity take-off method are developed by the development of estimated quantities of materials to be removed, fabricated, or installed. Individual labor unit work hour values are applied to (i.e., multiplied by) the various categories of quantities to arrive at a total number of work hours per category. Individual craft (or crew) labor rates with productivity and location adjustments are applied to these work hours in order to determine total labor costs.

The term "take-off" describes the process by which quantities of materials to be installed are "taken off" the design drawings. If the drawing from which the quantities are being taken off is preliminary, a "take-off allowance" should

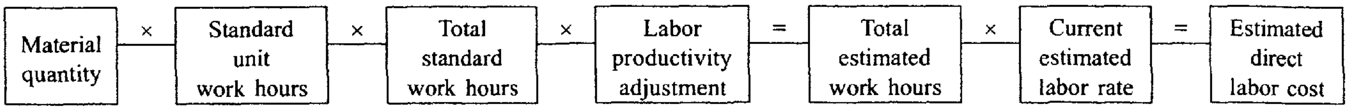

Figure 2 Quantity take-off method, direct labor cost.

be applied to account for quantities not yet detailed on the drawing. See Figure 2 for a flowchart describing this method.

C. Direct Cost Construction Equipment

This method is applicable for those types of projects that are primarily dependent on the production of major construction equipment as opposed to tasks performed by individual craft work crews. In these instances the cost for construction equipment is usually carried as a direct project cost (as opposed to the normal practice of considering these costs to be indirect.) Typically the cost of the equipment operator, oiler, etc. will be incorporated into a standard (all-inclusive) hourly rate for each piece of equipment.

Examples of this method include heavy civil excavation, paving, road work, offshore work, pipelines, and tunneling.

D. Level of Effort Estimating

This method can be applied to both *direct* and *indirect* labor cost estimates. It is most often used for estimating the cost of indirect support staff (e.g., supervision, clerical, guards, warehouse, material handling, tool room attendants, timekeepers.) It is appropriate for the type of effort, such as supervision, in which specific quantities cannot be readily defined.

Level of effort estimating for *indirect labor* is based on correctly identifying the number and types of personnel required over an estimated time duration to support direct labor craft activities. This method requires the development of a manning table that identifies the individual field support positions together with their appropriate composite labor rates and assignment durations for each position.

Use of the *level of effort estimating* method for determining *direct labor* costs is normally based on a predetermined composite construction crew (e.g., crew chief, craft journeymen, and helpers) together with an hourly or daily total crew cost. These data are then applied to an estimated rate of production/hr or per day.

For example: a given crew can lay x miles of 24-in. heavy wall pipeline/day, with crew cost being inclusive of craft labor, construction equipment, indirect, overhead costs, and profit.

Similarly this method can be used in developing unit cost rates to be applied to an "indefinite quantity" type of contract or as a simplified means for pricing contract change orders. See Figures 3a and b for a flow chart of this method as applied to indirect and direct costs.

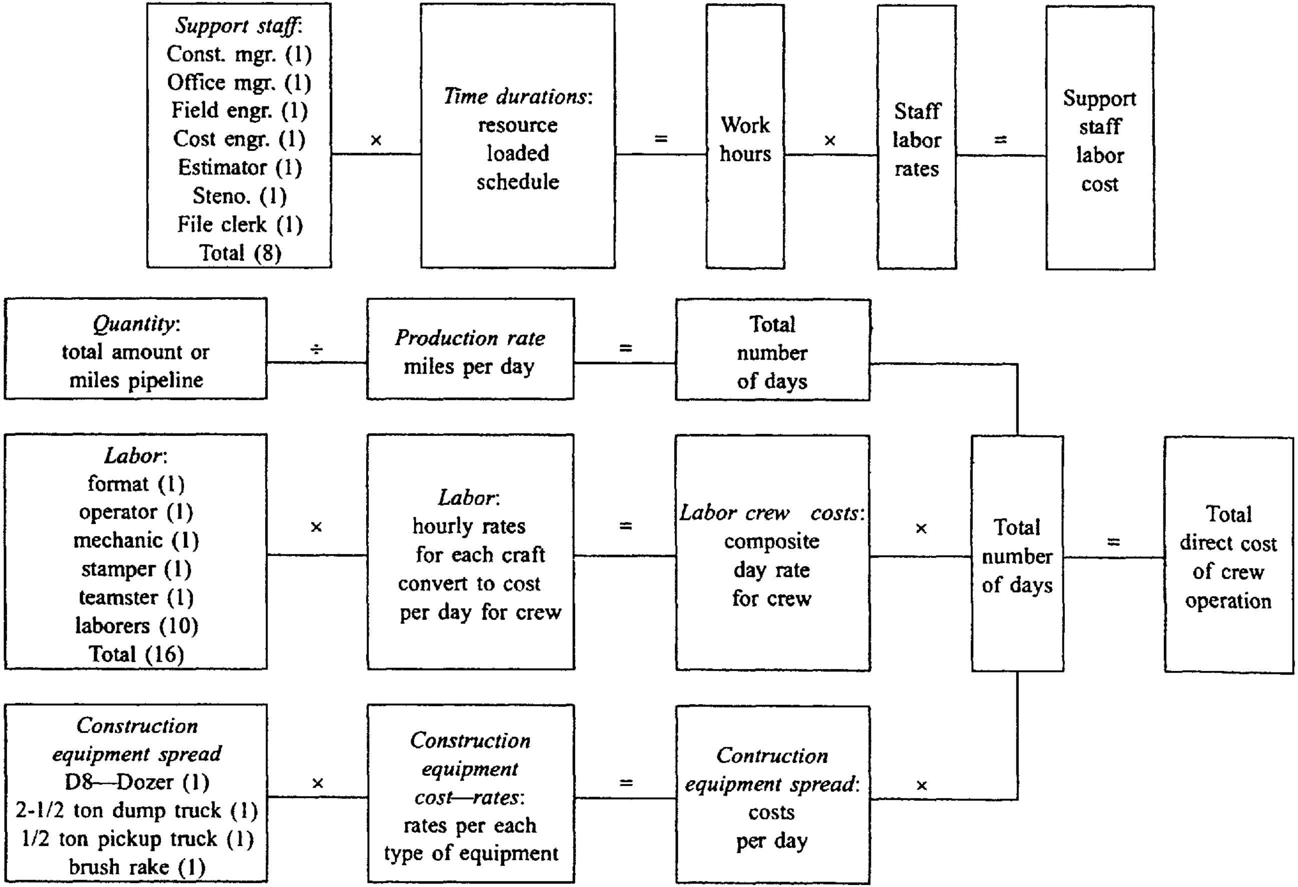

Figure 3 Level of effort method. A. Indirect labor cost. B. Direct labor cost of crews.

E. Apportioned Effort Estimating

This method is most commonly used in developing certain types of specialized indirect labor and/or subcontracted construction services estimates.

The *apportioned effort estimating method* relies upon the use of historical relationships that indicate the indirect cost proportion to the performance of specific direct labor work activities.

Examples include site surveying, soil compaction tests, and inspection of welds, where the cost of these activities is expressed as a percentage of direct labor. See Figure 4 for a flowchart describing this method.

VI. THE FOUR ELEMENTS OF CONSTRUCTION LABOR ESTIMATES

There are four fundamental building blocks in the development of construction labor estimates. They include the determination of:

1. Project quantities
2. Work hour unit rates per quantity
3. Hourly craft bare wage rates
4. Crew mix

Each of these will be described in detail.

A. Determination of Project Quantities

For some types of materials, detemining the quantity information necessary for construction labor estimating is straightforward. For example, it is relatively easy to accurately determine the total quantities of excavation, soil compaction, formwork, rebar, concrete placement and backfill associated with a simple equipment foundation, parking lot or roadway of known proportions.

Conversely it becomes increasingly more difficult to determine the total quantities of earthwork, excavation, rebar, concrete, steel, equipment erection, pipe erection and welding, bulk electrical and instrumentation installation, painting and insulation, etc. for a complex process plant unless the detailed design effort has been substantially completed.

Frequently the project estimator is tasked with determining categories of estimated quantities for complex projects at a relatively early stage of design development. In these instances the estimator should seek assistance from the lead engineering and discipline design specialists. These technical specialists are best positioned to determine both the availability and accuracy of initial quantity data. Preneed discipline checklists identifying preliminary design data, drawings, sketches, line lists, etc. are often helpful for this purpose.

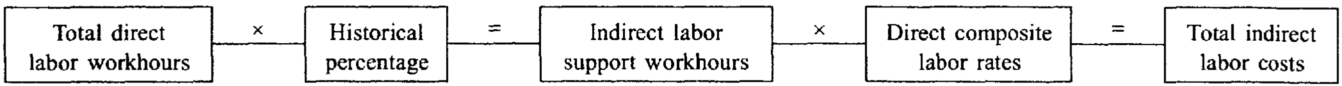

Figure 4 Apportioned effort method, indirect labor cost.

The estimator, working with the project engineer, construction representatives, and individual discipline specialists, should develop an acceptable plan as to the basis, technical sources, and relative accuracy of quantity data.

Actual "final" quantity data from similar types of completed facilities is a useful, yet often overlooked, source of estimating information. These types of historical data are especially helpful in gauging both total quantity requirements and ratios of various quantities for projects where only minimal amounts of design work have been completed by the time an estimate must be produced.

If historical quantity data is used as part of the current estimate basis, it is important that some form of rudimentary technical review and comparison be made between the historical facility data and the planned new facility in order to highlight any obvious layout, design or capacity differences.

The estimator should compile and organize the quantity information into a suitable work breakdown structure. At the same time the estimator must insure that adequate individual *design development allowances* have been incorporated based on the degree of design completion for the respective work elements covered by the estimate. The design development allowance is to account for the increases in defined quantities that inevitably occur as the design progresses.

Rather than relying exclusively on quantity take-offs of partially completed drawings for a particular class of materials, e.g., carbon steel pipe, the estimator should also seek to secure a representative cross section of "as-built" quantities from similar completed projects. Sources for these types of historical quantity data may include company final cost reports, client/owner records, or commercially purchased normalized data for plants and facilities having similar production capacities and characteristics.

B. Determination of Work Hour Unit Rates Per Quantity

Once physical project quantities have been established for each cost account, a determination must be made by the estimator as to the number of craft work hours required to complete each unit quantity (e.g., average of x hours per running foot to install a 24-in. diameter underground concrete pipe).

In today's market, many commercial sources are available that routinely classify, update, and publish standard unit costs for a wide array of typical construction tasks. These commercial sources include:

R.S. Means Co.
Richardson Engineering Services
F.R. Walker Co.

Typically these sources offer the unit cost data in both printed and electronic versions that can be directly loaded into estimating spreadsheets. With proper review and adjustment for project specific productivity factors and jobsite location, these commercial sources represent a reliable source for unit costs on a per quantify basis.

Actual "company specific" unit cost experience, when compiled from several recently completed projects, may be a preferred approach. Historical unit cost data, when used as the basis for subsequent estimates, should be reviewed and normalized to ensure that common methods were used in the collection process. For example, was dewatering of open excavations charged against a separate WBS account or included as part of an underground pipe installation account?

Experience and professional judgment on the part of the estimator and construction craft supervision are an integral part of the process used to arrive at per quantity unit work hour rates for a specific project. Comparisons between actual company experience and commercially published data should be encouraged at all times. The estimator may find, for example, that the company's unit rate experience in a given category tends to be a certain percentage over the value provided by published data.

Estimates which, for competitive reasons, reflect the planned achievement of quantity unit rates significantly better than company or industry averages should be supported by specific productivity enhancing measures planned for the affected accounts.

C. Hourly Craft Bare Wage Rates

Projects utilizing unionized crafts will typically have individual craft wage rates established as part of a combined regional and local bargaining agreement. Effective dates for future union wage increases are normally known well in advance and can therefore be made a part of the craft labor estimate.

Nonunion, or *open shop* craft wages, are typically a function of local area supply and demand. Current craft wage rates are normally available from a variety of local industry sources or may be derived from the U.S. Department of Labor wage surveys as a part of the recommended prebid "site survey."

Advance research and intelligence is especially importance in the establishment of accurate hourly craft wages. Knowledge regarding other construction projects in the local area that are planning to either hire or release crafts, as well as accurate information on local wage scales, should be an integral part of the estimate.

Plans regarding the construction work week, (e.g., guaranteed 40-hour work week, and/or scheduled overtime for critical labor skills,) have a direct bearing on the project's ability to draw and hold craft workers at a predetermined base hourly wage rate.

D. Crew Mix

This represents the ratio of semiskilled (or apprentice workers) and helpers compared to the number of skilled craft-persons (or journeymen) within a particular craft or individual *work crew*. Since base hourly wage rates for lesser skilled workers are typically well below the "journeyman" rate, assumptions regarding overall average crew mix can have a dramatic effect on the estimate's total craft wage component.

Projects utilizing unionized craft labor will generally be governed in crew mix calculations by local bargaining agreements that set forth parameters as to the maximum ratio of apprentice labor to journeymen.

Nonunionized, or open shop, projects, while not restricted in this same manner, must still exercise care when arriving at estimated crew mix assumptions. An estimate based exclusively on the use of journeymen workers runs the obvious risk of being noncompetitive on total price. Conversely, an estimate based on using higher ratios of less-skilled workers runs the combined risk of poor workmanship and low productivity.

When establishing estimated crew mix assumptions, the estimator should rely on the professional judgment of craft supervision and construction management coupled with actual crew mix results from recently completed projects.

VII. ESTIMATING INDIRECT CONSTRUCTION COSTS

Indirect Construction Costs are defined as: *All costs that do not become a final part of the installation, including (but not limited to): field administration, direct supervision, tools, temporary facilities, contractor's fees, insurance, taxes, etc.* [1].

In certain instances, requirements defining specific aspects of construction indirects are disclosed in the project's contractual bid conditions or client specifications. An example of this may be the owner defining unique requirements for temporary office space to support a predetermined number of their field staff, telephone services, construction pickups, etc., all of which are to be furnished by the successful contractor as a part of the total bid price.

In other instances, the scope definition for construction indirects may only be inferred through contractual statements of responsibility directed at the contractor. In as much as these somewhat open-ended indirect cost items, on a combined basis, approach 15% of the total direct cost estimate, it is imperative that a comprehensive effort be directed toward a thorough scoping of all items [2].

By definition, most indirect costs (i.e., both labor and nonlabor related items) are predominantly a function of the project's planned *duration of need*, as extended (or multiplied) by a definable estimated rate per hour, per week, or per month, together with an estimated cost associated with site mobilization/transport and final demobilization. Other key issues affecting the cost of construction indirects include the following [3]:

1. Relative Size of the Project—typically expressed in terms of the total number of "direct" craft work hours
2. The Type of Project—expressed as a new or "grassroots" facility as opposed to an existing plant site where selected indirect support facilities may (pre)exist
3. Local Labor and Construction Practices—such as practices governing the use of construction equipment, or the reuse/dismantling of job scaffolding, etc.
4. Site Specific Location and Conditions—such as an extremely remote site requiring daily transport of craft workers to/from the jobsite, or special allowances for seasonal weather conditions, etc.

Good estimating practice requires that the estimator thoroughly document all major assumptions that affect the scope and costing of the construction indirect estimate. This documentation should also specify which indirect construction requirements are included as part of the Home Office Services scope (e.g., business travel, computers, preparation of "as-built" drawings, etc.).

Indirect construction costs have been grouped into the following general cost categories as shown in Table 1 for ease of presentation and discussion purposes, relative to individual scoping and costing strategies.

Each of these will be discussed in detail.

Table 1 General Categories of Indirect Construction Costs

1.	Field supervision and indirect support staff
2.	Travel/relocation/subsistence and field per diems/and relocation
3.	Temporary facilities and structures
4.	Temporary support systems and utilities
5.	Construction equipment and tools
6.	Safety and first aid
7.	Field office furnishings—supplies and communications
8.	Construction consumables
9.	Insurance/taxes, statutory payroll burdens and benefits
10.	Miscellaneous overhead and indirects

A. Field Supervision and Indirect Support Staff

This general category of indirect construction cost customarily encompasses all field labor as "required to make it possible for *direct labor* to take place," direct labor being defined as "labor that produces direct physical progress [4]."

For purposes of estimate definition this indirect labor category is best accomplished by the preparation of a *project specific construction organization chart.* Notations on this should identify planned start dates and anticipated total duration of the assignment for each position. Care must be exercised to insure that only the minimum number of indirect staff are assigned during the initial construction mobilization phase. Likewise a phased "destaffing" of indirect field staff should take into account the requirement to close out all site accounting, payrolls, and business activities.

Those positions intended to be staffed by "permanent hire" personnel—as opposed to "local or project duration" personnel—should be clearly specified so as to aid in the proper cost estimation of staff relocation, travel, monthly field per diems, and employee payroll benefit cost calculations.

A well-defined project schedule, showing start dates and overall durations for all major construction activities is essential to the development of an accurate estimate for indirect supervision and related support staff.

It is also possible to ascertain the total work hours required for field supervision and indirect support staff by *factoring* this portion of the estimate from other recently completed projects with similar size, duration and project execution characteristics. However, it is preferable to develop a complete project-specific construction organization chart with indirect staff durations determined from the project master schedule. Historical data may then be utilized as an overall check on the estimate.

Determination of total "bare" cost estimates for indirect labor—i.e., gross payroll/labor costs excluding statutory burdens and company contributions towards employee benefits—is routinely determined by extending (multiplying) the estimated indirect staff durations by a predetermined labor rate per hour, week, or per month in the case of salaried staff. The appropriate competitive indirect labor salary/wage rates for any given project position are normally calculated and set by corporate personnel policy as developed in conjunction with input from senior construction management.

Prevailing hourly wage rates for *local hires* such as clerks, timekeepers, warehouse attendants, etc., are normally ascertained as part of the Jobsite Investigation/Survey Report described earlier.

Statutory burdens, as required by state and federal regulations, as well as individual company allocations for employee benefits (e.g., medical insurance, 401k plans) should be performed by individual calculations or spreadsheet formulas. Consideration must be given to the fact that "project duration or

Table 2 Checklist of Indirect Supervision and Support Staff

Functional Area	Responsibility
Construction Site Manager/ Job Superintendent	Manages overall project
Individual Craft Supervision (General Foremen or Foremen)	Those supervisors overseeing craft tasks but not directly participating in performing the work
Field Office Manager (or) Site Administrative Supervisor	
Office (or) Field Engineers	General liaison with engineering/site layout
Field Procurement	Purchasing—expediting and material control tasks
Project Controls	Scheduling—cost control and scope control tasks
Field Personnel	Craft recruitment/screening and testing tasks
Field Warehouse Staff	Receive inventory—store and issue material
Safety Engineer	OSHA compliance/jobsite first aid
Construction Quality Assurance/ Quality Control	QA/QC tasks
Field Survey/Layout Crew(s)	Establish initial project benchmarks
Subcontract Specialists	Administer subcontracted work scopes
Field Drafting Staff	Construction detailing/pipe isometrics/as-builts
Field Clerical Staff	Full-time and/or part-time support to all functional groups
Janitorial Staff	General site support (drinking water/site clean-up, etc.)

Note: Other indirect labor related expenditures associated with the part-time utilization of laborer and craft crews (e.g., jobsite dewatering, construction and maintenance of temporary facilities, etc.) are addressed in subsequent segments.

local hire" employees *may not* be entitled to participate in certain optional company benefits. Likewise calculations for statutory burdens may be adjusted for expected lower turnover of indirect staff as opposed to direct craft employees. This type of estimate "fine tuning" is best accomplished with the benefit of accurate recent historical cost data.

The master *Checklist of Indirect Supervision and Support Staff*, as displayed in Table 2, identifies those major functional areas of responsibility that are customarily required on *"direct hire"* construction projects. Larger projects generally tend to have a *minimum* of one or more personnel fulfilling each of these Field Supervision and Indirect Support Staff positions. Smaller projects will (out of necessity to minimize indirect costs) typically attempt to allocate two or more functional areas of responsibility to a single experienced individual. For example, on smaller projects, the Field Administrative/Office Manager may also be responsible for payroll and time keeping functions. Likewise a Warehouse Supervisor may also be called upon to routinely perform field purchasing and material expediting functions.

The estimator should also discuss with construction representatives the potential cost trade-offs/savings associated with subcontracting certain routine aspects of the indirect support staff functions. Typically this may include initial site survey and layout tasks; janitorial cleaning services; employee payroll services and/or jobsite security guard services. Firm bid quotations for these types of third party contracted services should be obtained from local firms.

It is also advisable to ascertain which indirect construction services, such as security guards, janitorial services, etc., may be provided at little or no additional cost by the owner.

B. Travel/Relocation/Subsistence and Field Perdiems

Construction-related travel, relocation and subsistence costs are frequently understated during the development of the initial estimate. Defining, documenting, and costing the scope requirements for each of these indirect elements can go a long way towards improving estimate accuracy. Each indirect element is defined and discussed as follows:

Construction Travel

Typically this would include the costs of travel for construction management and staff while on short-term business trips away from the jobsite following their "permanent" relocation. Examples include trips to the contractor's or owner's offices for project review meetings as well as inspection trips by field staff to vendor fabrication shops.

Efforts should be made to calculate the total expected number of trips, by destination and duration. Costing should include airfares, lodging, rental car, meals and incidentals in accordance with existing company travel policies. Strategies to reduce this type of expense include advance contractual agreement to conduct internal and client review meetings via video conference and/or teleconference.

Construction travel may also be defined to include the mileage payments made to construction personnel utilizing their personal vehicles to conduct company business. While a reasonable allowance for this project cost should be contained in the estimate, much of this cost can be minimized if company owned jobsite pickup trucks are routinely made available for staff business use.

Construction Relocation

Typically this would include all costs associated with the transfer of key "permanent or direct hire" construction staff from their current assignment to the new project location. Individual company policies generally govern both the types of costs and overall amounts that are to be incurred on the part of the company.

Typical cost elements include auto mileage allowance and/or airfares, temporary lodging, meals, and storage or shipment of household goods within certain limitations. Many companies offer increased relocation reimbursement for employees with families, therefore reasonable assumptions as to family status must be made. This is especially true when estimating costs for foreign relocation (e.g., increased airfares, home leave policies, medical evacuation, etc).

In certain instances companies may elect to offer a fixed lump sum payment in lieu of reimbursement actual relocation expenditures. This type of fixed relocation payment incentive is sometimes offered to craft foremen or skilled craftsmen that may be in short supply and/or for jobsites that are in geographically remote locations. If contemplated or required for a specific project, these types of payments should be clearly defined and documented based on discussions with construction management and the company's personnel department.

When estimating construction relocation expenses it is normally advisable to consider both the total number of "permanent hire" staff anticipated to be assigned to the project and a reasonable allowance for staff turnover.

Subsistence and Field Perdiems

Typically this would include payments made to key construction supervision and staff to help offset the cost of housing and meals while assigned to a jobsite that is geographically distant from the company's home office and/or the employee's address of record.

The project estimator should work closely with the corporate staff specifically charged with setting travel, relocation reimbursement, and subsistence policies to insure that all site specific requirements are adequately addressed. For example, on foreign assignments this may include the estimation of costs for dependent schooling and/or company paid home leave trips.

Additionally the Internal Revenue Service (IRS) has numerous rules and regulations governing both the "allowability" and tax treatment for payments made to employees relative to relocation and subsistence. In many instances tax treatment is governed by the length of the assignment. In all cases the project estimator should request instructions from the appropriate corporate legal staff as to any actual or potential cost implications chargeable against the project's budget.

C. Temporary Facilities and Structures

Accurate estimation of costs associated with *temporary site facilities and structures* necessitates the preparation of a project-specific *Site Facilities Plan*—i.e., one that sets forth the total anticipated facilities requirement for the proposed project. This plan need not be formal or elaborate in nature. However, it is important that the plan set forth a comprehensive description of all temporary facilities and structures that can reasonably be anticipated as necessary. The plan should address the housing and support for project personnel, as well as the protection of construction materials, tools, and supplies from damage or theft. Anticipated required need dates and total time durations for each temporary facility should be identified based on an analysis of the project's *master schedule.*

This site facilities plan is most appropriately developed by the key construction staff slated to execute the project being estimated. Or, alternately, prepared by an experienced construction manager who is familiar with the planned construction scope, the relative project size, and site specific conditions (e.g., areas available for temporary site layout, presence of existing client/owner facilities, etc.).

The master *Checklist of Temporary Facilities and Structures*, as displayed in Table 3, identifies potential types of temporary facilities that are customarily required on *direct hire* construction projects.

Project sites that are spread over large land areas and/or individual projects with multiple geographic construction sites may tend to require "decentralized" temporary facilities (e.g., multiple crew trailers, multiple warehouses, administrative offices, etc.). In these instances the project estimator should examine cost trade-offs including:

1. *Craft commuting distances and potential nonproductive time*—i.e., as expended by crews to obtain and transport materials, supplies and to review construction drawings.
2. *Increased rental, lease, or purchase costs*—for multiple (smaller) temporary facilities versus a single larger centralized facility.
3. *Increased costs to install and maintain temporary utilities*—to widely separated locations (e.g., power, water, telephone, etc.).

Various alternative project strategies affecting the estimated cost of the temporary facilities include:

1. *Monthly rental of third party facilities versus lease/purchase option.* Depending on the type of contract being executed, ownership under the lease/purchase option may ultimately pass to either the contractor or the

Table 3 Checklist of Temporary Facilities and Structures (as associated with direct hire projects)

On-site Project Offices	As required to house contractor's Supervision and Administrative Staff (refer to Table 2)—including conference facilities.
Offsite Project Craft Recruiting Office	Generally a leased facility in an easily assessable public location that is utilized for craft screening and testing purposes. Costs may be shared with other concurrent projects.
Warehouse/Materials Storage Facilities	May be located on- and/or off-site depending on unique project storage capacity requirements. Certain projects may also require humidity/temperature controlled storage for delicate instrumentation.
Fabrication/Mill Shop Facilities	Weather protected work areas used for pipe spool fabrication, welding, and pre-assembly of materials.
Tool Room Storage/ Checkout	Utilized to secure large or expensive tools for "sign-out" by individual craftsmen on an "as needed" daily basis.
Individual Craft Offices/ Trailers	Requirements generally dictated by local labor agreements and/or the overall level of project participation by individual crafts.
Craft Change House(s)	Requirements generally dictated by local labor agreements and/or unique project safety/health requirements such as the wearing of specialized protective clothing (e.g., Nomex suits, etc.).
Site Control Access/ Guard Shacks	Generally small buildings located at each plant access gate. May include sanitary facilities and HVAC.
Client or Subcontractor Facilities	Potential separate/duplicate site facilities as may be required for use by the client/owner and/or specialty subcontractors. Include in estimate costing only if required.

client. The lease/purchase option may offer a residual or resale value that can be applied to lower the overall cost booked against the project.

2. *Outright purchase with "buy-back" arrangements* in which the temporary facility is fully paid for in advance with the proviso that the facility may be "repurchased" by the original supplier at a specified future date and a predetermined minimum price.
3. *On-site "stick-built" facilities using contractor's crews and materials.* This option may offer certain pricing advantages as compared to long term temporary facility rental or leasing arrangements. The price of building materials coupled with the availability of craft labor and supervision early in the construction phase need to be considered. This

Table 4 Checklist of Temporary Support Systems and Utilities (as typically associated with direct hire projects)

Roads and Bridges/Parking and Lay-down Areas
As required to meet peak construction demand. Typically includes labor, materials, and equipment for installation and maintenance. May include payments to third parties for use of private property and removal/restoration costs.
Temporary Utilities
Typically includes labor, materials, and equipment to install all utility systems necessary to support peak construction demand. Ongoing charges may include monthly consumption fees for power, water, natural gas, telephone, etc. Other utility costs may include drilling of water wells, truck hauling of purchased water, use of temporary power generators, satellite link for remote sites, temporary HVAC systems in severe climates, etc.
Jobsite Sanitation
Typically includes rental of trash dumpsters and portable toilets in accordance with government requirements for project size. Ongoing costs include monthly rental charges and disposal fees. Other sanitation related costs may include janitorial services, jobsite dewatering, insect/pest control services, dust control, and general site cleanup.

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option is most viable when the "temporary" facility will receive long-term project use and/or the owner anticipates additional follow-on projects at the same location.

D. Temporary Support Systems and Utilities

Accurate estimation of costs associated with temporary support systems and utilities necessitates the preparation of a project specific *Site Facilities Plan* as described in the preceding section.

The master *Checklist of Temporary Support Systems and Utilities*, as displayed in Table 4, identifies various types of temporary systems including roads, storage/lay-down areas, employee parking areas, jobsite sanitation, weather protection enclosures, water, power, lighting, telephone, etc.

Estimates addressing these temporary systems will vary depending on the:

1. *Jobsite location in relation to existing roads, utility mains, trunk lines, electrical substations, etc.* The cost of extending support systems to the construction site, including charges from utility firms or governmental agencies, may be correctly classified as part of *permanent facility construction.* An estimate determination should also be made concerning direct payment of these third party costs by the facility owner rather than being classified and paid as part of the construction contractor's temporary facilities cost.

2. *Capacity of existing support systems that may be operational.* The estimate should reflect any cost benefit of existing owner support systems. As a general rule the "Invitation to Bid" documentation should delineate existing services and support systems that will be made available during the construction period and the charges, if any, for their routine use.
3. *Timing and accessibility of new permanent support systems.* Installation of new or expanded permanent support systems early in the construction period will typically reduce the requirement for more expansive temporary systems. Advance agreement concerning use of these permanent support systems should be reached between the owner and construction contractor prior to finalizing the estimate. Provision should be made in the estimate to repair or refurbish permanent support systems that may be damaged during construction (e.g., Repairs to permanent roads, bridges, parking lots, etc.).
4. *Requirement to relocate existing utility mains, power lines, natural gas pipelines, etc.* In some instances the proposed site location requires relocation of existing support systems. Although technically not part of the "temporary" support system scope, the costs of relocating existing systems is often incurred and invoiced in conjunction with other third party temporary work scope. The estimator should document these types of special requirements as part of the estimate assumptions and qualifications.
5. Construction Equipment and Tools

As a general rule, the project estimator should obtain definitive construction equipment and tool requirements directly from craft supervision slated to perform the work.

Each indirect element is defined and discussed as follows:

Construction Equipment

Typically this includes the cost of third party rental, leasing or outright purchase of construction equipment items (e.g., trucks, cranes, welding machines, forklifts, etc.) as well as the cost of fuel, lubricants, and repairs.

Estimates should be based on a comprehensive, time-phased equipment needs list as developed by the construction craft supervisors for their respective crafts and reviewed by construction management.

Estimates for major crane usage and other heavy lifting apparatus should be based on approved site rigging studies and equipment setting plans. These plans should incorporate realistic delivery time frames for all materials and permanent equipment items requiring field assembly or erection.

Whenever practical, multiple competitive quotes should be obtained from equipment rental firms with a proven record of reliability. Construction equipment pricing based on average historical rental/lease costs should be treated as a secondary method and only utilized to cover any gaps in current quotations.

The construction equipment estimate should reflect the most cost effective rental rates, e.g., hourly, daily, weekly, or monthly based on estimated total time span of planned project utilization.

In some instances equipment rental rates may be quoted as either "bare" or with operators/oilers and maintenance supplied for a predetermined daily shift. Care must be exercised by the estimator to align these rental assumptions with the estimate developed for indirect support crafts that typically may include equipment operators, fuelers, and maintenance crews.

Construction equipment estimate provisions should also address:

1. Key assumptions as to plans for extended work weeks and/or double shifts that will, in turn, impact on fuel consumption, maintenance costs, and possibly the rental/lease rates charged by the vendors.
2. Assemble/disassembly costs for major cranes, e.g., rigging time, cable, etc.
3. Provision for on-site maintenance, fueling and servicing of equipment.
4. Factors for taxes, insurance, and depreciation for construction equipment that is purchased rather than leased or rented.
5. Mobilization/demobilization costs to and from the jobsite including escort services for oversized cranes, etc.
6. Provision for purchase or rental of equipment-related support items such as welding leads, crane mats, slings, spreader bars, etc.
7. A cost benefit analysis for purchase of vehicles or equipment items that may be utilized on subsequent projects or resold for a profit at project completion.
8. A cost benefit analysis for on-site operation of a concrete batch plant, rock crusher, etc. versus time and costs for individual unit price batch deliveries.
9. Provisions for standby time typically associated with large cranes and/or marine equipment such as barges, tugs, crew boats, etc.

Construction equipment items that are owned by the contractor and rented to various projects may offer a significant competitive pricing advantage. The estimator should fully document all assumptions regarding use of "in-house" equipment resources after confirming their availability to the project being estimated.

E. Construction Tools

Typically this includes the cost to purchase, rent, and maintain a wide range of power and hand tools used by construction crafts. For estimating and control purposes, the differentiation between a large power tool and a construction equipment item is normally set by company policy. For example, certain items costing more than $3,000 to $5,000 per unit may be classified and estimated as construction equipment rather than a tool for record keeping purposes.

Tool estimates should be based on a comprehensive needs list as developed by the construction supervisors for their respective crafts and reviewed by project management. The precise basis and techniques used for tool estimates will vary depending on corporate policies and practices, project location and craft labor agreements.

The following issues should be considered by the project estimator when developing the scope and pricing basis for project tool costs:

1. Individual craftsmen are often required to provide their own small hand tools (e.g., pliers, screw drivers, wrenches, etc.) as part of the employment agreement. However, this may not be the case in certain labor jurisdictions and/or in overseas locations.
2. Small hand tools, when purchased and provided by the company, typically should be treated in the estimate as a consumable item with no residual or resale value.
3. Company policy may dictate that larger power tools be priced in the estimate with a residual or salvage value based on the planned resale or transfer of ownership to subsequent projects.
4. Adequate allowances should be made in the estimate for short-term rental of specialized tools that typically may not be carried as part of the normal field tool inventory.
5. Costs associated with tool repair versus outright replacement should be included in the estimate based on company practices and historical cost data.
6. Estimate provisions should be made for tool security in keeping with company practices for storage, inventory and sign in/out policies, e.g., use of tool rooms, crew gang boxes, etc.

Use of broad based historical cost factoring methods, such as x dollars per craft work hour, to arrive at total construction equipment and tool costs should normally be used only as an overall check.

F. Safety and First Aid

Accurate estimation of costs associated with jobsite *safety and first aid* typically requires definitive input from construction safety specialists experienced in compliance with government mandated safety requirements (e.g., OSHA) as well as a working knowledge of corporate safety policies and programs. Development of a project specific Health, Safety, and Environmental Com-

Table 5 Checklist of Construction Related Safety and First Aid Items (as typically associated with direct hire projects)

Construction Personnel Screening
Most firms have definitive procedures for pre- and postemployment physicals, hearing and eye-sight tests, urine and blood tests for presence of drugs or toxic chemicals, etc. The estimate should incorporate all contractor and/or client screening requirements including a reasonable allowance for applicant failure rates and worker turnover during the course of the project.
Personal Protection and Safety Training
Most firms have well defined policies regarding the provision of basic protective gear including hardhats, ear, eye, and hand protection, safety belts, etc., typically at no cost to the employee. The estimate for these basic protective items should incorporate an allowance for loss and employee turnover rates. Note: Project circumstances requiring the purchase and use of specialized protective gear including breathing apparatus, Nomex suits, etc., as part of the standard work conditions should trigger an evaluation of worker productivity on the affected direct labor activities. Safety orientation/certification programs may have a cost per employee in instances where this service is provided on a contracted basis.
Fire Protection
Typically will include purchase of sensors, alarms, fire extinguishers (including servicing). May also include rental or purchase of advanced fire fighting equipment for use on jobsites in remote locations. The estimate may include "fire-watch" labor as typically required during welding or other hazardous activities.
Jobsite Medical and First Aid
Typically will include purchase of consumable medical and first aid supplies. May also include the purchase or lease of specialized medical equipment (e.g., ambulance, x-ray machine, etc.) for use on remote jobsite locations
Site-Wide Safety Compliance Programs
Typically will include cost of safety barricades, warning signs and lights, posters, safety nets, railing, and shoring. May include the cost of items awarded to workers for maintaining a safe work site.
Support Staff
Typically will include cost of safety and medical specialists. Remote jobsites may require full-time medical doctors and nursing staffs.

pliance Plan at the earliest stages of a project serves as an excellent checklist for construction cost estimate impacts.

The master *Checklist of Construction Related Safety and First Aid Expenditures*, as displayed in Table 5, identifies various broad categories of potential safety related project costs including personal screening, protection and training, fire protection, jobsite medical and first aid, job-wide safety compliance programs, and safety and first aid support staff.

Estimates addressing these items are directly affected by:

1. *Applicable federal, state and local regulatory and administrative law requirements.* The estimated cost of safety related regulatory compliance can vary significantly depending on the type and location of construction being undertaken—e.g., deep excavation, tunneling, height requirements, proximity to large bodies of water, etc. Construction activities in existing facilities, with the potential for worker exposure to toxic materials, fire or explosion, also impact the cost of accident prevention and worker protection.
2. *Construction contractor policies and procedures.* The estimated cost of safety and first aid related expenditures are in part dictated by the degree of voluntary prevention measures undertaken by the contractor. Safety training and worker awareness programs, as well as awards and prizes for safe behavior should be part of the estimate when applicable.
3. *Compliance with specific client/owner policies and procedures.* The estimator should insure that any unique client/owner safety requirements are adequately addressed in the estimate. Typical requirements may include enhanced use of periodic drug screenings, pre- and postemployment hearing tests, blood tests for the presence of toxic elements, use of on-site ambulance service, etc.

G. Field Office Furnishings, Supplies, and Communications

Estimation of costs categorized as field office furnishings, supplies, and communications typically is closely aligned with the number and types of *Field Supervision and Indirect Support Staff* required for the project (refer to checklist No. 2). The master *Checklist of Field Office Furnishings—Supplies and Communications*, as displayed in Table 6, identifies various items including office furnishings, personal computers, reproduction expenses, office consumables, etc.

Estimates for these categories of indirect costs may be derived (or verified) using historical cost ratios for projects of similar size and duration. Costs are typically estimated on an average cost per month basis.

Estimates addressing these items are directly affected by:

1. *Indirect and Overhead Staffing requirements*—including total peak project demand and expected durations of assignments of both contractor and client field staffs.
2. *Contractor policies regarding the purchase or ownership of office furnishings and equipment.* The estimate should reflect the optimum mix of purchase, lease, or rental of new or used office furnishings and equipment in keeping with established policies.
3. *Compliance with specific client/owner policies and procedures.* The estimator should insure that any unique client/owner requirements are ade-

Table 6 Checklist of Field Office Furnishings—Supplies and Communications (as typically associated with direct hire projects)

Office Furnishings
Typically includes the purchase, lease, or rental of desks, tables, chairs, filing and storage cabinets, drawing racks, etc.
Office Equipment
Typically includes the purchase, lease, or rental of photocopy equipment, fax machines, microfilm readers, portable radios, calculators, etc. Estimate should include allowances for maintenance contracts, repairs, excess copy charges, etc.
Personal Computers and Software
Typically includes purchase, lease, or rental of PCs and laptops. Estimated project costs may be in the form of fixed monthly charges from a corporate MIS department including provision of business software on a per PC basis.
Office Consumables
Typically includes purchase of standard office supplies, paper products, etc. May include optional bottled water and coffee supply services.
Communications
Typically includes postage, express mail services, monthly telephone charges, long distance charges, dedicated lease lines for computer links, portable telephones, satellite links for remote jobsite locations, etc.

quately addressed in the estimate. Typical requirements may include client purchase of selected office furnishings and equipment that will be continue to be required at the completion of the construction phase.
The estimate should also reflect client/owner preference to provide selected office supplies and services such as drawing reproduction as a means of quality assurance or cost savings.

H. Construction Consumables

Construction Consumables typically comprise a broad category of material items that lose their unique identity during the construction process. The master *Checklist of Construction Consumables*, as displayed in Table 7, represents only a partial listing of items that may be classified as construction consumables. A more comprehensive listing of construction consumable items should be developed for each type of construction project typically estimated. Estimates for construction consumable costs are most accurately derived using historical cost ratios for projects of similar size and duration (e.g., typically expressed as a percentage of direct labor). The total value of construction consumables typically represents a significant percentage of field indirect costs.

Table 7 Representative Checklist of Construction Consumables (as typically associated with direct hire projects)

Welding rods and gases
Lumber (for shoring, cribbing, weather protection, etc.)
Plastic sheeting and tarps (for weather protection, etc.)
Shims and grout
Caulking, tape, and patching compounds
Ice, cups, and coolers (for drinking water)
Spray paint and material tagging devices
Small hand tools (typically valued at under $*x.xx* per tool)
Saw blades, axes, and files
Flash lights, batteries, and light bulbs
Rope, slings, and cable
Fasteners (e.g., nails, screws, bolts, etc.)
Test materials (e.g., welding coupons, purging gases, etc.)
Cleaning supplies (e.g., rags, brooms, mops)
Lubricants and oil
Fuels: diesel and gasoline (note: may also be estimated and grouped with construction equipment cost categories)
Other construction consumables (as defined by the project team)

Table 8 Checklist of Insurance and Nonpayroll Taxes (as typically associated with direct hire projects)

Builder's Risk Insurance	Affords coverage against risks of physical damage to the facility being constructed as well as project equipment and materials in storage.
Liability Insurance	Affords coverage against liability for death or injury incurred by third parties as a result of acts committed by the insured.
Property Insurance	Affords coverage against physical damage or loss to contractor's own equipment and buildings (i.e., apart from the facility under construction).
Vehicle Insurance	Affords protection for loss/damage of covered vehicles as well as injury/loss to employees, passengers, and third parties.
Permits, Occupation, and Business Taxes	Fees or taxes paid to various government entities to secure authorization to undertake the construction work. Typically based on the total value of the project.
State Sales Tax	Normally calculated as a fixed percentage of material/equipment cost at time of purchase. Typically may be consolidated and paid under a corporate tax number as issued by individual states.

I. Insurance and Taxes, Statutory Payroll Burdens and Optional Benefits

The *Checklist of Insurance and Nonpayroll Taxes*, and *Checklist of Statutory Payroll Burdens and Optional Benefits* as displayed in Tables 8 and 9 respectively, reflect only the major elements applicable to this broad category of indirect costs. A more definitive master checklist should be developed by the estimator based on corporate policies as well as applicable state and local laws for individual project locations.

Estimates for these indirect cost categories should typically be initiated by obtaining up-to-date rate formulas from corporate tax and insurance specialists. Written citations should also be obtained from the appropriate federal, state, and local governmental agencies.

Table 9 Checklist of Statutory Payroll Burdens and Optional Benefits (as typically associated with direct hire projects)

Federal Social Security (FICA)
Employer's tax rate contribution and individual earnings cutoff point are established on an annual basis. Estimator should verify current percentages and earnings cap. Medicare component of FICA is exempted from any annual wage earnings cap.
Federal/State Unemployment Insurance (FUI/SUI)
Employer's tax rate contribution and individual earnings cutoff point, typically will vary depending on general level of state unemployment. Note: Individual contractors may be subject to retroactive SUI assessments imposed due to actual experience with employee claims over the life of the project.
Worker's Compensation Insurance
Employer's premiums are set by individual states based on individual contractor's record of WCI claims filed and the historical injury/death rate experienced for different types of crafts employed. Note: Individual contractors may be subject to retroactive WCI assessments imposed due to actual experience with employee claims over the life of the project.
*Optional Employee Benefits**
As set by corporate policies. Typically may include:
- Major medical (estimator should consider only the employer contributions)
- Group dental and eyesight policies
- Group life and/or disability coverage
- Employer paid retirement plan and/or contributions to 401k plans

Note: Actual benefits and corresponding estimates for self-imposed premium assessments may differ for "project duration" local hires versus so called "permanent hire" supervisory staff.

* All unionized craft benefit premiums are subject to national and local agreements as negotiated with individual unions.

The estimator should also obtain any necessary clarifications as to how each tax rate and benefit formula is to be applied (e.g., possible exclusion of overtime pay in calculations, cutoff limits on annual earnings per employee, applicability of rate formulas to salaried staff payrolls versus hourly craft wages, etc).

Care and judgment must be exercised by the estimator when applying various insurance, tax, and benefit formulas. Estimate impact considerations include the following variables:

1. Employee turnover within a single calendar year or premium reporting period
2. Project time-frames that span two or more calendar years
3. Threshold for meeting eligibility requirements as applied to optional employee benefits (e.g., 401k contributions, medical coverage, etc)
4. Client/owner option to provide "umbrella" insurance coverage
5. Possible project tax abatements as issued to encourage economic activity or to exempt materials exported to jobsites outside state or federal jurisdiction

Estimate adjustment factors for these types of multiple variables should be developed based on recent historical experience of similar projects and locations.

J. Miscellaneous Overhead and Indirect Costs

The *Checklist of Miscellaneous Overhead and Indirect Costs,* as displayed in Table 10, reflects indirect cost elements that, as a general rule, cannot be allocated to specific projects when first incurred. These overhead elements can best be defined as *the cost of operating a business.*

The internal methodology utilized to capture and allocate each of these overhead and indirect elements will vary from company to company. However, the cumulative costs are typically recovered against individual projects as either corporate overhead allocations or as project fee.

Typical cost recovery methods include applying a percentage markup to a project's direct hire labor services (e.g., engineering, design work, and/or field craft payrolls), or as a fixed percentage of total estimated project cost. Some firms also elect to markup other project specific support services such as reproduction, proprietary software programs, etc., as a supplemental means of corporate overhead recovery.

Project estimate methodology for recovery of these overhead costs should typically begin by obtaining current allocation requirements from corporate accounting and financial specialists charged with this responsibility of tracking these nonproject costs. The project estimator should also maintain a continuous dialogue with key management decision makers throughout the estimate development process regarding possible changes to overhead recov-

Table 10 Checklist of Miscellaneous Overhead and Indirect Costs

Major elements typically recovered as part of "Home Office Overhead"
Lease or mortgage payments for central office space
Home office furnishings
Home office utilities and telephone system
Vehicles and aircraft used by executives and home office staff
Salaries and payroll burdens for home office staff (e.g., administration and executives not directly billable to projects)
Home office equipment, PCs, office consumables, etc.
Purchased services: legal fees, auditors, insurance, etc.
Major elements typically recovered as part of "Project Fee"
Compensation for contractor's project management expertise and utilization of skilled resources.
Compensation for risks incurred during project execution.

Note: Fee typically can be categorized as *profit* only to the extent that there is a surplus amount after all direct project expenses and overhead allocations are paid.

ery strategies and application of project fee. The amount of project fee applied to the estimate typically will vary based on the:

Perceived degree of project risk
Number and types of skilled resources employed on the project
Current market conditions
Competitive nature of the project

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7
Productivity Analysis

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I. INTRODUCTION

Companies in the business world are constantly concerned with improving their "bottom line"—increasing their rate of return on investment, increasing the ratio of profit to revenues, or simply increasing total profit. Using programs with buzz-word titles such as *Productivity Improvement, Total Quality Management, Reengineering, Time-Based Competition, Horizontal Management, Down-Sizing,* and *Right-Sizing,* they reorganize, trim staffs, invest in training, automate, computerize, and otherwise do whatever is considered necessary to "optimize" or "maximize" the company's performance and beat the competition. But, whatever the name of the program, the goal is the same—spend less to make more money or spend less to provide the same or better service. For production-type activities, this translates into reducing worker and equipment hours per unit of output—i.e., improving productivity. For support and professional activities it means improving efficiency and overall performance. For all activities, it includes reducing waste of time, materials and equipment. Altogether it means improving the outcome of the total organization.

Numerical evaluation of total organizational performance is possible using the *Success Index* (SI). It could be called *Performance Index,* but doing so might cause it to be confused with the *Productivity Index (PI)* to be described and used later. Eq. 1 is the formula for the Success Index for a profit-oriented business. Eq. 2 is for a service organization, such as a government.

$$\text{Success Index} = \frac{\text{net profit}}{\text{total costs}} \tag{1}$$

$$\text{Success Index} = \frac{\text{value of services rendered}}{\text{costs of providing services}} \tag{2}$$

It should be noted that the Success Index is really an expression of organizational productivity because it relates a form of output (profit or value) to a form of input (cost).

To continue the discussion, the denominators of Eqs. 1 and 2 can be re-expressed as shown in Eqs. 3 and 4

$$\text{Success Index} = \frac{\text{net profit}}{\text{essential costs} + \text{cost of waste}} \tag{3}$$

$$\text{Success Index} = \frac{\text{value of services rendered}}{\text{essential costs} + \text{cost of waste}} \tag{4}$$

The denominators in both equations now divide total costs into two broad categories—essential costs and cost of waste. Essential costs are those personnel, material, equipment, tax, and other costs that would be incurred if the organization were efficiently organized and running perfectly. As for waste, these are major categories:

Inefficiencies inherent in the design and operation of the workplace
Individual inefficiencies
Noncontributing (wasted) time by individuals
Waste of materials, supplies, and services (misuse, overuse, loss)
Waste of equipment (abuse, misuse, loss)
Functions which no longer add value to the output of the organization

In the past, management tended to focus on productivity improvement as the key to reducing costs and/or improving the bottom line. That subject was and still is given significant attention in technical literature. This is to be expected since production activity can be readily measured, it can be expressed in hard numbers, its trends are easily noted, and it lends itself to detailed analysis and improvement studies. The problem is that there are many people and much equipment within a company performing functions whose effectiveness and contributions are not properly measured on the basis of output per unit of input. Personnel in this category include most support and professional staff—secretaries, design engineers, managers, etc. Equipment types include word processors, tower cranes, and administrative vehicles. True, there are outputs associated with many of these individuals and pieces of equipment, but productivity is not the basis for their selection. For example, a receptionist or a security guard must be present to handle whatever comes up; their performances would not be evaluated on the basis of quantity output. Similarly, a tower crane at a building construction site is selected on the basis of lifting capacity at various boom radii—one does not think in terms of tons per hour. There have been efforts to apply productivity measurement concepts to individuals in this category who do have products (e.g., secretaries and design engineers), but with little or no success. In fact, doing so may create stress and cause quality to be compromised as individual goals shift from quality to quantity production of the item designated for measurement (e.g., correspondence processed or drawings produced).

To expand on the above, within an organization's population are people who *produce* things and people who *perform* things. Most individuals do both to some degree. *Performance* may be associated with units of output but the real performance standard is something other than quantity (e.g., engineering drawing quality, ability to write or responsiveness in an emergency). Performance is evaluated subjectively (e.g., "above average" or "7 on a scale of 10").

One would like to assume that every organization seeks to do everything possible to promote performance and productivity. Unfortunately, the real-life situation tends to be as depicted in Figure 1. It shows that an individual has

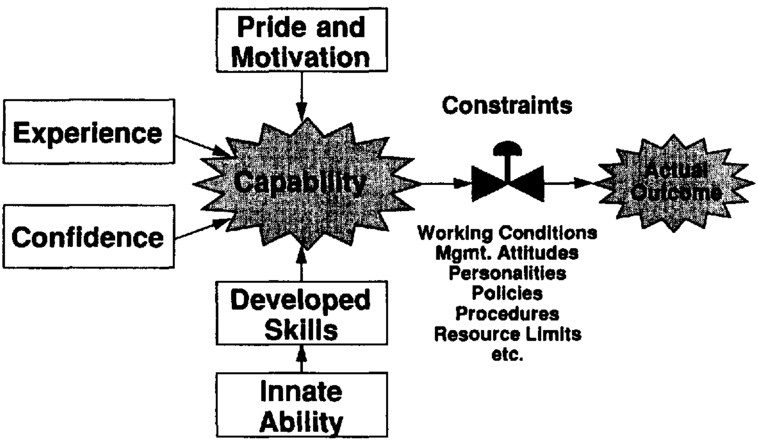

Figure 1 Performance expectancy model.

a basic capability resulting from many factors. What that individual can produce with that capability becomes restricted by organizational constraints.

What should an organization do? To borrow an expression from a U.S. Armed Forces recruiting commercial, the organization should do whatever is necessary to make each individual "the best that you can be." That is done by eliminating or minimizing conditions within an organization that limit performance and productivity and by creating conditions that promote them. Remaining sections of this chapter provide guidance for doing this. The first section will focus on the challenge of improving performance of a total organization. That will be followed by a discussion relating specifically to those personnel in the workforce involved in production activity. Finally, the role of incentives in performance and productivity management will be reviewed.

II. THE OVERALL PERFORMANCE ISSUE

A. The Challenge

An organization's Success Index will always be less than that potentially available if perfection had prevailed because human beings are involved and Murphy's Law has yet to be repealed ("If anything can go wrong, it will!"). Figure 2 illustrates how performance potential is lost through inefficiency and

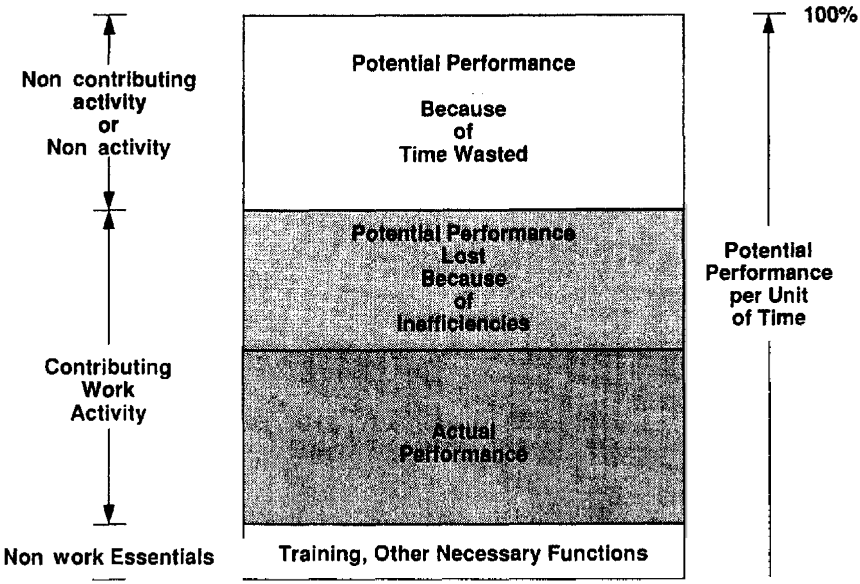

Figure 2 The performance problem.

waste. The goal must be to eliminate or minimize the factors contributing to that degradation.

B. Losses Through Inefficiency

Inefficiencies are both organizational and individual. Inconvenient positioning of office reproduction equipment, shortages of equipment or materials, lack of procedures, excessive management layering, and poor lighting are typical organizational inefficiencies. Failure to plan, refusing to use labor-saving equipment (such as a computer), and sloppy filing are typical individual inefficiencies. All of these translate into time loss and higher costs. The problem with inefficiencies is that the losses tend to be hidden—an observer watching an individual doing what appears to be contributing work may not realize that the work is being done very inefficiently.

C. Waste Through Interruptions

Everyone acknowledges that interruptions are disruptive, but interruptions are seldom treated as a subject area with significant potential for improving productivity and performance. Take the typical office situation shown in Figure 3 where an individual is trying to write a report. A series of interruptions in the form of telephone calls and visitors reduces the individual's average productivity significantly.

If something could be done to reduce these interruptions (e.g., electronic mailbox, visitor screening, providing better office privacy), the individual's

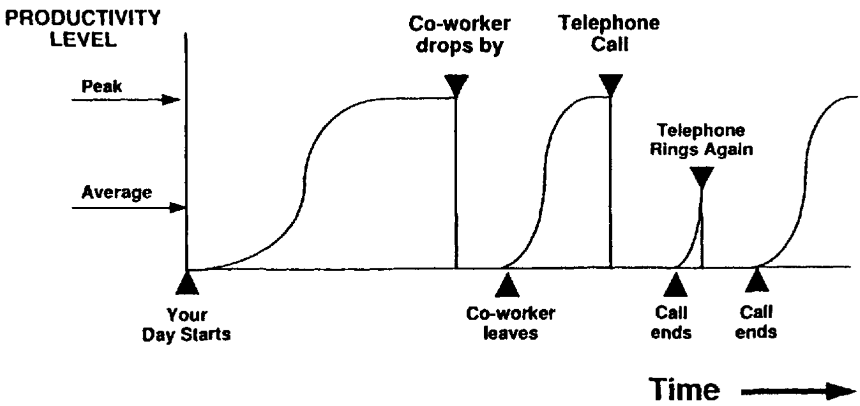

Figure 3 Impact of disturbances on performance. Office example—writing a report.

potential output would be improved. The lesson to be learned is simple: *Review work practices in an organization to determine where avoidable interruptions occur and then take corrective action.*

D. Other Time-Wasters

Interruptions are but one form of time-waster; there are many more. Here is a list of events or situations that are accepted parts of life in most organizations, but each causes interruptions and some result in wasted time.

Official meetings and appointments
Telephone calls
Personal breaks; lunch breaks
Official visitors
A need to interrupt current activity to make a copy of something, send a Fax, or coordinate with another worker
Fire drills; hazard alarms; other emergencies
Adverse weather
Power outages
Equipment breakdowns
Holds for quality checks or coordination
Absentees whose work must be absorbed by others
Turnover of key personnel—new ones must be brought up to speed
Higher headquarters or outside agency inspections, audits, and reviews
Secretaries/clerks delivering mail and messages
Noise and conversations from adjacent work areas
Unusual activity outside office windows
Running out of something—paper, staples, etc.
Misplacing something
Forgetting something

Certain actions or policies may minimize the disruption and time loss effect of some of the above items, but the potential is not significant.

The next list contains more events and situations which create time loss in an office setting. In this case, all have significant potential for elimination or reduction through better planning and management.

Unnecessary and unstructured meetings
People late for meetings
Social visits or greetings from passing fellow employees
Sales calls without appointments
Waiting for engineering and vendor information
Errors or omissions on engineering drawings
Lack of communication—somebody didn't "get the word"

Too many people or organizations involved in getting an answer, approval, or decision
Excessive time taken to make decisions, or approve/coordinate something
Too few support personnel available (e.g., clerical) so professional staff must perform own support
Inadequate support equipment (e.g., copy machines) causes waiting

In the case of construction field sites, these are controllable time-wasters,

Ill-defined scope forcing constant reworking of schedule
Contractual disputes
Labor disputes and adverse union activity
Arbitrary work rules
Personality problems among key personnel on owner, engineer, and contractor staffs
Late materials or installed equipment deliveries
Materials and equipment for installation that do not meet specifications or have fabrication errors
Materials and equipment that are allowed to deteriorate in storage so as to be unusable
Materials and equipment listed on warehouse inventory that cannot be found
Failure to pick up all needed materials the first time
Excessive distances between work areas and tool rooms, warehouses and laydown areas
Wrong or defective tools issued
Waiting for support equipment (e.g., crane)
Waiting for an approval to do something
Lack-of information or waiting for instructions
Issuing instructions after work has started
Waiting for other crews to get out of the way
Individuals that don't understand their roles or responsibilities and must always ask questions
Limited availability of a critical skill that must be shared among crews (e.g., "competent" person required by OSHA for certain operations)
Late start/early quits
Absentees—causing work that must be reorganized
Discipline problems
Permits (such as hot work permits) that are not available
Daily renewal of permits
Conflicts with operating plant personnel on revamp work
Operating personnel, having not been consulted during development of the project, who seek to make changes "on the fly"
Changes, both formal and constructive

Unexpected conditions that require work reorganization
Waiting for access or removal of lockouts
Over-inspections
Outdated policies or procedures that must be interpreted to fit current needs
Work that is started before being fully planned and without all resources needed
Safety incidents
Construction mistakes

Many actions can be taken to eliminate or minimize the time-wasters listed above. For many, the nature of the problem makes the solution obvious. However, to provide several ideas with respect to one major time-waster, consider the problem of meetings—too many, too big, too unstructured.

Some ideas that have worked for others to correct the situation are:

Prepare and implement a written policy or procedure for conduct of meetings. Train meeting sponsors on the policy.
Prepare and work from an agenda for all meetings. Establish a limit of time and start promptly.
Prepare minutes of minutes to include all decisions made, items remaining open, and actions assigned to individuals (with target dates for completion).
As an occasional attention-getter, require meeting sponsors to prepare a timesheet for each meeting which lists individuals attending, time spent, and their hourly billing rates (wages + fringes). The sponsor must extend and total the cost figures and submit the summary to his/her supervisor. This makes meeting sponsors think twice about scheduling questionable meetings, encourages them to better plan the meeting, and forces them to think in terms of benefits and costs.
For any individual late to a meeting, fine them $5 and put it in the coffee or flower fund.
Arrange the tables and chairs with respect to the entrance so that a latecomer cannot "sneak in." He/she must walk by the chairman and everyone else so that he/she will be embarrassed.
Schedule meetings at beginning of day, just before lunch, just after lunch or just before quitting time. Scheduling them in the middle of work half-days creates a major interruption.

E. Waste Through Rework

Rework is a special form of waste. One tends to apply the term only to redoing work because the work is flawed or changed. But, one will find countless other forms of rework going on within organizations every day when you use the more general definition of rework: *The repeating of an activity* *(and consequent expenditure of resources) with no value added to the final output.* Because activity during rework usually looks the same as when work is done the first time, it is easily overlooked as an area of waste with tremendous potential for reducing costs. Common examples of rework in an organization are:

Marketing Rework: Constantly looking for new work because the organization cannot attract significant repeat business.

Management/Supervision Layering: Maintaining excessive levels of supervision—a higher level essentially repeats the work of the lower level.

Materials Management: Double (or more) handling of materials before use.

Reorganizations: Reconfiguring an organization with no significant change in missions or workload.

Physical Relocations: Moving personnel and equipment to accommodate a new organizational structure or otherwise.

Lack of Electronic Data Links: Receiving data in hard copy and reentering it into another computer system instead of electronically Linking computer systems.

Computer Illiteracy: A manager or other professional staff member who is computer averse, still does everything long hand, and turns it over to a clerk for entry into a computer.

Excessive Administrative Review: Requiring excessive numbers of approvals on documents such as purchase orders or travel claims.

Failure to Provide Management Guidance: manager failing to provide guidance when tasks are assigned and then rejecting the output as not being what he/she was looking for.

Excessive Quality Control: Maintaining separate contractor and owner quality control operations on a project site.

Post-Production Engineering Review: Performing review of engineering deliverables after the deliverables have been fully drafted by the engineering staff. After being marked up, drawings must be redone.

Reinventing the Wheel: Failing to conduct post-project reviews to develop experience data and "lessons learned" that can be used in future planning.

Scope Revision During Detailed Engineering: Failing to completely define scope during conceptual engineering. Detailed designs must be reworked with each scope change. May create construction rework.

Claims: Expending significant resources in the pursuit of claims, particularly the research and reconstruction of records to find out "what really happened."

Estimating Formats: Developing an estimate against one format and then reconfiguring it for project control

Continual Hiring and Training of New Personnel: Experiencing high turnover because the organization is unable to retain trained personnel.

Misuse of Fax: Using a fax to transmit a copy of something that is also being transmitted in hard copy.

Not Invented Here: Refusing to acknowledge good ideas that have been demonstrated by others, and, as a matter of "hard-headedness," doing it another way.

Using Second Shift to Continue Work of First Shift: Passing work from one crew to another at a shift change results in lost time as the new shift determines the status of work in place. They also may redo some work.

Out-of-Date or Incorrect Specifications: Designing to out-of-date or incorrect specifications results in design rework and can create field rework or delays.

Resolution of Time-Card Discrepancies: Correcting time-card discrepancies because of wrong coding, wrong totaling, etc.

Untimely Input on Design: Introducing additional design requirements after design development is underway.

F. Promoting Performance

As one reads through the lists of time and cost wasters above, potential corrective actions are almost obvious. Thus, the first step in waste elimination or minimization is to acknowledge that these conditions exist. Through surveys or group discussion, lists of negative conditions can be identified. Usually the list will be too long to attack in total at one time, so the list should be narrowed down to those with greatest potential for improvement. Specific solutions can be generated through group problem-solving sessions using the various problem solving tools associated with Total Quality Management (TQM), such as flow charts, cause-and-effect diagrams, force-field analysis, and various statistical analyses. As problems from the original list are solved, return to the list, determine if others should be added, and select new targets for improvement. The result of these efforts will be continuous improvement, the ultimate goal of any TQM program. Of course, a proactive approach to promoting performance is always better than a reactive one. The following specific guidelines are appropriate:

Plan! Plan! Plan!—this is universal guidance for any operation.

Establish written policies and procedures—these become the standard references for how things are to be done.

Involve users and constructors in design decisions affecting them.

Control changes—changes degrade performance because they delay and demoralize.

Give priority to safety and quality—many claim that performance is directly related to quality and safety.

Control disturbances and interruptions—this should be an area of major emphasis.
Take advantage of modern technology—most productivity gains in the industrial world result from use of better technology.
Employ partnering and team-building—the team approach is always better.
Communicate—an essential element within a true team.
Involve employees in planning—this establishes their commitment.
Use employee group problem solving techniques—this makes them part of the solution.
Make work place a "good place to work"—this promotes employee loyalty and stability, and limits distractions and inefficiency.
Recognize employee achievements—let them know you appreciate their contributions; this will stimulate continued achievement (see later discussion of incentives).
Promote first-level quality control—this is the best way to minimize rework.
Train managers, supervisors, and workers—this promotes professionalism and consistency within the organization while also showing you care. One major industrial firm claims that they get $30 in benefits from every dollar spent on training.
Be selective in hiring—quality control of personnel cannot be overemphasized.

III. THE PRODUCTIVITY ISSUE

A. The Challenge

For any business involved in producing goods or providing services, the productivity of its production personnel and equipment directly influences that business' competitiveness and profitability. It follows that these businesses continually seek ways to improve their productivity. Usually, production is dependent upon some combination of machines and personnel so both must be examined when seeking productivity improvements. In some situations, a company's production potential is totally constrained by the machines being used—they can produce only so may items per unit of time. If so, the solution is to either add more machines or find higher output machines. If human beings are a factor in the rate of production, improving their productivity is more complex,

The construction industry has a somewhat unique challenge when it comes to productivity. It is a fact that a large percentage of construction work is awarded on a fixed-price, target-price or target-workhour basis. In this arena, competing contractors must base their bids or proposals on productivity assumptions for all crafts involved. Then, once the contract is awarded, the contractor has the challenge of meeting or beating the productivity assumptions in order to make a profit (or at least not lose money). With labor costs often being 40 percent or more of total installed cost and with profit margins in construction often being less than 5 percent, it is easy to see how errors in productivity estimation and management can ruin a contractor. Recognizing the particular challenges of the construction industry, the remaining discussion in this section will use it as the example.

A major point to be made and emphasized is that productivity on the same type of work varies significantly from project to project within a country and from country to country. That variation is caused by many factors which may be grouped as shown below.

B. Variability

Sociological (Area) Factors

Some variation in productivity can be attributed to differences in the sociological makeup of the local population, local work ethic, level of mechanization, education and training levels of workers, climate, the organized labor situation, and urban vs. rural factors. Recognizing this, most major construction contractors and some owners maintain proprietary data on area productivity differences to be used in their estimating of construction costs. Typically, they will select one area as the base and give it an index of 1.00. Other areas are given indices that relate their general productivity to the base area with indices less than 1.00 being less productive and those with indices greater than 1.00 being more productive. For example, these are extracts from an index register used at one time by one owner company:

Houston (base area)	1.00
Baton Rouge	0.85
Corpus Christi	1.10
Chicago	0.80
Denver	0.95

Internationally, the variation is even greater. The article, *International Labor Productivity,* in the January 1993 issue of AACE International's *Cost Engineering* magazine by J. K. Yates and Swagata Guhathakurta, provides relative productivity data for many countries. Its indices use a format that is the inverse of the above and it provides ranges for each country. Examples:

Washington, D.C. (base area)	1.00
Belgium	1.25–1.52*
Jamaica	1.49–3.05
China	2.60–4.50

* Interpretation: comparable work in Belgium will require 25–52% more work hours than in Washington, D.C.

Location Factors

As location varies, so do these factors:

Weather patterns	Traffic access to site
Altitude	Attitude of nearby communities
Access	Transportation network
Availability of skills	Local economy
Availability of logistical support	

Project and Contract Characteristics

No two projects or contracts are exactly alike. These differences definitely influence productivity potential:

Project size; single craft size	Form of contract
Schedule constraints	Budget constraints
Adequacy of scope definition	Quality of engineering
Constructability of design	Degree of congestion or confinement
Exposure to hazards	Relationship to existing facilities
Environmental requirements	Relationship to other construction
Height or depth of work	

Human Factors

The ultimate determinants of project performance are the humans doing the managing and building. Overall performance is a function of these human factors:

Management competence	Experience (point on learning curve)
Supervisor competence	Worker attitudes
Individual worker skills	Crew stability; key personnel turnover
Work rules	Owner/contractor relationships
Personal pride	Value system of the time
Stability of employment	Personalities
Overtime	

Field Organization and Management Factors

Finally, there are those factors which are most completely in the hands of management to control:

Site layout for construction	Materials availability and quality
Availability of support equipment	Tool availability and quality
Project controls system	Safety program
Quality management program	Adequacy of support facilities
Technology/methodology used	Degree of planning
Subcontractor performance	Vendor performance
Degree of communication	Control of interruptions
Crew balance	

C. Accounting for Variability in Estimates

Acknowledging that there are many variables which influence overall productivity on a project, contractors bidding on fixed-price or target-price work must somehow determine how these variables will interact to affect worker productivity. Ideally, a contractor will maintain historical data files containing actual productivity data from past projects. For this data to be useful on future projects, several criteria apply:

A standard chart of accounts for crew tasks must be used for all projects so that data from one project can be realistically compared to data from another.

The breakdown of crew tasks for purposes of estimating must be the same as that used for reporting so that estimated and actual performance can be truly compared.

In addition to the numerical data collected on each project, the conditions under which work was performed (e.g., weather, congestion, materials availability) should be described since those conditions affect the outcome.

When preparing bids for a new project, estimators will research the historical files to find productivity data on similar work performed under similar conditions. Unfortunately, such efforts usually prove to be only partially successful so available data must be adapted data to the new project. Fortunately there are some tools available to facilitate this process.

Range Estimating. Range estimating is a generic term applied to several commercial and company-developed computer programs which utilize a Monte Carlo statistical modeling technique to deal with events where the outcome can occur over a range represented by a frequency curve. It is particularly useful for evaluating the combined effect of multiple independent variables such as productivity. Chapter 12 provides details of this technique so it will not be discussed further here. The point to be made is that use of range estimating can reduce the risk associated with productivity variability on a number of different work tasks.

Checklists and Worksheets. Some individuals and companies have developed structured approaches in the form of checklists or worksheets to help them with productivity estimates. As an example, the Appendix to this chapter provides a description and sample of a *Productivity Index Evaluation Worksheet* developed by the author.

D. Promoting Productivity

To promote productivity on a project, managers must first be aware of the many factors that can affect it. These have been listed in previous paragraphs. During the premobilization stage and using these lists as checklists, managers can identify those factors with potential to adversely affect productivity. From this list, they can identify those factors that cannot be controlled, those that can be partially controlled, and those that can be completely controlled. It is then a matter of prioritizing the controllable factors and developing positive programs to eliminate or minimize the effects of these factors.

As implied in the previous paragraph, a proactive approach to promoting productivity will yield greatest return. If, during the course of a project, productivity is not what managers feel it should be, reactive action is required, but it will follow the same steps. Additionally, since productivity is but a subset of performance, the guidance contained in "Promoting Performance" paragraphs of "The Overall Performance Issue" section, above, is fully applicable to productivity management programs.

IV. PRODUCTIVITY ANALYSIS

A. Determining Percent Complete

The primary purpose of this section is to explain methods for measuring and analyzing productivity. However, use of these methods requires an understanding of methods for measuring percent complete of work activities so these will be described first. There are six methods:

Units completed. This method is suitable when the total scope of an activity consists of a number of equal or nearly equal parts and status is logically determined by counting parts completed and comparing that to the total number of parts in the total activity. Ideally, each unit is of relatively short duration. In engineering, a possible application is in the writing of a number of specifications of a given type where all specifications are considered to have essentially equal weight. In construction it finds use in activities such as earthwork, concrete work, and wire pulling.

Incremental Milestone. This method is appropriate for activities of significant duration which are composed of easily recognized, sequential subactivities. Percentage completion values are established based on the effort estimated to be required at each milestone point relative to the total for the activity. This method is ideal for control of engineering drawings and can be used in procurement. A typical example for drawing control is:

	Percent complete
Start drafting	0
Drawing is drawn, not checked	20
Drawing is complete for office check	35
Drawing is to owner for approval	70
First issue of drawing	90

Vessel installation and assembly is a classic example in construction. For example:

Vessel is received and inspected	15
Vessel setting complete	35
Vessel alignment complete	50
Internals are installed	75
Testing is complete	90
Vessel is accepted by owner	100

Start/Finish Percentages. This method is applicable to those activities that lack readily definable intermediate milestones and/or the effort required is very difficult to estimate. For these tasks, controllers credit 20–50% when the activity is started and 100% when it is finished. The reason that a percentage is assigned for starting is to compensate for the period between start and finish when no credit is being given. In engineering, this method is appropriate for work such as planning, designing, manual-writing, model-building, and studies. It can also be used for specification-writing. In construction it is appropriate in any situation where scheduling is detailed with multiple, short-term tasks.

Ratio. This method is applicable to tasks, such as project management, constructability studies, project controls, and comparable activities that involve a long period of time, have no particular end product, and are estimated and budgeted on a bulk allocation basis rather than on some measure of production. It can also be used on some tasks for which the Start/Finish method is appropriate. Percent complete at any point in time is found by dividing hours (or dollars) spent to date by the current estimate of hours (or dollars) at completion. This method finds use on any project where nonproduction accounts (such as overhead) must be statused individually and summarized with production accounts to determine overall percent complete.

Supervisor Opinion. This is a subjective evaluation of percent complete and should be used only where more discrete methods cannot be used. There is a natural tendency to overestimate the level of completion of an activity in its early stages.

Weighted or Equivalent Units. This method is applicable where the task is a major effort involving a long period of time and composed of two or more overlapping subtasks, each with a different unit of measurement (e.g., each, CY). To set this up all subtasks are listed along with their respective units of measure and quantities. The subtasks are then weighted using relative work-hours as weighting standards—the total of all weights equals 1.00 or 100%. The progress of each subtask is reported using one of the five measurement techniques described previously. When this percentage is multiplied by that subtask's weighting factor, its contribution to overall task completion

Table 1 Weighted or Equivalent Units Example for Structural Steel Erection

Weight	Subtask	U/M	Total quantity	Equivalent steel TN	Quantity to date	Earned tons
0.02	Run fdn bolts	each	200	10.4	200	10.4
0.02	Shim	%	100	10.4	100	10.4
0.05	Shakeout	%	100	26.0	100	26.0
0.06	Columns	each	84	31.2	74	27.5
0.10	Beams	each	859	52.0	0	0.0
0.11	Cross braces	each	837	57.2	0	0.0
0.20	Girts/sag rods	bay	38	104.0	0	0.0
0.09	Plumb & align	%	100	46.8	5	2.3
0.30	Connections	each	2977	156.0	74	3.9
0.05	Punchlist	%	100	26.0	0	0.0
1.00	STEEL	TON		520.0		80.5

Percent complete = Earned ton ÷ total tons
= 80.5 ton ÷ 520.0 ton = 15.5%

is calculated. Those for all subtasks are added to give the overall percent completion of the major activity. A classic example is concrete placement, which is frequently estimated and reported in terms of cubic yards in place; it can be broken up into the subtasks of base preparation, forming, reinforcing steel installation, concrete placement, curing, form stripping, and patching. Another example is steel erection which is traditionally estimated and controlled in terms of tons of steel (see Table 1).

Notice in this example how ton of steel is the account's unit of measure and all subtasks are converted to equivalent tons. It may also be noted that percent complete could have been calculated by this formula:

$$\text{Percent complete} = \sum [(\text{weight})\ (\text{percent complete each subtask})]$$

B. Productivity Measurement of Individual Work Tasks

Owners and contractors are always interested in comparing actual field productivity to that estimated and budgeted. When dealing with a single work activity, the calculation of productivity is very simple:

$$\text{Productivity} = \text{number of units completed} \div \text{work hours consumed}$$

What is more difficult is the calculation of productivity at a summary level or for an entire project.

C. Productivity Analysis at a Summary Level

While a comparison of earned to actual work-hours is used by some practitioners to provide an evaluation of productivity at a summary level, that approach is valid only if actual quantities of work are exactly equal to those budgeted. (Note: See Chapter 15 for a discussion of *earned value*.) This is not always true, particularly on fixed-price, lump-sum contracts, so another tool is needed to evaluate productivity. That tool is *Credit Work-Hours.*

Credit work-hours (CWH) are derived quantities and are found using this formula for work items completed:

CWH = budgeted unit rate × units completed to date

The budgeted unit rate = budgeted hours per *unit* of work. For individual work packages in progress (not yet complete), this formula is appropriate:

CWH = percent complete × budgeted unit rate

The Productivity Index (PI) for a single work package is found by this formula:

Productivity Index = CWH to date ÷ actual work hours to date

The Productivity Index (PI) for a combination of work packages or for a total project uses this formula:

$$\text{Productivity Index} = \sum \text{CWH} \div \sum \text{actual work hours}$$

The format of these equations is such that an index of less than 1.0 is unfavorable while one that is equal to or greater than 1.0 is favorable.

D. Use of Productivity Data

It is a waste of time to collect data that is not used for the benefit of the project or the company. Recalling that project estimates include productivity assumptions for the various work tasks, a very important use of actual performance data is to compare estimated with actual productivities. It is unlikely that estimated and actual productivities associated with a single work task will ever be exactly equal, but significant variations should be cause for concern—the difference may be attributable to a poor estimate and/or it may be attributable to field performance. In any event, significant variations should be investigated and the results shared with the estimators since their databases may need updating.

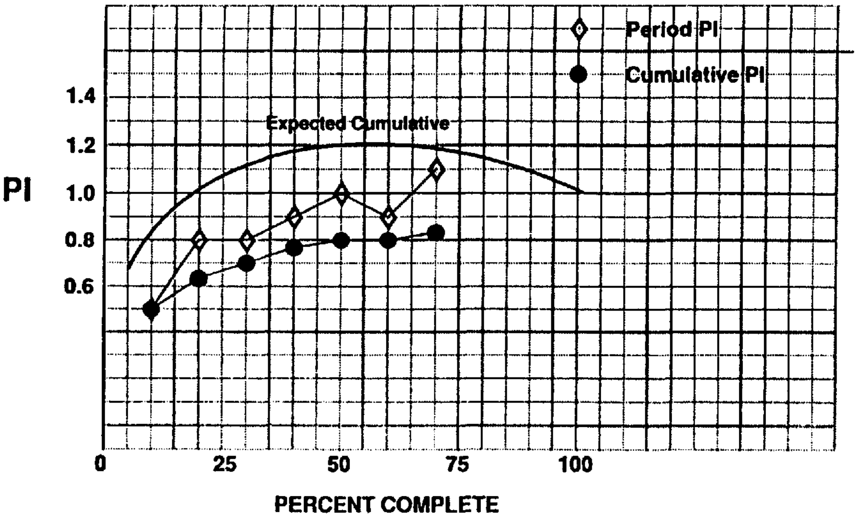

Figure 4 Productivity index: example plots.

Also, as illustrated in Figure 4, the Productivity Index for a given work task or the total project can be expected to vary as the work progresses. Figure 4 shows example plots of a Productivity Index on both a period and cumulative basis. A PI of 1.0 is the datum line and represents the estimated or budgeted productivity. Also shown is the "Expected Cumulative" plot. As drawn, that curve reflects the typical course of the cumulative PI over the life of an activity or total project—typically it runs below 1.0 during the early reporting periods, increases gradually to a peak of 1.15–1.20 about the are 50 percent complete point and then decreases, ideally becoming 1.0 at the 100 percent complete point. On this example, the actual cumulative PI has been running consistently below the expected cumulative curve meaning that, in spite of the fact that at some points the period PI was above 1.0, the cumulative PI will probably be less than 1.0 when the project or activity is complete.

V. INCENTIVES

A. Why Incentives?

Incentive programs must be included in any discussion of performance and productivity. Such programs have the potential to:

- Increase performance and productivity
- Reduce waste
- Reduce absenteeism
- Improve employee morale
- Promote teamwork
- Identify more cost-effective work procedures
- Improve equipment design
- Improve quality
- Share business risks and rewards with employees

In doing these, the profitability of the organization is certainly improved. But, increasing profitability is not the only potential benefit. Users have found incentive programs to be excellent tools for opening lines of communication between managers and employees and for committing employees to the goals of the organization.

B. The Stimuli

If incentives are intended to stimulate employees to support management goals, it is important that management understand the stimuli that can be mobilized. These may be grouped into two categories from the perspective of the employee:

Possibility of "winning"

- Excitement of winning something
- Personal satisfaction in achieving a goal
- Euphoria of being singled out for recognition
- Financial gain
- Career enhancement
- Pride of association with a winning team
- A chance to do something different

Fear of "losing"

- Potential embarrassment
- Potential loss of status, job, potential for promotion, etc.

Certainly the best incentive programs are based on the concept of "win-win;" i.e., both the employer and employee are potential winners. Those which capitalize on the employee's fear of losing are more fragile and can be counterproductive.

C. Rewards Within the "Winning" Scenario

Each incentive program in the "win" category has some reward associated with achievement of some objective. In designing incentive programs and incentive awards it is important to realize that rewards have two values—intrinsic and extrinsic. The intrinsic value is the exchange or cash value of the reward. The extrinsic value is that value above and beyond the cash value that accrues to the recipient because of what the award means to him or her—some might call this esteem value. It is essential that every reward have some value—it may have either or both intrinsic and extrinsic value, but it is not necessary that it have both. A medal for heroism and the Eagle badge in Scouting have little intrinsic value but tremendous extrinsic value to the awardees. If an employer gives a gold watch to every employee completing 25 years of service as an incentive to reduce turnover, that watch has considerable intrinsic value but minimal extrinsic value because the quality of an employee's performance during those 25 years is not a factor. Achievement of professional registration has high extrinsic value and can also have significant intrinsic value if it means a raise in pay or chance for promotion.

Rewards whose value is almost totally extrinsic are certainly the most cost effective. The fact that such rewards can also be effective stimuli puts incentive programs within reach of every employer. Specific examples of rewards in both categories will be incorporated within following discussion of specific programs.

D. Example Incentive Programs and Activities

The following summaries of programs or activities that have been or are being used successfully illustrate the range of incentive program options that may be considered.

Open-Book Management. This incentive program is really a revolutionary way of doing business and might be considered an advanced form of Total Quality Management. As the name suggests, the company's books, strategies, good news, and bad news are fully shared with employees, the theory being that employees will make better decisions and perform better if they know exactly how the company operates and what contributes to profits and losses. The incentive involved is a sharing of annual profits among employees (typically 25 percent) For this management form to work, the following conditions must prevail:

Management must be willing to openly share information with employees.
Employees must be trained in the basics of business.
Employees must be given all details in the life cycle in the production or goods or provision of services by the company so they can fully understand where there is potential for savings or losses.
Management must regularly and frequently communicate the current status of business to employees.

There must be an open-door policy for employee questions.
Employee suggestions and input into decision making must be encouraged.

The "Green Stamp" Program. Under this program employees earn credits (or "green stamps") for achievement of various objectives. Typical objectives are zero defects, no accidents, no late starts/early quits or no absenteeism during a given period; achievement of a production or productivity goal; approval of a suggestion; etc. The number of credits awarded are commensurate with the achievement. Credits are allowed to accumulate in the employee's account for conversion to gift certificates at his/her convenience. Each credit is usually worth $1. This program has several advantages: (1) the employee can pick the reward, (2) the accumulation feature stimulates continuing achievement, (3) it brings in the influence of an employee's family (they cheer the employee on) since awards can be significant and of the type the whole family chooses, and (4) it is open to all employees.

Suggestion Program. These programs have been around a long time. Employees make suggestions that are reviewed by selected committees for possible adoption. Adopted suggestions usually result in a cash award that is based on anticipated savings. If a suggestion is not adopted, or the benefits are other than cash savings, the reward is usually a letter of appreciation but may include some token merchandise item. Suggestion programs have enjoyed mixed success. A high rate of suggestion rejection or excessively complex and time-consuming submission and processing procedures can quickly dim employee enthusiasm.

Sharing Savings. On fixed-price or target-price contracts, an incentive program can be established whereby field personnel will share in any savings realized. These are usually distributed based on salaries or wages paid during the life of the contract. An interesting form of this has been used by an open shop contractor to keep fixed-price projects within budget. First, all budgeted direct costs within the control of construction crews were allocated to their individual work packages. Then, as crews completed the work, actual costs were accumulated. These costs included labor costs, materials costs, equipment and tool costs, costs of accidents, and any other costs attributable to the crew's assigned work. At well-defined milestone points in the project a tally was made of budgeted and actual costs in the covered period. Any savings were distributed totally to the workers, the distribution being proportional to worker hours or earnings during the period involved. There were no penalties for overruns—these are assumed to be a result of bad estimates and budgets. This program promotes teamwork and crew balancing, safety, conservation of materials and improved productivity, all while preserving company profit.

Target Bonuses. Often an owner will establish a target completion date or a target cost for a project knowing those targets can be met only with exceptional effort. To stimulate this effort, they will set aside a sum of money to be divided among the field personnel if the target is met.

Honoraria. These are given to individuals for specific achievements relating to professional development such as professional registration/certification, writing and publishing a professional paper, or representing the company in a professional forum.

Service Awards. These are usually a combination of a certificate and a merchandise prize to recognize years of service with a company. The value of the merchandise increases with length of service. Often, a special luncheon or dinner is held to distribute these awards.

Merit Raises or Bonuses. Salary raises and bonuses are often used to reward excellent performance. Bonuses are the preferred reward since they are a one-time expenditure and each year becomes a new year to excel, whereas a salary increase is an expense that continues into subsequent years and quickly loses its luster.

Cross-Training. An employer who provides cross-training for workers provides a measure of job security for those workers and this is motivating for the employees.

Special Training. If a limited number of individuals are selected each year for some special training, competition for selection becomes a strong motivator for excellent performance.

Many successful incentive programs capitalize on the extrinsic value of the rewards involved and, in so doing, achieve results at low cost. Examples:

The Simple "Atta Boy!" A simple pat on the back or word of appreciation, particularly when given in front of everyone in a work unit, can do wonders to motivate many people.

Management by Walking Around. It is good management practice to maintain visibility with employees through frequent visits to work areas during which they chat with employees. By showing sincere interest in the individuals and their work, a manager effectively motivates employees.

Letters or Certificates of Appreciation and Achievement. A document which commends an individual for an accomplishment has high, long-term value since it is written proof of special capability and may be the document needed in some future job search.

Certificates of Completion. These recognize completion of some training program. They have significant value only if the participants in the program had to pass some meaningful test to graduate.

Decals. These are usually used in conjunction with other awards. For example, someone completing a First Aid or CPR course would receive both a Certificate of Completion and a decal to put on his/her hard hat.

Token Awards. Awards in this category include inexpensive items such as T-shirts, coffee cups, baseball caps, calculators, and pen knives. These are appropriate for minor achievements by an individual or crew such as short-term safety, quality, or attendance records. Slightly higher cost items, such as a windbreaker jacket, engraved desk sets, and clocks are suitable for more significant achievements, such as long-term safety or quality records.

"Exclusive Clubs" on the Job. Individuals take pride in being part of a group whose membership is exclusive. For example, a group of earth-movers had a "Million Yard Club" on their project. Production, safety, and quality goals can be set to qualify for membership in comparable clubs. Achievement of membership in the club is recognized through certificates, decals on the hard hat, T-shirts, bumper stickers, etc.

Employee or Crew of Month. This program is very common in the service industry. A committee selects the recipients based on recommendations from managers, customer comment forms, or other criteria. The reward is usually a picture of the individual or crew displayed in a prominent location plus a certificate. It can include a cash award or special luncheon/dinner. This program must be carefully managed so it does not degenerate into a popularity contest or "Who's turn is it this month?" form of selection.

Problem Solving Teams. These are similar to quality circles except they are ad hoc and are given a specific problem to solve by management. Their work can result in cash or credit awards; however, a letter of appreciation or commendation may be adequate. These teams are motivators since they are another form of participative management.

Team Builders. There are a number of relatively inexpensive actions that can be taken to stimulate group morale and team spirit (and thus productivity and quality) on a project or in other workplaces. Examples are:

Creating a project logo and using this logo on signage, hard hat decals, bumper stickers, stationery, etc. It is recommended that a project-wide contest be held to design the logo.

Publish a newsletter. Have a contest to name the newsletter.

Use the newsletter or bulletin boards for publication of "Hats Off" type notices to recognize accomplishments of individuals.

Occasionally put out coffee for workers as they check in for work or cool beverages as they leave work on a hot day.

Have the project photographer take pictures of individuals and crews on the job. Display these pictures on a bulletin board near check in area. Make copies available to pictured individuals.

An alternate to the above is to provide video coverage of the project with the product being a weekly tape of about 15–30 minutes in length. On this tape review project status, show crews at work, etc. Show the tape during lunch in protected break areas.

Use a special message board in a prominent location on which project status is displayed, special accomplishments are announced, and human interest stories told about project participants.

Sponsor charity work by the workers—food and toy drives, painting or repairing homes for needy, building playgrounds, etc.

When a major project milestone is reached, allow an extra hour for lunch and have a catered lunch for the workers. Use opportunity to give out safety and other awards.

Sponsor "family day" at the project, plant or nearby park with a picnic lunch, tours of project/plant and games.

Put first names of workers on their hard hats

Sponsor bowling, softball, and other teams in local leagues.

Issue press releases on project and employee accomplishments.

Recognize birthdays or other events with a congratulatory letter.

Do whatever you can to provide job security for employees—cross-training, information on upcoming jobs, outplacement service, etc.

If the project receives some cash award for safety or other achievement, divide the award up into $50 packages and give them away in a raffle. All workers who contributed to the achievement are included in the drawing.

Do anything to make site "a good place to work"—e.g., strong safety program, decent worker facilities, good layout, dust control, etc.

E. Incentive Program Guidelines

In analyzing the many individual and team incentive programs that have enjoyed success, a number of guidelines evolve.

Learn from the experiences of others.

Program must balance both employer and employee goals.

Get work force into the planning of program if possible. If union personnel are involved, the union *must* be included.

Keep each program element as simple as possible.

Criteria for awards must be specific and understandable.
Performance criteria must be achievable.
Successful achievement of goals must be within control of target individual or group.
Programs based on subjective criteria are more difficult to manage impartially.
The program will be most effective if the awards resulting from an accomplishment directly accrue to the individual or team making the accomplishment.
Mobilize as many of the stimuli as possible in establishing reward structure.
Avoid any potential for discrimination in determining award recipients.
Make certain the program is well publicized.
Publicize achievements by individuals and teams.
Insure that the program is well-managed.
Incorporate potential for many winners.
Provide opportunities for the entire work force.
Don't turn off nonwinners—"maybe next time."
What works in one environment won't necessarily work in another. An example can be cited where a contractor used preferential parking as a reward and the program was very successful. Another contractor tried it and the rewarded workers found their tires slashed.
Be aware of tax implications of awards. Merchandise awards of nominal value (e.g., turkeys, coffee cups, etc.) are not taxable. Cash awards or awards equivalent to cash (e.g., gift certificates) or costly merchandise awards (e.g., TV, pickup truck) are taxable.
Proceed with caution when launching an incentive program. Start small and work up to more ambitious programs which build on the success of early programs. A failed incentive program can have strong negative effects.

F. Concluding Remarks

Incentive programs have established a place in the business world. A variety of programs already have proven successful. Companies can learn from these programs and design adaptations of them to fit their particular environments.

Experience with incentive programs suggests that the benefit to cost ratio is in the range of 4:1 to 10:1. Whatever the ratio, results have shown that well-managed incentive programs can very positively influence teamwork, safety, quality, and overall performance.

VI. SUMMARY

The ultimate performance index for an organization is the one that relates its net profit or value of services to the costs of achieving that profit or providing those services. An organization seeking to maximize that index must examine the operations of its total work force, not just those of its production units. It must target waste in all forms—not only materials or equipment waste, but the waste associated with inefficiencies, interruptions, rework, and an assortment of other time-wasters, all which effectively constrain their employees' ability to produce, perform, and achieve. And, most of all, that organization must provide a workplace with the facilities, procedures, atmosphere and attitudes which stimulate performance.

VII. APPENDIX: PRODUCTIVITY INDEX EVALUATION WORKSHEET

A. Purpose

This worksheet (Table 2) is intended to facilitate a comparison of productivity potential of a proposed project with respect to a completed project. For this purpose, a Productivity Index of 1.0 is average, a PI less than 1.0 is less than average (unfavorable), and a PI greater than 1.0 is better than average (favorable).

Evaluating productivity variation among projects is not an exact science. This worksheet serves only to force planners to seriously consider many conditions that can affect productivity and to evaluate their individual effects as well as their cumulative effect. The productivity elements and the weighting factors used are not fixed—users should adjust them to reflect experience over time.

B. Use of Worksheet

1. For a reference (completed) project, complete an evaluation of each of the 7 categories of Productivity Elements. This is best done by several individuals familiar with the project so that the result represents group consensus. Note that each category is made up of 2 or more subcategories so that evaluations can be made at the subcategory level to yield the category score. For example, note that the first category, General Area Economy, has three subelements. Assume that the group makes the following analysis of a completed project:

a. Construction volume in the area at the time of the project was somewhat low compared to previous years when several major plants were built. Now, most construction activity involves homes and small commercial projects. This subcategory is given an index of 110.

b. The unemployment rate in the area was about average for the state, but better than the national average. There were jobs available, but most were of the minimum wage category. This subcategory is given an index of 100.

Table 2 Productivity Index Evaluation Worksheet

Productivity element	Weight	75–99 low	100 average	101–125 high	Score Product
1.	General area economy	10	Prosperous	Normal	Depressed
	Construction volume in area	4	High	Average	Low
	Unemployment situation	4	Low	Average	High
	Local business situation	2	Stimulated	Normal	Dead
2.	Project character	25	Complex	Average	Favorable
	Schedule	6	Compressed	Normal	Ample slack
	Complexity of work	6	Complex	Average	Simple
	Contract form	5	Reimbursable	Fixed-price	Incentive
	Project type	5	Revamp	New work	Repeat work
	Size	3	Mega	Average	Small
3.	Craft workers and foremen	25	Poor	Average	Good
	Quality and availability	8	Poor	Average	Excellent
	Distance to project	5	More than 60 min	30-60 min	Less than 30 min
	Substance abuse program	5	None	Policy only	Full program
	Use of overtime and multiple shifts	4	Much	Some	Exception
	Rate of force build-tip	3	Fast	Comfortable	(Not used)
4.	Project operating conditions	20	Poor	Average	Good

	Congestion and hazards	6	Considerable	Average	Little
	Management quality	6	Inexperienced	Average	Highly qualified
	Materials and tools availability	3	Shortages	Average	Adequate
	Required workmanship	3	Exceptional	Normal	(Not used)
	Site access	2	Restricted	Normal	Open
5.	Weather	10	Poor	Average	Good
	Amount of protected work	2	Limited	Normal	Significant
	Precipitation days	2	Frequent	Normal	Occasional
	Cold and wind days	2	Often	Average	Rare
	Days of extreme heat	2	Many	Average	Rare
	Days of extreme humidity	2	Many	Average	Rare
6.	Construction equipment	5	Poor	Average	Good
	Condition	3	Poor	Average	Excellent
	Maintenance/repair availability	2	Remote	Nearby	On site
7.	Delays and interruptions	35	Numerous	Some	Minimum
	Rate of changes expected	10	High	Normal	Low
	Materials deliveries	6	Uncertain	Normal	Timely
	Operating planVother interferences	6	Frequent	A few	None possible
	Site work permits	6	Frequent	Occasional	Not applicable
	Labor unrest potential	5	Could happen	None expected	(Not used)
	Public protest potential	2	Could happen	None expected	(Not used)
Totals		130			

Productivity index = $\left(\sum \text{product} \right) \div 13.000 =$ __________

c. The local business situation was basically healthy, neither robust or depressed. This subcategory is given an index of 100.

d. The resultant score for Category 1, General Area Economy, is:

$$110 \times 4 = 440$$
$$100 \times 4 = 400$$
$$100 \times 2 = 200$$
$$1040 \div 10 = 104$$

2. Continue the evaluation of the remaining categories to develop the score for the completed project.
3. Make a similar evaluation for the proposed project. Then compare the scores to determine a multiplying factor to use in estimating productivities on the new project using productivities for similar work on the completed project as a reference.

Productivity multiplying factor for proposed project =
PI proposed project ÷ PI completed project

4. The above does not consider regional differences in general work force productivity due to sociological and other differences among worker populations. If planners believe such differences exist, they must further modify the multiplier obtain in paragraph 3 by multiplying it by a factor found by dividing the Area Productivity Index of the Proposed Project by the Area Productivity Index of the reference project.
5. Use the resultant productivity multiplier in conjunction with relative wage rates to determine relative labor costs for the same volume of work.
6. This worksheet can also be used to "normalize" data from past projects for entry into the historical database. Since the raw data from each project is distorted because of numerous project-unique conditions, normalizing it has the effect of bringing the data down to a baseline not affected by those conditions.

8

Cash Flow Analysis

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I. INTRODUCTION

This chapter will outline the information needed to develop the cash flow profile for a typical design and construction project. It will cover the self perform and construction management approaches for these projects, and will show how to define and classify project costs for preparation of a typical cash flow. Analysis of historical data from completed projects will be used to show how to develop cash flows for new projects. This chapter will discuss the necessity for cash flow management for a typical construction project.

II. WHAT IS CASH FLOW?

Cash flow can be defined as the schedule of payments over a time period that an owner has to make in order to build a typical project. Cash flow is strongly influenced by the type of contract used.

It is possible to make one lump sum payment to a contractor upon final acceptance of the project by the owner. However, this cash flow method causes the contract price to be higher than other cash flow methods, since the contractor has to finance the project until acceptance and final payment is made. These finance costs will be included in the contract price. Lump Sum contracts with more favorable cash payment terms will save money because the contractor does not have to finance the project over the full project time frame.

Cost reimbursable contracts involve almost no finance costs because the owner reimburses the contractor for his costs as they occur. However, some owners desire lump sum contracts because they want the contractor to share the risk of the overall project cost.

Each of these contracting techniques will produce a different cash flow curve. A Cost Reimbursable contract will produce a cash flow based on payments as they come due and are billed by the contractor within a short period of time from the actual cost payment for materials and labor on the project. Lump sum projects require the contractor to incur cost for materials for which he may not get reimbursed until the materials are installed or until a mutually agreed milestone has been accomplished. The contractor will probably charge the finance cost until he gets reimbursed.

III. CLASSIFICATION OF COSTS

Construction project costs cover a wide range from materials and labor to the indirect costs of construction. Direct costs include the following items: site preparation, concrete, steel, architectural, process equipment, piping, instrumentation, and electrical. Indirect costs includes the following: home office, field office supervision, temporary construction, tools and consumable, con-

Table 1 Typical Construction Estimate Items of Direct Cost by Process Area

Description	Labor cost ($)	Material cost ($)	Process equipment cost ($)	Subcontract cost ($)	Total cost ($)
Site preparation	8,240	2,463	0	228,900	239,603
Concrete	12,682	26,487	0	0	39,169
Steel	9,461	32,890	0	0	42,351
Architectural	6,658	45,713	0	238,921	291,292
Process equipment	24,897	42,000	1,256,000	425,931	1,748,828
Piping	159,357	246,789	0	60,340	466,486
Instrumentation	6,248	62,129	452,369	0	520,746
Electrical	124,892	445,000	624,987	0	1,194,879
Total direct cost	352,435	903,471	2,333,356	954,092	4,543,354

Table 2 Typical Construction Estimate Summary Items of Construction Indirect Cost

Description	Labor cost ($)	Material cost ($)	Process equipment cost ($)	Subcontract cost ($)	Total cost ($)
Contractor indirects					
Home office costs	40,000	22,000			62,000
Field office management costs	80,000	20,000			100,000
Temporary construction	100,000	60,000		28,000	188,000
Small tools and consumables	4,000	28,000			32,000
Construction equipment		60,000			60,000
Field office supplies		41,000			41,000
Insurance and payroll taxes		1,100,000			1,100,000
Labor burdens and benefits		80,000			80,000
Miscellaneous costs	10,000	40,000			50,000
Total indirect costs	234,000	1,451,000	0	28,000	1,713,000
Engineering	87,000	13,000			100,000

struction equipment, insurance, payroll taxes and benefits, insurance and bonds, etc. When developing a cash flow curve for a new project, one needs to be very aware of the classification of costs for a project. These costs may and most likely will occur at different intervals in the construction time frame and will most likely be expended at varying rates of cash flow. A typical construction project estimate direct cost summary sheet is shown in Table 1. These estimate summary sheets should be prepared for each process area in a facility as well as a summary for all areas. A typical estimate summary for the indirect cost for a typical construction project is shown in Table 2.

IV. TYPES OF CONSTRUCTION COSTS

A typical construction project will have types of costs, including: material, labor, subcontract, and process equipment. Each of these costs affects the cash flow because of the time frame in which they occur. Understanding the types of costs associated with the contract is necessary to prepare a good overall cash flow curve.

The type of cost and cash flow will vary with construction method. When the construction is performed on Cost Reimbursable contract most of the work will be performed by a general contractor who will subcontract any specialty work. The subcontracted work may include such items as site preparation, railroads, field erected tanks, tile chests, engineered process systems, glass and glazing, sprinklers, or finish carpentry work. The general contractor usually will perform such items as concrete, steel, process equipment, piping, instrumentation, and electrical.

When the construction method of constructing a project is lump sum, the owner may act as his own construction manager or may hire a general contractor to act as construction manager. The construction manager will choose the number of subcontracts from two options. One option is to bid large subcontracts for such items as civil, mechanical, electrical and instruments as well as the specialty subcontracts. The second option is to bid numerous small subcontracts based on the amount of design drawings available for bid preparation. Each of these contracting options will produce different cash flows. The general contractor self perform approach and the construction management approach using a few large subcontractors will produce a longer, smoother cash-flow curve. The cash-flow curve for a project using multiple subcontractors will likely have peaks and valleys because of the start and completion of subcontractors performing relatively small parts of the work.

V. USING HISTORICAL DATA TO DEVELOP A CASH FLOW ANALYSIS

Historical cash flow data is very valuable. After actual cash flows from a number of completed projects have been analyzed, a distinct pattern will develop depending on the type of project. For instance, a cash flow for a refinery project will be different from a power plant, and a chemical plant cash flow will not be similar to a metal or mining project. Cash flows for dams, highways, and bridges will be distinctly different from commercial projects such as high rise construction and shopping centers. In all cases, the historical cash flow data is analyzed on the basis of percent of cost expended versus the percent of time expended. A typical historical cash flow analysis for the total construction project is shown in Table 3. This cash flow covers direct cost for a direct hire construction project with subcontracting of specialty items and construction materials, and does not include process equipment or engineering costs. A historical cash flow analysis for direct labor, material, subcontracts are shown in Table 4. After a historical cash flow analysis has been prepared, comparisons should be analyzed from the percent of time versus the percent of cost expended. Table 4 is an example of this comparison. In this example, the time milestones in increments of 10% are compared to the percent of cost expended. After the historical cash flows for a number of similar projects have been analyzed, cash flow trends will develop. These trends will not be consistent, but will usually fall within a plus or minus 3% range for a cash flow milestone. In order to use this historical data for future projects with different time spans, interpolation can be used to fill in the cash flow time points between the milestone time points. The cash flow data can be developed for projects with slightly longer or shorter time periods. However, the cash flow milestones for a 27- or 28 month project should not be interpolated for the cash flow milestones for a 10- or 12 month project. Cash flow analysis is not an exact science and historical data from similar length jobs should be used.

The information shown in Tables 3 and 4 represent the cash flow analysis of a project's direct costs as described in the classification of costs section. The same analysis can be applied to a project's indirect costs and are shown in Tables 5 and 6. Normally, it could be assumed that indirect costs are a function of labor because so much of the indirect cost is related to labor such as insurance, payroll taxes, construction equipment and tools, and temporary construction. However, this is not always true because the analysis in Table 7 shows a slightly different perspective. Direct labor cost cannot be expended on the project until the temporary infrastructure has been erected and the construction materials received on site to begin work. The percent of indirect costs proceeds at a faster pace than direct cost because of the contractor's home office costs, which are expended to expedite the project startup, plus the procurement of construction materials and subcontracts to begin work on the project. When the comparison of the percent of cost expended for direct labor, material, subcontract, and total direct cost versus the indirect cost is analyzed, it is apparent that the indirect cost cash flow is not a function of direct labor cost but is based on the purchase of construction materials and subcontracts as well as the initial expenditure of indirect cost to establish the temporary facilities for the project. Table 7 shows the comparison of direct labor, material, subcontract, total direct and indirect cost expended versus the percent of time expended. An analysis of these cost items that are shown in Figure 1, demonstrates that all the cost items tend to approach 70% of cost expenditures in the area of 70% of time expended except for labor which approaches 80% of cost expended at the 80% of time expended benchmark. Figure 2 tends to show that the incremental increases for all cost items tends to peak at the 60% of time expended mark.

VI. CASH FLOW ANALYSIS OF A ENGINEERING, PROCUREMENT, AND CONSTRUCTION PROJECT

Tables 8 and 9 analyze the cash flow data of a typical Engineering, Procurement and Construction project. Table 10 analyzes the Engineering design hours expended for the same project. Table 11 analyzes all the cost items as percentages of cost expended versus the percentages of time expended. When

(text continues on p. 237)

Table 3 Historical Analysis of Total Construction Cost Cash Flow

Month No.	Labor cost ($)	Material cost ($)	Subcontract cost ($)	Total cost ($)	Percent of time	Cummulative percent of cost	Incremental percent of cost
1	0	125,994	0	125,994	3.33%	0.04%	0.04%
2	0	781,694	18,073	799,767	6.67%	0.23%	0.19%
3	120,705	1,553,927	134,275	1,808,907	10.00%	0.51%	0.29%
4	257,096	2,626,156	514,904	3,398,156	13.33%	0.96%	0.45%
5	945,089	3,909,924	963,565	5,818,578	16.67%	1.65%	0.69%
6	1,746,956	6,255,753	1,483,162	9,485,871	20.00%	2.69%	1.04%
7	2,928,775	9,057,752	2,031,717	14,018,244	23.33%	3.97%	1.28%
8	4,494,632	12,152,906	2,656,596	19,304,134	26.67%	5.47%	1.50%
9	6,804,111	16,609,963	3,358,157	26,772,231	30.00%	7.59%	2.12%
10	9,595,085	21,207,749	4,204,036	35,006,870	33.33%	9.92%	2.33%
11	12,997,561	26,144,494	5,296,325	44,438,380	36.67%	12.59%	2.67%
12	16,488,965	32,090,032	6,504,689	55,083,686	40.00%	15.61%	3.02%
13	21,492,064	41,960,566	8,001,587	71,454,217	43.33%	20.25%	4.64%

14	26,671,228	53,109,148	10,217,110	89,997,486	46.67%	25.51%	5.26%
15	32,386,784	66,141,904	12,519,923	111,048,611	50.00%	31.47%	5.97%
16	41,694,495	78,674,620	14,958,071	135,327,186	53.33%	38.35%	6.88%
17	52,178,378	90,352,734	17,919,205	160,450,317	56.67%	45.48%	7.12%
18	62,470,569	100,866,782	20,334,683	183,672,034	60.00%	52.06%	6.58%
19	72,643,015	110,050,756	22,575,202	205,268,973	63.33%	58.18%	6.12%
20	81,809,608	118,784,155	24,297,200	224,890,963	66.67%	63.74%	5.56%
21	90,518,497	127,306,253	25,745,727	243,570,477	70.00%	69.03%	5.29%
22	98,443,003	135,300,011	26,765,834	260,508,848	73.33%	73.83%	4.80%
23	105,344,476	142,725,521	27,687,271	275,757,268	76.67%	78.16%	4.32%
24	111,806,388	149,809,473	28,579,159	290,195,020	80.00%	82.25%	4.09%
25	118,212,638	156,475,473	29,357,819	304,045,930	83.33%	86.17%	3.93%
26	124,486,388	162,995,955	30,071,743	317,554,086	86.67%	90.00%	3.83%
27	130,215,708	169,010,355	30,754,860	329,980,923	90.00%	93.52%	3.52%
28	135,330,371	174,642,555	31,446,418	341,419,344	93.33%	96.77%	3.24%
29	139,113,628	178,984,257	32,092,741	350,190,626	96.67%	99.25%	2.49%
30	139,812,588	179,567,486	33,448,229	352,828,303	100.00%	100.00%	0.75%

Note: Does not include process equipment or engineering costs.

Table 4 Historical Analysis of Total Constructon Cost Cash Flow

Month No.	Percent of time	Percent labor cost	Incremental labor percent	Percent material cost	Incremental material percent	Percent subcontract cost	Incremental subcontract percent	Percent total of cost
1	3.3333%	0.00%	0.00%	0.07%	0.07%	0.00%	0.00%	0.04%
2	6.6667%	0.00%	0.00%	0.44%	0.37%	0.05%	0.05%	0.23%
3	10.0000%	0.09%	0.09%	0.87%	0.43%	0.40%	0.35%	0.51%
4	13.3333%	0.18%	0.10%	1.46%	0.60%	1.54%	1.14%	0.96%
5	16.6667%	0.68%	0.49%	2.18%	0.71%	2.88%	1.34%	1.65%
6	20.0000%	1.25%	0.57%	3.48%	1.31%	4.43%	1.55%	2.69%
7	23.3333%	2.09%	0.85%	5.04%	1.56%	6.07%	1.64%	3.97%
8	26.6667%	3.21%	1.12%	6.77%	1.72%	7.94%	1.87%	5.47%
9	30.0000%	4.87%	1.65%	9.25%	2.48%	10.04%	2.10%	7.59%
10	33.3333%	6.86%	2.00%	11.81%	2.56%	12.57%	2.53%	9.92%
11	36.6667%	9.30%	2.43%	14.56%	2.75%	15.83%	3.27%	12.59%
12	40.0000%	11.79%	2.50%	17.87%	3.31%	19.45%	3.61%	15.61%

13	43.3333%	15.37%	3.58%	23.37%	5.50%	23.92%	4.48%	20.25%
14	46.6667%	19.08%	3.70%	29.58%	6.21%	30.55%	6.62%	25.51%
15	50.0000%	23.16%	4.09%	36.83%	7.26%	37.43%	6.88%	31.47%
16	53.3333%	29.82%	6.66%	43.81%	6.98%	44.72%	7.29%	38.35%
17	56.6667%	37.32%	7.50%	50.32%	6.50%	53.57%	8.85%	45.48%
18	60.0000%	44.68%	7.36%	56.17%	5.86%	60.79%	7.22%	52.06%
19	63.3333%	51.96%	7.28%	61.29%	5.11%	67.49%	6.70%	58.18%
20	66.6667%	58.51%	6.56%	66.15%	4.86%	72.64%	5.15%	63.74%
21	70.0000%	64.74%	6.23%	70.90%	4.75%	76.97%	4.33%	69.03%
22	73.3333%	70.41%	5.67%	75.35%	4.45%	80.02%	3.05%	73.83%
23	76.6667%	75.35%	4.94%	79.48%	4.14%	82.78%	2.75%	78.16%
24	80.0000%	79.97%	4.62%	83.43%	3.95%	85.44%	2.67%	82.25%
25	83.3333%	84.55%	4.58%	87.14%	3.71%	87.77%	2.33%	86.17%
26	86.6667%	89.04%	4.49%	90.77%	3.63%	89.91%	2.13%	90.00%
27	90.0000%	93.14%	4.10%	94.12%	3.35%	91.95%	2.04%	93.52%
28	93.3333%	96.79%	3.66%	97.26%	3.14%	94.02%	2.07%	96.77%
29	96.6667%	99.50%	2.71%	99.68%	2.42%	95.95%	1.93%	99.25%
30	100.0000%	100.00%	0.50%	100.00%	0.32%	100.00%	4.05%	100.00%

Note: Does not include process equipment or engineering cost.

Table 5 Historical Analysis for Indirect Costs

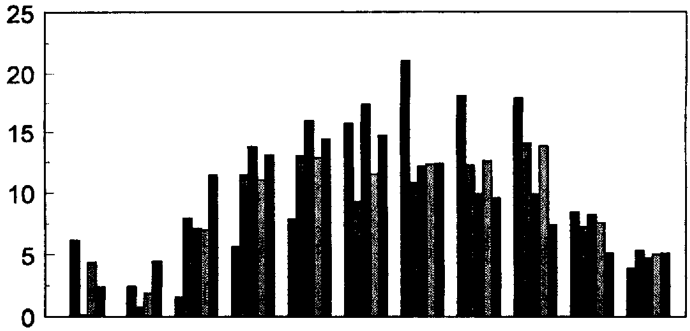
Month No.	Labor cost ($)	Material cost ($)	Subcontract cost ($)	Total cost ($)
1	0	0	0	0
2	110,464	121,684	0	232,148
3	223,962	1,020,063	18,073	1,262,098
4	545,465	1,976,412	45,245	2,567,122
5	1,034,643	3,192,602	220,554	4,447,799
6	1,893,919	4,932,147	234,080	7,060,146
7	2,659,961	6,810,748	286,625	9,757,334
8	3,959,382	8,555,445	311,853	12,826,680
9	4,617,217	11,167,697	318,491	16,103,405
10	5,979,869	13,156,382	335,290	19,471,541
11	7,061,584	15,507,778	378,074	22,947,436
12	8,501,803	17,956,828	404,697	26,863,328
13	9,920,298	20,969,760	427,575	31,317,633
14	11,581,985	24,917,887	435,522	36,935,394
15	14,799,309	27,862,190	558,243	43,219,742
16	16,059,557	34,548,134	503,379	51,111,070
17	17,853,476	41,120,526	551,064	59,525,066
18	20,026,565	47,077,673	610,013	67,714,251
19	21,750,981	53,030,071	651,470	75,432,522
20	23,480,247	57,668,504	696,194	81,844,945
21	25,377,286	61,974,434	747,997	88,099,717
22	27,063,443	65,345,784	791,908	93,201,135
23	28,919,175	67,991,552	834,340	97,745,067
24	30,907,497	70,220,621	878,380	102,006,498
25	32,403,747	72,640,621	920,268	105,964,636
26	35,348,553	73,230,621	948,928	109,528,102
27	35,407,500	76,006,071	950,511	112,364,082
28	36,138,449	77,848,471	970,133	114,957,053
29	36,504,289	79,994,671	979,954	117,478,914
30	36,870,110	82,001,109	990,117	119,861,336

Table 6 Historical Analysis of Indirects Costs

Month No.	Percent of time	Percent total indirect cost	Indirect incremental percent
1	3.33%	0.00%	0.00%
2	6.67%	0.19%	0.19%
3	10.00%	1.05%	0.86%
4	13.33%	2.14%	1.09%
5	16.67%	3.71%	1.57%
6	20.00%	5.89%	2.18%
7	23.33%	8.14%	2.25%
8	26.67%	10.70%	2.56%
9	30.00%	13.44%	2.73%
10	33.33%	16.25%	2.81%
11	36.67%	19.14%	2.90%
12	40.00%	22.41%	3.27%
13	43.33%	26.13%	3.72%
14	46.67%	30.82%	4.69%
15	50.00%	36.06%	5.24%
16	53.33%	42.64%	6.58%
17	56.67%	49.66%	7.02%
18	60.00%	56.49%	6.83%
19	63.33%	62.93%	6.44%
20	66.67%	68.28%	5.35%
21	70.00%	73.50%	5.22%
22	73.33%	77.76%	4.26%
23	76.67%	81.55%	3.79%
24	80.00%	85.10%	3.56%
25	83.33%	88.41%	3.30%
26	86.67%	91.38%	2.97%
27	90.00%	93.75%	2.37%
28	93.33%	95.91%	2.16%
29	96.67%	98.01%	2.10%
30	100.00%	100.00%	1.99%

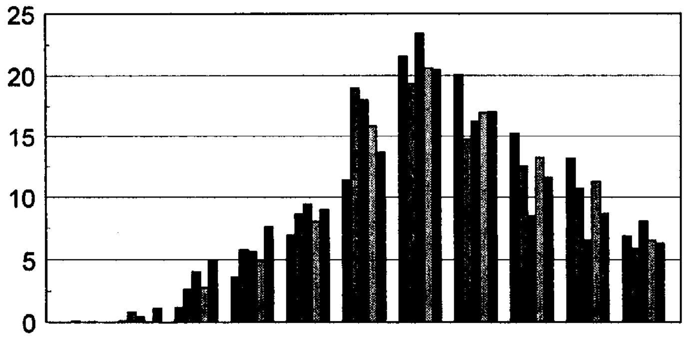
Table 7 Comparsion of Direct and Indirect Cash Flow Data (Cumulative Percent). Data Presented Graphically in Figure 1.

Percent of time	Direct labor cost	Direct material cost	Direct subcontract cost	Total direct cost	Total indirect cost
3.30%	0.00%	0.07%	0.00%	0.04%	0.00%
6.70%	0.00%	0.44%	0.05%	0.23%	0.19%
10.00%	0.09%	0.87%	0.40%	0.51%	1.05%
13.33%	0.18%	1.46%	1.54%	0.96%	2.14%
16.67%	0.68%	2.18%	2.88%	1.65%	3.71%
20.00%	1.25%	3.48%	4.43%	2.69%	5.89%
23.33%	2.09%	5.04%	6.07%	3.97%	8.14%
26.67%	3.21%	6.77%	7.94%	5.47%	10.70%
30.00%	4.87%	9.25%	10.04%	7.59%	13.44%
33.33%	6.86%	11.81%	12.57%	9.92%	16.25%
36.67%	9.30%	14.56%	15.83%	12.59%	19.14%
40.00%	11.79%	17.87%	19.45%	15.61%	22.41%
43.33%	15.37%	23.37%	23.92%	20.25%	26.13%
46.67%	19.08%	29.58%	30.55%	25.51%	30.82%
50.00%	23.16%	36.83%	37.43%	31.47%	36.06%
53.33%	29.82%	43.81%	44.72%	38.35%	42.64%
56.67%	37.32%	50.32%	53.57%	45.48%	49.66%
60.00%	44.68%	56.17%	60.79%	52.06%	56.49%
63.33%	51.96%	61.29%	67.49%	58.18%	62.93%
66.67%	58.51%	66.15%	72.64%	63.74%	68.28%
70.00%	64.74%	70.90%	76.97%	69.03%	73.50%
73.33%	70.41%	75.35%	80.02%	73.83%	77.76%
76.67%	75.35%	79.48%	82.78%	78.16%	81.55%
80.00%	79.97%	83.43%	85.44%	82.25%	85.10%
83.33%	84.55%	87.14%	87.77%	86.17%	88.41%
86.67%	89.04%	90.77%	89.91%	90.00%	91.38%
90.00%	93.14%	94.12%	91.95%	93.52%	93.75%
93.33%	96.79%	97.26%	94.02%	96.77%	95.91%
96.67%	99.50%	99.68%	95.95%	99.25%	98.01%
100.00%	100.00%	100.00%	100.00%	100.00%	100.00%



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Direct labor	0.00	0.09	1.25	4.87	11.79	23.16	44.68	64.74	79.97	93.14	100.00
Direct material	0.07	0.87	3.48	9.25	17.87	36.83	56.17	70.90	83.43	94.12	100.00
Direct subcontract	0.00	0.40	4.43	10.04	19.45	37.43	60.79	76.97	85.44	91.95	100.00
Direct	0.04	0.51	2.69	7.59	15.61	31.47	52.06	69.03	82.25	95.52	100.00
Total indirect	0.00	1.05	5.89	13.44	22.41	36.06	56.49	73.50	85.10	93.75	100.00

Figure 1 Comparison of direct and indirect cash flow data. Cumulative percent of cost expended based on time.



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Direct labor	0.00	0.09	1.16	3.62	6.92	11.37	21.52	20.06	15.23	13.17	6.86
Direct material	0.07	0.80	2.61	5.77	8.62	18.96	19.34	14.73	12.53	10.69	5.88
Direct subcontract	0.00	0.40	4.03	5.61	9.41	17.98	23.36	16.18	8.47	6.51	8.05
Total direct	0.04	0.05	2.81	4.90	8.02	15.86	20.59	16.97	13.22	11.27	6.48
Total indirect	0.00	1.05	4.84	7.55	8.97	13.65	20.43	17.01	11.60	8.65	6.25

Figure 2 Comparison of direct and indirect cash flow data. Comparison of incremental percent of cost expended versus the percent of time expended.

Table 8 Percent of Total Project Cost Expended Includes Direct, Indirect, Process Equipment, and Engineering Costs. Data Presented Graphically in Figure 2.

Month No.	Labor cost ($)	Material cost ($)	Subcontract cost ($)	Total cost ($)	Percent of time	Percent of total cost
1	0	13,562,781	80,217	13,642,998	3.70%	4.32%
2	0	14,322,417	80,217	14,402,634	7.41%	4.57%
3	0	20,988,447	534,849	21,523,296	11.11%	6.82%
4	81,383	32,612,064	1,222,107	33,915,554	14.81%	10.75%
5	325,535	37,892,346	3,837,723	42,055,604	18.52%	13.33%
6	691,761	40,471,192	4,844,187	46,007,140	22.22%	14.58%
7	1,342,831	46,491,264	8,340,588	56,174,683	25.93%	17.81%
8	2,156,668	56,919,018	10,934,037	70,009,723	29.63%	22.19%
9	3,214,656	68,467,017	13,200,258	84,881,931	33.33%	26.91%
10	4,557,487	84,594,525	17,178,777	106,330,789	37.04%	33.71%
11	6,225,853	91,969,467	20,961,747	119,157,067	40.74%	37.77%
12	8,138,371	99,890,976	23,106,504	131,135,851	44.44%	41.57%
13	10,417,115	108,151,086	28,733,388	147,301,589	48.15%	46.69%
14	12,980,702	114,944,493	31,142,487	159,067,682	51.85%	50.42%
15	15,829,131	122,435,439	32,551,701	170,816,271	55.56%	54.15%
16	18,921,713	132,601,809	35,892,996	187,416,518	59.26%	59.41%
17	22,095,677	141,250,386	38,455,056	201,801,119	62.96%	63.97%
18	25,351,026	151,398,538	40,575,624	217,325,188	66.67%	68.89%
19	28,565,683	162,474,753	42,251,469	233,291,905	70.37%	73.95%
20	31,536,188	171,303,429	44,081,523	246,921,140	74.07%	78.27%
21	34,099,775	189,620,280	46,411,155	270,131,210	77.78%	85.63%
22	36,337,827	196,187,019	48,293,709	280,818,555	81.48%	89.02%
23	38,250,344	203,448,666	50,942,925	292,641,935	85.19%	92.76%
24	39,511,792	208,060,974	52,356,402	299,929,168	88.89%	95.07%
25	40,244,245	214,629,618	53,400,201	308,274,064	92.59%	97.72%
26	40,569,780	218,983,668	53,842,848	313,396,296	96.30%	99.34%
27	40,691,856	220,310,136	54,467,667	315,469,659	100.00%	100.00%

Labor cost = total craft labor cost
Material cost = construction commodities, process equipment, and engineering costs
Subcontracts costs = all subcontracts issued for project

Table 9 Percent of Total Project Cost Expended Includes Direct, Indirect, Process Equipment, and Engineering Costs

Percent of time	Percent of labor cost	Percent of material cost	Percent of subcontract cost	Percent of total cost
3.70%	0.00%	6.16%	0.15%	4.32%
7.41%	0.00%	6.50%	0.15%	4.57%
11.11%	0.00%	9.53%	0.98%	6.82%
14.81%	0.20%	14.80%	2.24%	10.75%
18.52%	0.80%	17.20%	7.05%	13.33%
22.22%	1.70%	18.37%	8.89%	14.58%
25.93%	3.30%	21.10%	15.31%	17.81%
29.63%	5.30%	25.84%	20.07%	22.19%
33.33%	7.90%	31.08%	24.24%	26.91%
37.04%	11.20%	38.40%	31.54%	33.71%
40.74%	15.30%	41.75%	38.48%	37.77%
44.44%	20.00%	45.34%	42.42%	41.57%
48.15%	25.60%	49.09%	52.75%	46.69%
51.85%	31.90%	52.17%	57.18%	50.42%
55.56%	38.90%	55.57%	59.76%	54.15%
59.26%	46.50%	60.19%	65.90%	59.41%
62.96%	54.30%	64.11%	70.60%	63.97%
66.67%	62.30%	68.72%	74.49%	68.89%
70.37%	70.20%	73.75%	77.57%	73.95%
74.07%	77.50%	77.76%	80.93%	78.27%
77.78%	83.80%	86.07%	85.21%	85.63%
81.48%	89.30%	89.05%	88.66%	89.02%
85.19%	94.00%	92.35%	93.53%	92.76%
88.89%	97.10%	94.44%	96.12%	95.07%
92.59%	98.90%	97.42%	98.04%	97.72%
96.30%	99.70%	99.40%	98.85%	99.34%
100.00%	100.00%	100.00%	100.00%	100.00%

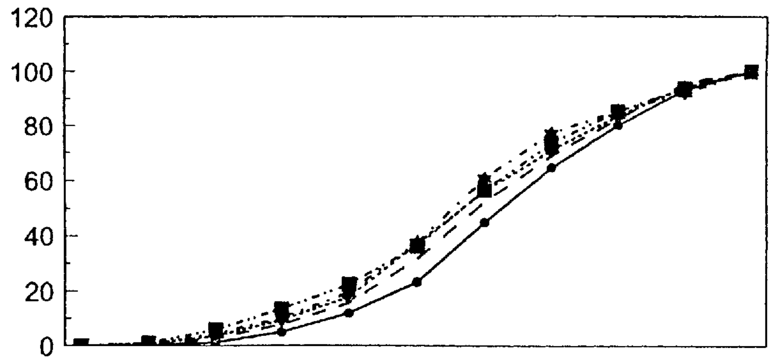
Table 10 Percent of Detailed Engineering Hours Expended Versus Percent of Time

Month No.	Engineering hours expended	Percent of hours expended	Percent of time expended
1	37,929	2.37%	3.70%
2	78,027	4.88%	7.41%
3	120,975	7.57%	11.11%
4	178,569	11.17%	14.81%
5	241,047	15.08%	18.52%
6	324,381	20.29%	22.22%
7	390,030	24.40%	25.93%
8	461,022	28.84%	29.63%
9	556,518	34.81%	33.33%
10	642,501	40.19%	37.04%
11	744,654	46.58%	40.74%
12	835,983	52.29%	44.44%
13	912,489	57.07%	48.15%
14	1,002,552	62.71%	51.85%
15	1,068,154	66.81%	55.56%
16	1,148,535	71.84%	59.26%
17	1,222,056	76.44%	62.96%
18	1,274,820	79.74%	66.67%
19	1,324,779	82.86%	70.37%
20	1,378,914	86.25%	74.07%
21	1,418,433	88.72%	77.78%
22	1,462,746	91.49%	81.48%
23	1,493,298	93.40%	85.19%
24	1,525,278	95.40%	88.89%
25	1,561,224	97.65%	92.59%
26	1,582,953	99.01%	96.30%
27	1,598,766	100.00%	100.00%

Table 11 Percent of Total Project Cost Expended Includes Direct, Indirect, Process Equipment, and Engineering Costs

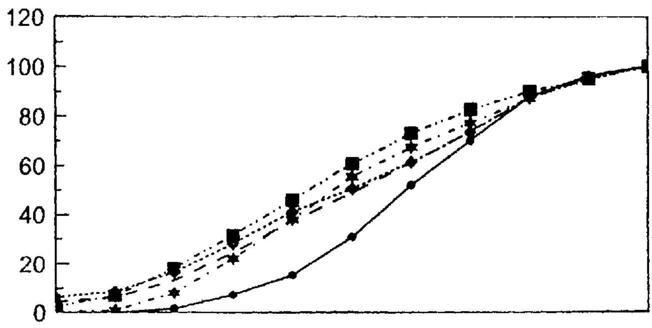
Percent of time	Percent of labor cost	Percent of material cost	Percent of subcontract cost	Percent of total cost	Percent of engineering hours expended
3.70%	0.00%	6.16%	0.15%	4.32%	2.37%
7.41%	0.00%	6.50%	0.15%	4.57%	4.88%
10.00%	0.00%	8.57%	0.88%	6.14%	6.81%
11.11%	0.00%	9.53%	0.98%	6.82%	7.57%
14.81%	0.20%	14.80%	2.24%	10.75%	11.17%
18.52%	0.80%	17.20%	7.05%	13.33%	15.08%
20.00%	1.53%	16.53%	8.01%	13.13%	18.26%
22.22%	1.70%	18.37%	8.89%	14.58%	20.29%
25.93%	3.30%	21.10%	15.31%	17.81%	24.40%
29.63%	5.30%	25.84%	20.07%	22.19%	28.84%
30.00%	7.11%	27.97%	21.81%	24.22%	31.33%
33.33%	7.90%	31.08%	24.24%	26.91%	34.81%
37.04%	11.20%	38.40%	31.54%	33.71%	40.19%
40.00%	15.02%	40.99%	37.79%	37.09%	45.73%
40.74%	15.30%	41.75%	38.48%	37.77%	46.58%
44.44%	20.00%	45.34%	42.42%	41.57%	52.29%
48.15%	25.60%	49.09%	52.75%	46.69%	57.07%
50.00%	30.76%	50.31%	55.14%	48.62%	60.47%
51.85%	31.90%	52.17%	57.18%	50.42%	62.71%
55.56%	38.90%	55.57%	59.76%	54.15%	66.81%
59.26%	46.50%	60.19%	65.90%	59.41%	71.84%
60.00%	51.75%	61.10%	67.28%	60.96%	72.85%
62.96%	54.30%	64.11%	70.60%	63.97%	76.44%
66.67%	62.30%	68.72%	74.49%	68.89%	79.74%
70.00%	69.83%	73.36%	77.16%	73.56%	82.42%
70.37%	70.20%	73.75%	77.57%	73.95%	82.86%
74.07%	77.50%	77.76%	80.93%	78.27%	86.25%
77.78%	83.80%	86.07%	85.21%	85.63%	88.72%
80.00%	87.68%	87.43%	87.05%	87.40%	89.83%
81.48%	89.30%	89.05%	88.66%	89.02%	91.49%
85.19%	94.00%	92.35%	93.53%	92.76%	93.40%
88.89%	97.10%	94.44%	96.12%	95.07%	95.40%
90.00%	96.13%	94.70%	95.30%	94.99%	94.92%
92.59%	98.90%	97.42%	98.04%	97.72%	97.65%
96.30%	99.70%	99.40%	98.85%	99.34%	99.01%
100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

CUMULATIVE PERCENT OF COST EXPENDED BASED ON TIME



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Labor cost	0.00	0.00	1.53	7.11	15.02	30.76	51.75	69.83	87.68	96.13	100.00
Material cost	6.16	8.57	16.53	27.97	40.99	50.31	61.10	73.36	87.43	94.70	100.00
Subcontract cost	0.15	0.88	8.01	21.81	37.79	55.14	67.28	77.16	87.05	95.30	100.00
Total cost	4.32	6.14	13.13	24.22	37.09	48.62	60.96	73.56	87.40	94.99	100.00
Engineering hours	2.37	6.81	18.26	31.33	45.73	60.47	72.85	82.42	89.83	94.92	100.00

Figure 3 Percent of cost expended based on time.



	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Labor cost	0.00	0.00	1.53	5.58	7.91	15.74	20.99	18.08	17.89	8.45	3.87
Material cost	6.16	2.41	7.96	11.44	13.02	9.32	10.79	12.26	14.07	7.27	5.30
Subcontract cost	0.15	0.73	7.13	13.80	15.98	17.35	12.14	9.88	9.89	8.25	4.70
Total cost	4.32	1.82	6.99	11.09	12.87	11.53	12.34	12.60	13.84	7.59	5.01
Engineering hours	2.37	4.44	11.45	13.07	14.40	14.74	12.38	9.57	7.41	5.09	5.08

Figure 4 Incremental percent of cost expended based on time.

analyzing projects that produce milestones that are not exactly on the 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% milestones, these time increments are added and the cost expended values for these milestones are interpolated from the closest milestone value. Figure 3 shows that all the cost items tend to approach approximately 70% of cost expended at the 70% of time expended time frame except for engineering which is understandable for a project of this nature. Figure 4 shows that the incremental expenditures tend to peak approximately at 60% of time expended. As more data is analyzed, the degree of accuracy for these statements is usually in the 5% range.

VII. SUMMARY ANALYSIS

The information provided in this chapter shows the analysis of cash flows from completed Engineering and Construction projects. The trends will generally be in a range of 3–5% for different projects. Other guidelines are listed below:

1. For total project cost cash flow, the percent of cost expended will lag behind the percent of time until the percent of time expended reaches 65% to 75% complete. As a general rule 40% of the cost will be expended in the first 50% of time expended, and 60% of the cost will be expended in the last 50% of time. If the percent of cost expended does not equal, or exceed the percent of time expended in the time range of 60–75% complete, the project will probably not finish on time and/or will experience a budget overrun.
2. When comparing material and subcontract cash flows for a project, the percent of material cost expended will lag behind the percent of time expended until the percent of time reaches the 40–50% range. The percent of subcontractor cost expended will lag behind the percent of time expended on a project until the percent of time reaches the 45–60% time range. However, there are projects where a large portion of the work has been subcontracted, in which the subcontract percent of cost expended will continuously lag the percent of time expended. This is due to the invoice payment cycle that exceeds 30 to 45 days from invoice receipt.
3. Seventy percent (70%) of total cost will be incurred by 70% of time expended, within a range of ±5%
4. Forty-five percent (45%) of total material cost will be incurred by 45% of time expended, within a range of ±5–0%
5. Fifty percent (50%) of total subcontract cost will be incurred by 50% of time, within a range of +10 to –5%

6. Seventy percent (70%) of total labor cost will be expended by 70% of time, within a range ±5%
7. Thirty-five percent (35%) of total engineering design hours will be expended by 35% of the time expended, within a range of ±5%
8. Engineering should be 80% complete at 65–70% of time expended.
9. Commissioning, checkout, and startup for mechanical completion should occur in the 80–90% range of total time expended and startup generally is in the range of 88% of time expended with a –5 to +0% accuracy
10. Three percent (3%) to eight percent (8%) of labor hours will be expended after mechanical completion.

Cost expenditure curves and tables have been provided—however, these tables should not be used for any construction project. In order to prepare an accurate cash flow curve, historical data from completed similar projects should be analyzed, using the format shown.

ACKNOWLEDGMENT

The author would like to thank Charles M. Aardema for technical review and graphic assistance.

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Estimating the Cost of Escalation

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I. INTRODUCTION

Cost escalation or variation in prices are the result of many factors. There can be general increases in all prices caused by overall inflation in the currency; or there can be spot price changes in certain commodities caused by shortages, built-in price changes, or monopolies. Overall national inflation will be considered first.

To understand inflation we must first understand money. Money was invented to expedite transactions among members of a society. In ancient times all economic transactions were made through the use of barter trade. Later, gold was used as a medium of exchange because of its desirable properties. Until recently, most major currencies were on a gold standard that defined their relative values or exchange rates. In such a system, money is a promissory note issued by the government and guaranteed by the reserves it holds. For various reasons governments abandoned the gold standard. Today, Treasury Departments print money in an amount that represents the government's income generating capability. Therefore money is an indirect representation of the productive capability of the country.

All of this discussion does little to help us understand why the dollar has value; it does show that the value is not intrinsic, but is based on faith. We accept it because we believe we can exchange it for goods and services on a daily basis.

Inflation is the effect that occurs when the value of the currency declines measured by the rate at which the general level of prices increases. Since the goods and services that can be bought with dollars can vary it follows that the price for the same commodities can fluctuate. Most of the time this movement is up because of several economic forces. The nature and effect of these forces is a subject not clearly understood even by experts and is a subject of constant political debate. It is important that we recognize that price change in the context of this chapter means paying more (or possibly less) for the same commodities; the intrinsic value of these items does not change.

If the supply of goods decreases and/or if demand increases there will, in simple economic theory, be a change in price, provided there is no change in value. For this reason it is frequently stated that increases in productivity will keep inflation in check. On the other hand if productivity declines and the people of a country are constantly paying for imported goods it follows that inflation will result. This seems to be the situation in many of the nations of the world. This lack of internal productivity will also result in a decline in the value of the currency in the world market. If governments issue money in excess of the inherent productivity of their economy their currency will lose its value, which leads to inflation. There are certain advantages for governments to increase monetary supply including the ability to pay off national debts but the long-term effects are, as we have noted, crippling over time.

As long as inflation remains fairly low, say less than 5% annually, it is possible to deal with the problem; however, as rates of inflation increase it becomes difficult if not impossible to maintain a stable economy and serious dislocations occur. The entire psychology of a nation changes and buying and saving habits undergo changes that lead to further misery. The demand for commodities other than money, especially residential construction products, increases because they are a good hedge against rising prices. However, the long-term harm to savings and investments in general is considerable; to the extent that saving is discouraged by inflation, there is less money for large capital projects. In certain countries the currency has depreciated to less than one thousandth of its original value in terms of the U.S. dollar. The cost of living in these countries has varied between 10 and 500% per year. Rates such as these, once people become accustomed to them, have a considerable effect on economic behavior. Long-term lending at fixed rates ceases and people hold little money. Society as a whole is damaged; there is loss of faith in government and political chaos frequently results.

The above discussion illustrates the important point that serious inflation can make it virtually impossible to realistically estimate project costs; beyond the range of about 10% inflation prices can gyrate randomly and other economic by-products result, such as spot shortages, inability to get financing at any price, bankruptcies, and bank failures.

When local and foreign currencies are mixed the problem is even more complex. Of course the local currency is less desirable and the demand for foreign currency is great. Projects financed by foreign currency are quite frequent in developing countries. Estimating costs under these circumstances is difficult; local monetary devaluation causes banks and other agencies to have to raise local interest rates (or prices) to keep up with the payments they are making in the foreign currency. Say, for example, an international project is purchasing foreign equipment at a certain cost in foreign currency and is making a series of payments while the local currency is being devalued. In order to make payments they must raise prices to the user or suffer continual losses.

II. INFLATION TERMINOLOGY

In order to understand the effect of price inflation on currency we shall have to distinguish between two terms: "actual dollars" and "real dollars." We use the term "dollars" to mean any local currency. Assume that the price of a marketable commodity increases by 10% in one year and its value remains constant. That is, the item still has the same intrinsic worth; in economics, it is said to provide the same utility. During this year the item, for some reason, increased in price so that one must pay $1.10 to obtain it. The original real value, one year ago, remained constant, however. The current price is in actual dollars. The terms *actual* and *real* are used to define this change in the number of dollars (De Garmo et al., 1988).

Actual dollars are the number associated with a cash flow over time. In reality, the cash flow in the above example did change in one year. Sometimes actual dollars are referred to as *current* dollars and they include an allowance for general price inflation. General price inflation is the measure of the change in the purchasing power of the currency during a specified period of time. This price change is usually measured by some index; in the United States the consumer price index is the most widely publicized. Indices are discussed further below.

Real dollars are those expressed in terms of the same purchasing power relative to a particular time. Often real dollars are termed *constant* dollars. The base time period used to determine the purchasing power of real dollars can be any designated time. The base time is frequently set as time zero, reflecting the fact that one knows the price of commodities in real dollars at time zero.

Two other terms frequently used or misused are *price* inflation and *cost* inflation. They are very different and it is difficult to separate the two (Jones, 1982). Price inflation is a money phenomenon, the change in the purchasing power of the currency. It may be due to too many dollars; government policies can cause general price changes. Cost inflation is the result of real cost increases. Usually cost inflation is the result of a decrease in the supply of goods and services. This can be overcome if the market produces more to compensate. On certain commodities the effect is the same as price inflation—an increase in price. Unfortunately it is difficult to separate real price increases from dollar value changes.

III. LINKS BETWEEN INFLATION AND PRICE VARIABILITY

The correlation between inflation and price variability has been studied extensively. Generally a moderate increase in inflation leads to higher variability across product lines, but at high rates of inflation the variance is reduced. Another way of saying this is at moderate rates of inflation an increase in inflation tends to raise the relative *size* of each price increase but there is little synchronization of price changes. At high inflation rates most firms tend to raise prices uniformly within a short time (Benabou, 1993). As the rate of inflation increases, observed changes in price variability can be linked to the variability of the inflation rate; this link is probably due to inflationary expectations.

At relatively low rates of inflation there are "sticky" wage and price movements. These were investigated via a questionnaire of firms having annual sales over $10 million. The author found that the mean number of price changes per year is between 1 and 2; that the frequency of shocks has a large effect on price changes. The time between the shock and price changes averages 3 months; shocks are increases or decreases in demand or cost. The most important reasons for the price lags are delivery lags/service; coordination failure; and cost-based pricing. These mean that most firms would prefer to lengthen deliveries or provide fewer services when demand is high rather than raise prices. Secondly although firms would like to raise prices they hesitate to do so unless other firms move first; third, that prices are based on costs and do not rise until costs rise. Of the ten theories for sticky prices, judging quality by price is the worst: few firms believe that if they lower prices it will be interpreted as a lowering of quality (Blinder, 1993).

IV. THE IMPACT

In this paper we discuss the impact of inflation and escalation on any of the parties to a project; contingency and profit, discussed below, may be more applicable to the contractor, but we will treat these as costs to whomever shares the risks.

We are most concerned with the impact that price or cost inflation can cause in the prices of commodities in projects. In this paper "commodities" means direct or indirect materials, labor, and equipment. We are also concerned with the range of costs classified as general and administrative and, of course profit.

A. Material Costs

Anticipating probable increases in prices of *materials*, users can either resort to stockpiling or hedging against future needs or they can seek to protect themselves through escalation clauses. As long as the government does not interfere with the process of obtaining and pricing materials escalation clauses have been effective in low inflationary situations. Government price controls cause shortages and are a barrier to the decline in prices that may occur when supplies become more readily available. Scarcity of materials can lead to stockpiling and to very long lead times, such as those that occurred in the U.S.A. in the early 1970s. In some countries government controls have led to black marketing, with secondary markets causing even more price distortion.

B. Labor Costs

Labor costs are also based on supply and demand but, in addition, wages are a function of the perception of workers and unions as to whether there will be further increases in the overall economy. If workers perceive that they are going to suffer from steady loss in purchasing power they will demand wage and benefit increases to compensate themselves. This same effect can be felt in the salaries of white collar workers and retirees. Since long-run improvements in real wages can only be met by rising productivity, increase in labor costs without productivity gains will result in further cost inflation. There are several distinctions between labor and materials prices: labor gains are usually effective at the end of the year or some other period; meanwhile other prices are rising continually. Also labor rates tend to be regional and trade-oriented.

C. Equipment Costs

Equipment costs are a function of several variables: the costs to purchase, lease, or rent the equipment itself; the cost of maintenance and operation; and the costs of replacement of certain items such as tires. The equipment cost is a function of interest rates, depreciation, and taxes. Since all these are very sensitive to inflation and currency fluctuation, contractors will tend to lease or rent rather than buy major items of equipment. It is interesting that the replacement price of depreciated equipment can be as much as or more than the original price in actual dollars, but much less in constant dollars. Unfortunately taxes are based on actual dollars so that one is actually paying taxes on the inflated income from that equipment.

D. Other Costs

In high inflation conditions one must also consider other costs, such as home office and profits. It is not at all unreasonable to consider escalation clauses for general office expenses and for profit. Few, if any, U.S. companies would consider these in an escalation clause but they are real costs, nevertheless. If the price the contractor is paid remains constant while costs increase there is bound to be an impact on overhead and profit. If there is no mechanism to protect these costs the contractor should and probably will increase the contingency in the project price.

Financing costs are also affected. Inflation erodes the purchasing power of the currency and lowers the real rate of return on investments. Since lenders are aware of this they will charge an inflation premium to the rate they would have been able to accept absent inflation.

V. INDEXATION

Indexation is the measure and adjustment of price levels for goods and services across a broad sector of the economy. It is used today in the United States to escalate social security and pension funds. Indexation is used more extensively in practically every country suffering from some form of high inflation. It is a two-edged sword; generally it favors those with political clout, but can hurt unprotected groups. In order to use indices in the economy, it is necessary to standardize and get broad agreement on the means used to measure price changes. In the United States there is considerable controversy on the use of the Consumer Price Index (CPI). Even a small fraction of change will mean billions to the government.

There are several difficulties associated with indexation (Jones, 1982):

It is not always possible to determine the prices of commodities used in an index.

At any given time a given commodity sells at different prices at different locations.

The prices of commodities used to calculate a price index, called a basket, cannot be averaged directly to determine a price index. Some means of weighting the price change for each item must be used.

It is difficult to separate price changes due to changes in value or quality from other types of price changes.

New services and products come on the market for which there is no base to which prices may be compared.

Indexation has been responsible for eliminating some of the significant inflation-based distortions in the economies of countries. This has occurred through elimination of much of the risk and uncertainty associated with long-term financing and project costs, keeping commodities, indirect costs, and benefits in line with inflation. Indexing has also had some desirable consequences when applied to the system of taxation. It has increased collections while reducing inflation-induced tax increases. It could also reduce the initial cost of investments such as adjustable mortgages, which assist the buyer and financial institutions in long-term risk assessment.

There are many more disadvantages in using indices. Unfortunately the widespread acceptance of indexation can make inflation institutionalized; inflation becomes a part of both the government and private sectors, since indexing is the way all business is conducted. It is very important to recognize that indexing is a means of coping with the disease of inflation. It is not a cure.

VI. INTEREST RATES

There is usually an inflation rate built into interest rates; this rate reflects future inflation, not the experience of the past. There is confusion in the use of the inflation rate in financial analysis and engineering economy. Many students and others believe that the real value of money, expressed as the real interest rate, includes the general inflation rate. In fact the inflation rate is a premium on the cost of capital; investors, whether financial institutions, owners, developers, or contractors, expect a premium on the real market return to compensate for inflation. The real value of the discount rate is usually not known, because the investor is using an anticipated or forecast inflation premium.

Interestingly, costs escalate at the same rate as inflation there is no effect on the net present value (NPV). The following example shows this:

Let

r = the periodic real interest rate, expressed as percent

f = the periodic general inflation rate

I = the nominal interest rate; $I = (1 + r)(1 + f) - 1$

Assume that all periods are the same and the borrower attains a construction (or other) loan of X dollars to be repaid by an amount Y in n equal periods. The NPV of this transaction is:

$$\text{NPV} = X - Y\left(\frac{1+f}{1+i} + \frac{(1+f)^2}{(1+i)^2} + \ldots \frac{(1+f)^n}{(1+i)^n}\right)$$

For example if $f = 8\%$, $r = 6\%$, $e = 10\%$, $X = \$100$ million, the original loan, $Y = \$10$ million per month, $n = 12$, the NPV from the lender's perspective using constant dollars is:

$$\text{NPV} = -100 + 10\ (P/A,\ .487,\ 12) = \$16.19 \text{ million}$$

Under inflation, the actual return should be increased to compensate for the uncertainty so that

$$I = (1.08)(1.06) - 1 = 14.48\%$$

$$\text{NPV} = -100 + 10\ (P/A,\ 1.13, 12) = \$11.07 \text{ million}$$

that is, if the payments are constant, and the currency is depreciating at the rate of 8% per year, the bank stands to lose over $5 million. Now suppose the bank knows that it must increase payments monthly to compensate for the loss, so that each month the payments increase by the inflation rate. This is now a geometric gradient of payments, having the formula

$$\text{NPV} = -100 + \frac{10}{1.08}\left(\frac{\text{P}}{\text{A},}\ .487, 12\right)$$

This is the same result as above since the first term starts at the end of period 1 and is inflated.

There usually will be variation between the general price inflation rate and the best estimate of future price changes caused by factors mentioned earlier. This change in price is "escalation": Escalation is the change in the cost of a commodity resulting from changes in wages, production costs, market demand, reflected in the change in price of a finished product or service.

To demonstrate the effect of this variation assume that e = the periodic escalation rate of a borrower's basket of commodities. This escalation will include the effects of both the general price inflation and the differential price change which can be labeled e'. The relationship between e, e' and the general inflation rate in some period j is (De Garmo, 1988):

$$1 + e_j = (1 + f_j)(1 + e_j')$$

De Garmo shows that if either the general price inflation or differential price inflation (or both) are significant, price escalation should be considered in any engineering economy or other study.

The best way to include price escalation of certain commodities is through a spreadsheet, escalating the particular commodity costs each year then calculating the net present value of the entire cash flow. The example on the subsequent pages illustrates this. The use of geometric gradient formulas, demonstrated in most engineering economy texts, will provide an estimate of the net present value but the assumption of constant and uniform escalation over all commodities is a simplifying approximation.

VII. ESCALATION CLAUSES

Long-term projects, such as power plants, will almost certainly have to deal with escalating prices of certain commodities; to compensate for price movements, the supplier may require the use of an escalation clause. Estimating the increase in price over the long term is almost impossible because of the many uncertainties beyond the control of all parties. The same is true of long-term construction contracts, where escalation clauses have been required and are still used in many countries. Such clauses are needed to prevent severe financial overrun by the contractor and to reduce the amount of contingency in the contractor's bid. Escalation provisions in a fixed price contract are generally less costly than cost-plus or target contracts. The characteristics of such a fixed price with escalation (FE) contract are:

The contract should be simple and easy to administer.

The techniques employed should, theoretically, provide for reimbursing the contractor for escalation actually experienced, preferably using a procedural system that can be accessed by either party.

Price fluctuations should be evaluated throughout the contract and serve as the basis for contractor reimbursement.

Positive as well as negative price changes should be considered. In the event of negative adjustments, the contractor would reimburse the owner.

The escalation clause should not remove from the contractor those other risks for which it is normally responsible. This is not a simple differentiation process, because the nature of price movement involves factors such as scarcity, quality Variations, and national policies which are difficult to isolate. In some cases the very size and scope of the contract can have national or regional economic implications.

To organize the essential provisions of an escalation clause, the estimator of the party developing the clause should:

1. Itemize the contract costs in various categories, i.e. labor, materials classes, equipment, indirects, and general and administrative. A decision is needed as to whether only direct or other costs should be included in the clause. Most provisions provide for reimbursement of direct costs only.
2. Identify those contract resources whose price variations are considered to be beyond the influence of the contractor; for these the owner must assume

responsibility. Further, the percentage of reimbursement of costs must be decided. In some cases the contractor has no control over prices; in these cases the owner should pay the entire cost of upward price variation. In other cases, such as labor, the contractor should perhaps pay some of the costs.

3. Identify the indexes that will be used to measure price variations. If indexes are not available locally it will be necessary to develop same. An index should offer an objective means of calculating reimbursement such that it reflects changes in real purchasing power. If a reliable index can be found, the techniques of such adjustment are normally procedural and, once established, cannot be manipulated by either party.

The example on the subsequent pages illustrates these concepts and the effect on profit and cash flow.

VIII. INDEXES

Several indexes are used in the United States for construction projects, but on international projects frequently there is no government index that will suffice. There are several indexes for consumer goods, which may include cement, steel, lumber, tires, and food. Food and other consumables may have to be tracked if projects are in remote areas. Labor costs are measured by indexes in the United States and most developed nations, but in certain countries it is necessary to develop cost indexes for a project or use actual cost records. Labor costs can frequently be forecast if wages and benefits are to be negotiated by unions at known dates. In remote areas, of course, the wages and benefits may exceed those in the collective agreement. Workers who are imported may be paid in their own currency, an additional complication.

There are three major indexes used in the United States to measure overall inflation, the theory being that price changes for a large number of commodities reflect the actual decline in the dollar's purchasing power. The indexes most often used are the Gross National Product (GNP) implicit deflator, the Producer Price Index (PPI), and the Consumer Price Index (CPI). The GNP implicit price deflator is the most comprehensive price index of the economy and measures inflation at the macroeconomic level (Cassimatis, 1988). It is compiled by the U.S. Department of Commerce and is available monthly, quarterly, and annually. Price changes are measured for the whole economy, including personal consumption expenditures, gross private domestic investment, exports and imports, and government purchases. The annual inflation is measured using the GNP figures for year X compared to some base year.

The PPI and its components are compiled by the Bureaus of Labor Statistics and is designed to measure changes in the prices of materials and finished goods in the primary markets. The CPI is the most widely quoted and measures only changes in a select basket of consumer goods. It is heavily influenced by housing and fuel costs. The "cost of living" generally is based on this index; its reciprocal measures the decline in the purchasing power of the dollar (Cassimatis, 1988). The CPI is used to increase wages of a vast number of retirees on pensions and Social Security income.

Corporations are not using broad-based indexes but are using more specific industry-based price measures. Using a broad-brush index like the CPI can lead to serious over-depreciation of assets. If equipment costs are indexed to the CPI one fails to account for the decline due to rapid obsolescence such as is occurring in computers. Similarly the PPI is a reflection of manufactured goods prices but never covers certain goods companies want to sell. Some companies use specialized parts of the GNP deflator or derive their own index.

There are several cost indexes used in the construction sector. The best known and oldest is the *Engineering News-Record* (ENR) index, started in 1909, but the construction cost index was not established until 1921. The construction cost index is a weighted aggregate index of the prices of constant quantities of structural steel, Portland cement, lumber, and common labor. The base year was established as 1913, arbitrarily set to 100. With this base, the 1995 index is now 5435, or construction costs have increased 5,435% in 82 years. ENR now has three indexes, the building cost index, the skilled labor index, and the materials index. Labor makes up 76% of the CAI and 58% of the BC. The indexes are based upon labor craft rates in 20 cities and the costs of steel, lumber, and other construction materials in this 20-city sample. The CAI and BC indexes do not include an adjustment for labor productivity and, therefore may have a tendency to increase more rapidly than other indexes.

There are other construction indexes. These include:

Marshall and Swift Index. This is based on equipment costs in selected process industries: paper, cement, chemical, clay products, glass, paint, petroleum products, and rubber. Some of the related industries affected are electrical power and petrochemical (Couper and Rader, 1986).

Chemical Engineering Index. This index consists of four components: equipment and machinery, construction labor, building materials and labor, engineering and supervision. This index is designed to reflect trends in chemical process equipment plant costs. It is a complex index made up of 67 Bureau of Labor Statistics (BLS) price indexes covering 155 individual commodities, three BLS indexes covering 450 additional items and BLS hourly earnings data for five groups of employees. The equipment, machinery, and supports index is made up of seven subcomponents.

Nelson-Farrar Refinery Cost. Published in the *Oil and Gas Journal,* it is heavily weighted toward the petroleum and petrochemical industries. It is based on 40% material and 60% labor.

Building Indexes. At least 15 major indexes are compiled in the United States covering from one to seventeen types of buildings in from one to over two hundred different locations. Some of these are: Handy-Whitman General Building; Austin Co Industrial; Fru-Con Corp Industrial; Turner General Building; Smith, Hinchman, & Grylls General; Lee Saylor Subcontractor; Boeckh: Commercial/Manufacturing

Means Construction Cost Index. This index is designed to reflect the overall building industry escalation.

IX. LIMITATIONS ON USING PUBLISHED INDEXES

There is no perfect index. Any index is a statistical average and suffers from all the disadvantages of averages.

Most indexes represent reproduction costs; that is they do not account for any radical changes in technology.

There is a reporting time lag.

They lack sensitivity to short term economic cycle swings. Most indexes are based on published list prices rather than actual prices and average labor conditions. Actually there are significant swings in the economic cycle due to wage contract negotiations, shortages, overtime, and other factors.

Indexes are frequently not relevant to construction projects; this is true in many countries where the local indexing is applicable to a limited range of consumer items.

Price controls may be placed on materials for short or long periods. History shows many examples of countries, including the United States, who imposed price controls believing that these measures would control inflation. Generally when controls are removed prices skyrocket; the wide swings of indexes during these periods give an unrealistic picture of the actual inflation.

The basket of items or the weights assigned to them change over time, due to changes in consumption patterns; if the indexes do not change they do not reflect the true quality of consumer tastes or industry usage of commodities.

X. MANAGING ESCALATION

For most projects, forecasting escalation is risky, especially when the annual rate of escalation exceeds 5%. In countries with extreme inflation, owners and contractors must take great care to combat the effects of inflation. They must prepare daily or weekly cash positions; prepare detailed cash flow forecasts every 10 days; update inflation forecasts every ten days; prepare balance sheets in monetary units of comparable power; prepare budgets and forecasts and compare them with actual results in comparable units of purchasing power; seek out information on government actions that may cause changes in the economy; maintain inventory as an inflation hedge; use materials that do not have excessive price changes, if possible; fast-track design and construction; constantly update bidding practices and skills; standardize construction practices; and practice inflation accounting to be sure that profits are not overly stated.

Labor costs are very complicated, especially in instances where adequate government indexes do not suffice. The real costs are calculated from manpower curves and the average wage rates including base wages and fringes. Future costs are estimated from indexes or other information. Indexes, if available, may not consider all the factors that tend to raise labor costs. Labor unions may negotiate collective agreements, but actual costs can exceed these due to shortages of certain skills. Benefits are very difficult to estimate and control especially if they are complex and numerous. Workers can receive increases during the year, premiums for overtime, bonuses, hazard pay, travel, subsistence, and insurance. Not all of these can be forecast. In addition, these benefits may not be applicable to some sectors of the work force,

Engineering News-Record states that they do not attempt to forecast price changes more than one year in advance; however, contractors are required to do this frequently. The longer the contract period, the more uncertain the potential escalation. As an estimating tool, there are several methods in use. One can multiply annual real cost components by the factor $(1 + e_j^n)$ compounded for as many years n as desired. Certain refinements are possible, such as using monthly increases, $(1 + e_j^m)$ where m is 12 and e_j is now the monthly forecast rate of escalation.

XI. ESTIMATING ESCALATION

There are several means available and several assumptions needed to forecast escalation. A broad annual rate of increase may be applied to the total project estimate, or to major components such as labor, manual and nonmanual, bulk materials, home office, installed equipment, construction equipment, engineering and home office, contingency, and subcontracts. Materials may be further subdivided into lumber, steel, cement, piping, and other. Published indexes for these commodities can be used but should be compared with actual costs periodically. Labor may be escalated at one rate or considered separately for crafts if one or more are skills are scarce or subject to a collective bargaining

Table 1 Calculation of the Real Cost of the Project

Six month period	1	2	3	4	5	6	7	8	9	SUM	NPV
Item and commodity class											
Delivered equipment [machinery 100%]	17	17	17	17	17	17	17	17		132	
Installed equipment [machinery 90%, labor 10%]	15	15	15	15	15	15	15	15		120	
Piping and instrumentation [nonferrous metals 50%, labor 50%]				30	30	30	30	30	30	180	
Structural steel [iron and steel 80%, labor 20%]			25	25	25	25				100	
Site development [construction equipment 80%, labor 20%]	20	20	20	20						80	
Indirects [construction equipment 10%,labor 90%]	5	5	5	5	5	5	5	5	5	45	
Home office [engineering and admin 100%]	8	8	8	8	8	8	8	8		64	
Total cost of each commodity class											
Machinery	30	30	30	30	30	30	30	30	0	240	
Labor total including engineering	19	19	24	39	35	35	30	30	20	247	
Nonferrous metals	0	0	0	15	15	15	15	15	15	90	
Iron and steel	0	0	20	20	20	20	0	0	0	80	
Construction equipment	16	16	16	16	0	0	0	0	0	64	
Total direct and indirect real cost	65	65	90	120	100	100	75	75	35	721	
Contingency		3	3	3	3	3	3	3	3	24	@2.5%/6
Real profit @5% of all real costs [no inflation]	3	3	5	6	5	5	4	4	2	37	33
Real cash flow ea six months	68	71	97	129	108	108	81	81	40	782	695
Cumulative estimated real cash flow	68	139	236	364	472	580	661	742	782	782	

agreement. Permanent and construction equipment should be treated separately. If procured from different sources, having widely varying escalation rates, further differentiation is needed. Transportation costs should be included.

The escalation rates are very difficult to forecast, regardless, and should be updated frequently. The difference in rates between the actual escalation and forecast can have substantial effect on earnings. Escalation should be applied using a compound percentage rate. Ideally, one would apply escalation to the center of each period, but with the rates themselves so indefinite, this added refinement may be unnecessary. If escalation is computed for the entire project cash flow, one can use the center of gravity of all project costs or the center of gravity of each commodity. In the example that follows a single calculation of the entire project cash flow is compared to the estimate obtained using each six-month period. The center of gravity of the cash flow is that point where 50% of the currency is expended. In both Table 1 this real cash flow expenditure occurs at about 26 months; in Table 2, the actual cash flow at 10% escalation per six months has a center of gravity at about 30 months. The time schedule should indicate when the mid-point of the cash flow occurs.

XII. THE EXAMPLE

In the following example Tables 1 and 2 illustrate several points. This example pertains to a large power plant with a fifty-four month engineering and construction period, starting in six months. Other activities, such as procurement, would be underway earlier. The assumptions of the quantities shown in the table are:

Costs are aggregated by six month period and there are nine periods . The total cost of a work package and number of months over which its particular costs are expended can be deduced from the table. For example, *delivered equipment* costs $132 million and this cost is expended over months 0–48.

Payments are received promptly at the end of each period.

Costs for each work package are uniform throughout each period.

Contingency is $24 million and profit is 5% of all costs, including contingency.

Construction starts at the end of the first six-month period.

Escalation is the same as the general inflation rate. (1.5% per six months in the first case, 10% semiannually in the second).

Escalation is the same for all commodities. This is not realistic, but is done here in order to show that the NPV remains constant when the actual discount rate keeps up with the overall inflation-escalation rate.

Table 2 Calculation of the Effects of Inflation and Escalation

Six month period	1	2	3	4	5	6	7	8	9	Sum	NPV [6mo]
Actual profit and cash flow											@2.5%
Profit @1.5 inflation ea 6 mos	3	3	5	6	5	5	4	4	2	37	33
Profit @10% inflation ea 6 mos	3	3	3	4	3	3	2	2	1	24	22
Cash flow @1.5 inflation 6 mos	67	70	96	128	107	107	81	81	40	776	690
Cash flow @10% inflation 6 mos	65	68	93	123	103	103	78	78	38	746	663
Total escalated cost of each commodity class at 1.5% ea six months											
Machinery	30	31	31	32	32	33	33	34	0	257	
Labor	19	19	25	41	37	38	33	33	23	247	
Nonferrous metals	0	0	0	16	16	16	17	17	17	99	
Iron and steel	0	0	21	21	22	22	0	0	0	86	
Construction equipment	16	16	17	17	0	0	0	0	0	66	
Total direct and indirect costs	65	66	94	127	107	109	83	84	40	755	
Contingency escalated	0	3	3	3	3	3	3	3	3	26	

Profit @5% of actual costs	3	3	5	7	6	6	4	4	2	40	33
Estimated actual cash flow	69	73	102	137	116	118	90	92	46	837	695
Cumulative actual cash flow	69	142	243	380	496	613	704	795	841	841	
Escalation end of 6-mo period	1	2	4	8	8	10	9	10	6	54	
Average escalation[a]	27										27
Total escalated cost of each commodity class at 10% ea six months											
Machinery	33	36	40	44	48	53	58	64	0	377	
Labor	20	22	31	56	56	61	57	63	47	415	
Nonferrous metals	0	0	0	22	24	27	29	32	35	169	
Iron and steel	0	0	27	29	32	35	0	0	0	124	
Construction equipment	18	19	21	23	0	0	0	0	0	82	
Total direct and indirect costs	71	78	119	175	160	176	145	160	83	1167	
Contingency escalated	0	4	4	4	5	5	6	6	7	42	
											@12.75%
Profit @5% of actual costs	4	4	6	9	8	9	8	8	4	60	33
Estimated actual cash flow	74	86	129	188	173	191	159	174	94	1269	695
Cumulative actual cash flow	74	160	290	478	651	842	1000	1175	1269	1269	
Escalation end of 6-mo period	7	15	32	60	66	83	77	93	54	487	
Avcrage escalation[b]	243										239

[a] Calculated at center of gravity: $782/2 \times (1.015^{4.5}-1)$

[b] Calculated at center of gravity: $782/2 \times (1.1^{5}-1)$

In order to bid on this project the contractor should estimate, conservatively, the probable changes in the prices of all commodities. Then the bid price can be approximated by the average actual or escalated price of the entire project or the sum of the costs of the individual commodities, plus an anticipated increase in the contingency and profit needed to compensate for increases in costs. The need to estimate actual profit will be shown, since there is a continuous decrease in the profit by the amount of general inflation. An approximation of this decrease per period is shown in the first section of Table 2. Table 2 also shows the result of escalating all entries at two escalation rates, one moderate (1.5% per six month period) and one severe (10% per six month period). To preserve the net present value of the six-month revenue stream there are several assumptions:

All costs, including indirects, contingency and profit are escalated at the general inflation rate.

The discount rate is equal to the real discount rate multiplied by the general inflation rate.

The real discount rate in this example is 2.5%, shown in Table 1. If the inflation rate f (affecting a decrease in actual profit) is less than the discount rate ($f < I$) the NPV is less than the NPV of the real profit (32.9 or 21.6 < 33.1) If the discount rate is lowered so that it is below the general inflation rate, the NPV will increase. Thus, if a borrower can secure a loan below the inflation rate, profits will improve even under inflation.

XIII. SUMMARY AND CONCLUSION

The United States has not been seriously affected by inflation and price distortions since the early 1980's but inflation is quite common in other areas of the world. If U.S. companies are to compete in these areas they must understand these problems and have ways to mitigate their effects. Inflation and cost escalation cannot be precisely forecast but must be considered in forecasting cash flow. Escalation on very large contracts over several years can be substantial. In the example the cumulative escalation over 54 months compounded at the rate of 10% per six months is more than half the real cash flow. This rate is not unusual in many countries.

There is a relationship between inflation and escalation of prices; this is not one-to-one, and prices can escalate for various reasons even if inflation is very low. Inflation decreases the real profit unless the amount is correspondingly escalated. This is true even under moderate inflation.

The impact of inflation can be reduced or increased by proper estimation of escalation. Escalation can be estimated by using one overall index, by estimating the movement of components of overall cost, or by actually estimating the escalated cash flow of each component commodity. The schedule for the project is the key. Each component commodity must be scheduled since they do not start and stop at the same time and there are different indexes and forecasts for each. (In the example the same index was used for all component commodities.)

The cost of money is a major factor in cash flow analysis under inflationary conditions. The present value of the cash flow and the profit can be increased or decreased, depending on the real and actual interest rates. If the general inflation rate is applied to the real discount rate, all actual cash flows are discounted to the real cash flows, regardless of the inflation-escalation rate.

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10
Location Factor Analysis

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I. INTRODUCTION

This chapter presents a generic method for developing location factors. It is the overall concept that is important to understand. Each user will need to tailor their own detailed process around their own needs and computing capabilities.

Location factors are used during preliminary project evaluations. They are not intended to be used when preparing appropriation quality estimates. Some useful definitions are shown below:

II. DEFINITIONS

Location Factor. An instantaneous (current—has no escalation or currency exchange projection) overall total project factor for translating all project cost elements of a defined construction project scope of work from one geographical location to another. This factor recognizes differences in productivity and costs for labor, engineered equipment, commodities, freight, duty, taxes, procurement, engineering, design, and project administration.

The cost of land, scope/design differences for local conditions and codes, and differences in operating philosophies are not included in the location factor).

Productivity Factor. A factor arrived at by comparing the direct work hours required to accomplish a given task divided by an established base.
Example. If it takes one worker 1.25 hours to perform a task normally performed by another worker in 1.0 hour, the productivity factor is 1.25/1.0 = 1.25. This factor is influenced primarily by methods of construction, working skills, use of labor-saving tools and equipment, climate, communication barriers, and social habits. This is a very subjective factor and we often rely on experience and relationships to other known locations to estimate productivity factors for new locations.

Location factors provide a means of evaluating relative cost differences between two geographical locations. They are often applied to conceptual estimates for identifying "go/no go" projects at an early stage. The ability to produce meaningful data during the conceptual stage is critical to the efficient management of the funds and resources of owner companies. This is what drives location factor developers toward methods that are accurate, flexible, easily managed, and quick. Below are some common methods of developing location factors:

Cost versus Cost. The drawback is that this method concists of comparing actual costs from two similar projects. There is no assurance that all costs have been captured, that the two plants were truly similar, or that the estimated average exchange rate conversions for offshore purchases were accurately identified. There is also the inherent vulnerability to error when trying to normalize historical project costs.

Cost versus Estimate. Again, the drawback is that this method consists of comparing the actual cost for a project at one location to an estimate for the same scope of work at another location. There is no assurance that all costs have been captured or that the estimated average exchange rate conversions for off-shore purchases were accurately identified on the cost side. In addition, actual costs and estimated costs may not be directly comparable.

Estimate versus Estimate. This method consits of comparing the same project scope of work estimated at two or more locations. Project scopes can be interpreted differently by as many estimators. This can lead to significant cost differences.

Aside from the drawbacks noted above, these methods require more time, funds, and resources than most companies are willing to spend. This is not to say that none of the above methods should be used. Under the right circumstances, they all can be. It is just that neither lends itself to an ongoing continuous process.

III. EVOLUTION OF THE FACTORING METHOD

Years ago, when many U.S. owner companies needed appropriation quality estimates for foreign locations, they would develop a major equipment list with detailed specifications. Then they would go out and get hard quotes from potential vendors who would be supplying this equipment for the project. For chemical and petrochemical projects, this could amount to 25–50% of the total project cost. Engineering/design/procurement and field administration budgets would make up another 20–30% of the total project cost. That left only the labor and commodities to estimate, which would account for the remaining 30–40% of total project cost. To do this, they would survey the foreign site for labor and commodity pricing (primarily steel, piping, and wiring) and compare these to U.S. cost. Labor and commodity factors would then be developed and applied to U.S. costs.

It was from this factoring activity that the "factoring method" evolved. Since computer estimating programs were written at that time to help with the factoring of labor and commodities, it became obvious that this factoring process could be extended to cost estimates used for nonappropriation purposes.

IV. THE FACTORING PROCESS

The term "factoring method" (see Figure 1) describes a process. A factoring process offers a disciplined, logical, manageable, and cost-effective approach for developing location factors. Although these factors are usually developed to reflect relative cost differences between various countries, they can also be developed to reflect regional differences within the base country itself. This method does require a certain level of computer-aided estimating capability. That amount will be dictated by the affordability and needs of the users. An overview of the factoring process includes:

Selecting a detailed estimate for the base location

Creating a parallel estimate by:

- Applying foreign labor, material, and equipment factors (all developed at a constant exchange rate) to the base estimate
- Calculating allowances for taxes, fees, import duties, freight, etc., with expected percentages for the foreign location.
- Calculating engineering, design, procurement, and project administration costs with expected percentages or factors for the foreign location.

Ratioing the base estimate to the parallel factored/percentaged estimate to produce a location factor.

The benefits of a factoring process include:

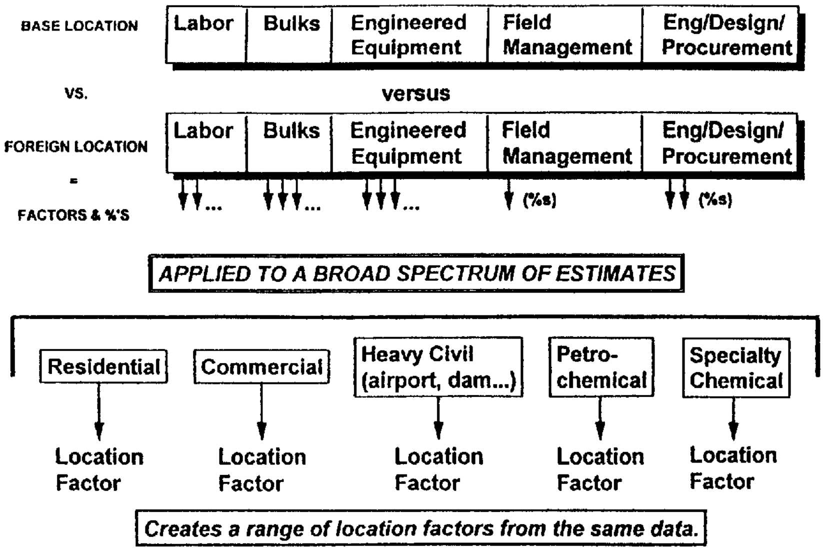

Figure 1 The factoring process.

Generates relative cost differences (%), not absolute currency values, which means:

Estimates for factoring can be used over and over again.

Various estimates can be used and maintained for providing location factors that represent various types of construction (civil, residential, petrochemical, specialty chemicals, etc.).

Pricing of labor, material, equipment and other project-specific data can be surveyed on a periodic basis, compared, and tracked. This can be an ongoing process, providing consistency and continuity of location factor data.

Quick turnaround.

Can be managed by one person.

A. Basis of a Factoring Process

A factoring process requires a detailed survey of labor, material, equipment, and other project-specific data to be completed for the base location on a periodic interval (say once a year). The same survey then can be priced out in a foreign location and compared to the base data as needed. The survey must be organized, constructed, and worded in such a way that the suppliers understand exactly what is being requested. What seems clear and precise in one culture may not be in another. With first-time suppliers, a face-to-face explanation, a walk-through of the survey, and a review of the factoring method that the survey supports should take place.

Once a survey is priced out and compared against comparable base location data, the individual factors, as well as the resulting location factor, should be shared with the suppliers. Obtaining several sources of data from a foreign location helps improve the accuracy of the output. The type of information that needs to be surveyed will depend on the structure and level of detail required for the specific factoring method used. The most common source for having a survey priced are active full-service design contractors (FSDCs) in the foreign locations.

V. EXAMPLE OF A FACTORING METHOD

Before starting, keep in perspective the impact of each major cost element on the location factor. For example, data for chemical-type projects in the U.S.A. indicates the following typical split in costs:

		Approximate %
1.	Labor	20
2.	Commodities	18
3.	Major equipment	37
4.	Field directs/indirects	8
5.	Engineering/design/procurement	17
		100

The above illustrates that all of the major cost components of a project are important. Too often emphasis is placed only on the labor portion. Percentages for those items beyond the detailed line items of an estimate (items 4 and 5 above) alone can influence the overall location factor by about 25% in the United States. Percentages applied for these items (items 4 and 5) are closely tracked by engineering companies and are obtained quite readily by industry and by country. For this reason the following example develops factors for labor, commodities, and equipment only. The common practice of using historical percentages for the foreign location for field supervision and engineering/design/procurement removes the need for detailed analysis on these items.

A. Labor

Table 1 is an example of how one might develop labor factors. To do this, wage rates from Tokyo, Japan, were acquired. We must be sure when comparing the wage rates that we are comparing them at the same level and from that specific area of the country that we are interested in. If the U.S. Gulf

Table 1 Foreign Labor Estimating Data

Site: Japan	Currency = Yen	Exchange rate: Yen/$ = 99.0 Date-Aug.'94
Rates effective: current	Rates expire: March 95	Productivity factor = 1.0

Craft	70% Mechanical	30% Helpers*	Average rate	Weights B and C	Weights M and E	Weighted B and C rates	Weighted M and E rates	Weighted average
Laborer	0	2,674	2,674	7%	3%	187.2	80.2	
Carpenter	4,784	3,987	4,545	6%	2%	272.7	90.9	
Millwright	4,784	3,987	4,545		5%	0.0	227.2	
Ironworker	4 784	3,987	4,545	2%	5%	90.9	227.2	
P.E.O.	4,784	3,987	4,545	2%	2%	90.9	90.9	
Painter	3,501	2,674	3,253	1%	2%	32.5	65.1	
Pipefitter	4,901	4,084	4,656		32%	0.0	1,489.9	
Plumber	4,901	4,084	4,656	3%		139.7	0.0	
Electrician	4,506	3,755	4,281	3%	13%	128.4	556.5	
Insulator	3,308	2,674	3,118		8%	0.0	249.4	
Sheet metal worker	3,220	2,674	3,056	1%	3%	30.6	91.7	
Totals [B and C/.25 and M and E/.75]						3,891.4	4,225.4	4141.9 Yen

Forecast of advancing wages:

1994	4%
1995	4%
1996	4%

Basic work week:	Days:	6
	Hours:	48
This job:	Days:	6
	Hours:	48

Included in above rates:

20% Retirement, insurances, welfare, recruiting, mobilization, education, training and 15% for overhead and profit — 35% × base wage,

Productivity factor ×	1.0	1.0	
Equivalent workhour	3,891.4	4,225.4	4141.9 Yen
Exchange rate ×	$0.0101	$0.0101	
Equivalent rates:			
Site: Japan (lf)	$39.31	$42.68	$41.84
Comparative rates:			
Site: La Porte **	$25.82	$26.78	$26.54
Labor factors =	1.52	1.59	1.58

Not included in above rates:

Field management:	5% of the project total
Contractors' material mark-up:	10%-20% on supplied material
Premium time provisions:	
Work week shift differential:	1.25 × rate up to 5 hrs.
	1.5 × rate 5–12hrs

* "All in" rates including social costs, contractors overhead, and profit

** Includes taxes, insurance, fees, overhead, and profit @100%

Coast labor cost in the base estimate (which will be factored) represents lump sum contractor "all-in" billing rates, then be sure that the rates for Tokyo also reflect an "all-in" billing rate. If the Gulf Coast labor cost in the base estimate represents base wage plus employee benefits, then compare the same for Tokyo.

Other pertinent labor data that is required to complete the analysis includes:

Mechanic/helper ratio.
Weighting by crafts. (Table 1 reflects a typical weighting for a chemical plant and then consolidates them into a building & civil (B&C) rate and a mechanical & electrical (M&E) rate.)
Labor productivity factor.
An exchange rate and date for the basis of our location factor.

Considering all of the above data for Tokyo, we can first develop the estimated average billing rates for a chemical plant; and then by adding in the productivity factor and an exchange rate, equivalent dollar rates to compare against identically developed open shop Gulf Coast rates to arrive at labor factors. The estimated weighted average billing rate in the local currency (4,141.9 Yen in Table 1) is something that should be confirmed with local engineering/construction companies for reasonableness. It is usually a quick and easy check that will support the process and add to the credibility of the labor factors.

When the developed labor factors are applied against the detailed labor portion of the base estimate (illustrated later under "Applying Factors"), the result is a foreign labor cost in U.S. dollars.

Note: Table 1 arrives at two factors (B&C and M&E). Some factoring methods develop a labor factor for each craft. As mentioned above, each user will need to decide what is right for his or her application.

Labor variables. The analysis shown in Table 1 was prepared on a spreadsheet that allows the user to easily substitute desired rates, ratios, weightings, productivity factors, and exchange rates. This allows the labor analysis to be tailored for a specific process, provided the historical data is available.

B. Equipment and Material

Equipment and material factors together impact the development of location factors more than any other element. Because of this, that portion of the survey must be well thought out and researched. The specifications for the material and equipment must be prepared in a way that is easy to translate and understand, gives examples of comparable equipment, and is not so specific that the vendor quotes a price for something that is uncommon and costly in the surveyed country instead of quoting an allowable substitute.

The survey of equipment and material pricing providing the 25 individual factors shown in Tables 2 and 3 is supported by detailed pricing of 11 major categories (Tables 3 and 4 provide examples of 2 of the 11 categories). These categories have anywhere from 3 to 12 items each and are weighted for a typical chemical plant. As mentioned above, the survey should be priced by those contractors who currently have the most project work going on in that specific location. Note that these surveys can require a significant amount of work-hours, so you should have the funding of this effort planned ahead of time.

A tailored material and equipment survey is not required for each estimate that you are going to factor. Instead, the survey should be generic and allow knowledgeable adjustments when choosing and applying the developed factors. The example given in Table 3 illustrates how to develop a stainless steel equipment factor. Items D, E, and F, given in Table 3 example, are for a small, medium, and large stainless steel vessel. They are weighted to arrive at an average factor for stainless equipment for a typical chemical project.

A different type of project, such as a pharmaceutical facility, would have a different weighting and thus result in a different stainless steel equipment factor. If a specific project had only stainless steel vessels that were comparable to the small vessels in the survey, then you might use only the factor arrived at by comparing the small vessels. Note that factors need to be adjusted for currency and inflation from the time that the survey was completed. As with labor, the material and equipment factors are applied to the U.S. based estimate line items to provide foreign costs in U.S. dollars.

Equipment and Material Variables

Some countries do not have the technology to manufacture certain specialized equipment. These items need to be identified in the parallel estimate so they do not get factored. Instead, use the estimated cost from the expected source (country) converted to the currency of the parallel estimate and apply the appropriate percentages for freight, import duties, customs, and brokers fees. Two other issues that must be addressed are:

1. Would certain items be imported because of quality or scheduling problems?
2. What equipment would be so costly in another country that it would be cheaper to import?

These assumptions can greatly affect the material and equipment costs for an actual project and thus a location factor when using this process. The location factor must consider expected or known project execution strategies and these assumptions must be documented. This way an adjustment could

Table 2 Foreign material data for Japan

	Aug. '94	This project
Currency exchange rates:	U.S. $ = 99.0 Y	99.0 Y

Category	Factor	Escalation factor	Currency adjustment	Adjusted factor
Tanks and columns C/S	1.11	1.00	1.00	1.11
Tanks and columns S/S	1.28	1.00	1.00	1.28
Heat exchangers C/S	1.39	1.00	1.00	1.39
Heat exchangers S/S	1.59	1.00	1.00	1.59
Pumps, steel	1.13	1.00	1.00	1.13
Pumps, S/S	1.93	1.00	1.00	1.93
Rotating equipment	1.30	1.00	1.00	1.30
Electrical equipment (major)	1.33	1.00	1.00	1.33
Instrumentation (major)	1.38	1.00	1.00	1.38
Piping C/S	1.15	1.00	1.00	1.15
Piping S/S	1.23	1.00	1.00	1.23
Insulation, Ca silicate	1.34	1.00	1.00	1.34
Insulation, polyisourethane	1.36	1.00	1.00	1.36
Insulation, mineral wool	0.98	1.00	1.00	0.98
Painted steel	1.24	1.00	1.00	1.24
Galvanized steel	1.29	1.00	1.00	1.29
A and C materials	1.66	1.00	1.00	1.66
Galvanized sheet	0.93	1.00	1.00	0.93
Aluminum sheet	1.85	1.00	1.00	1.85
S/S sheet	1.09	1.00	1.00	1.09
Ductwork mix	1.14	1.00	1.00	1.14

Table 2 (cont).

	Aug. '94	This project
Currency exchange rates:	U.S. $ = 99.0 Y	99.0 Y

Category	Factor	Escalation factor	Currency adjustment		Adjusted factor
Electrical supplies (commodities)	1.63	1.00	1.00		1.63
Instrumentation supplies (commodities)	1.40	1.00	1.00		1.40
Open structure					
Steel (galvanized)	1.29	1.00	1.00	84%	1.09
Concrete	1.66	1.00	1.00	13%	0.22
Lumber	2.85	1.00	1.00	3%	0.09
					1.39
Closed structure					
Steel (painted)	1.24	1.00	1.00	68%	0.85
Concrete	1.66	1.00	1.00	15%	0.25
Lumber	2.85	1.00	1.00	15%	0.43
Insulation	0.98	1.00	1.00	2%	0.02
					1.54

Additional material data:
Ocean freight—7% on equipment (avg.)
Import duty—5% on imported equipment + ocean freight
Broker and customs fees—2% on the above
Consumption tax—3% on material and equipment
Local freight—2% on material and equipment

Material escalation:	1994	1995	1996	1997
U.S	3%	4%	4%	4%
Japan	2%	3%	2%	3%
Year end exchange rates:				
Japanese Yen):	102.0	110.0	110.0	110.0

Table 3 Detail of Tank and Vessel Comparison

Category 1	Item weight	United States Unit price	United States Weighted price ($)	Japan Local currency	Japan Unit ($)	Japan Weighted prices
Tanks and vessels				Y 000		
Tank, straight side (2.4m×3.1 m); 4,300 gal. (16.3 m^3); flanged and dished top/bottom heads; 5116 ft (8mm) shell; six 3 ft nozzles; 22 in. manhole; ASME code or equal; 25 psig @100 C; 20 in. hg vacuum; shop fabricated w/spot X-ray; hydrostatic test; (4) support lugs., 304 S/S; 8 ft dia.×10 ft	43%	$30,000	$12,900	3,000 Y	$30,303	$13,030
Tank, (7.3m×9.1m); 100,000 gal. (379 m^3); dome roof/flat bottom; 5/16 ft (8mm) shell; (6) 6 in. nozzles; (1) 24 in. manhole; API 650 or equal; 2 ft vacuum; including galvanized ladder, Platform and handrail; shop fabricated: Field erected. (Includes cost of field erection) 304S/S, 24 ft dia.×30 ft h	35%	$120,000	$42,000	15,400 Y	$155,556	$54,444
Distillation column, 304 S/S; 12 in. dia.× 47 ft straight side (3.7m×14.3m); (20) 304 S/S sieve trays; 10 psi w/full vacuum (.7kg/cm^2); 8 ft (2.4m) skirt; (2) 18 in. dia. access openings; nozzles = (8) 4 in., (4) 2 in., (6) 6 in., (2) 10 in., (2) 12 in.; (2) 20 in. manways; ASME code or equal; 150 C; shop fabricated w/spot X-ray; hydrostatic test. (excludes cost of valve trays).	22%	$225,000	$49,500	30,000 Y	$303,030	$66,667
Category 1						
Sum-weighted S/S tanks and vessels			$104,400			$134,141
Factor to U.S.			1.00			1.28

be made to the overall location factor if the assumptions for another project are different.

Equipment and Material Adjustments

When the survey is priced out by only one source in a location, it is not uncommon to have some of the individual equipment and material comparisons be drastically different. When this occurs, contact those who filled out the survey and discuss the specification for the item(s) in question. Reviewing the specification and getting a revised quote usually solves the problem. If it is not possible to go back to the suppliers of the surveyed data, then eliminate that item(s) from the roll-up of that category (see Table 4). This is not difficult to do if there are enough items in each category. If the entire category comparison does not seem realistic, then an approximate factor can be estimated based on relationships with other categories. After working with a survey and region over a period of time, it will be possible to approximate a comparative factor prior to actually doing the analysis.

C. Applying Factors to Create an At-Location Estimate

Once the labor, material, and equipment factors are developed, it is time to apply them to the detail line items of the base estimate.

Example

Knowns =	99	Yen/$1.00 (August 1994)
	1.59	M&E labor factor
	1.63	Electrical commodities factor
	1.33	Electrical major equipment factor

Detail line item of an estimate

Estimate	Labor	Commodities	Equipment	Total
Electrical wiring (U.S.)	$32,670 +	$22,850 +	$45,660 =	$101,180
Factors	× 1.59	× 1.63	× 1.33	
Electrical wiring (Japan)	$51,950 +	$37,250 +	$60,730 =	$149,930

The above illustrates how electrical wiring was costing approximately 48% more in Tokyo, Japan, than in the U.S. Gulf Coast in August of 1994 @99 Yen/$1.00. Similar factoring would need to occur against all the detail line items of the base estimate. Each type of estimate (civil, commercial, chemical, etc.) would use a different mix of factors that would produce a different

Table 4 Adjusting for Questionable Data

Category 10	Item weight	United States: Unit price	United States: Weighted factor	Japan: Local currency	Japan: Unit $	Japan: Weighted factor
Electrical supplies		/MFT		/KM	/MFT	
(A) Cable, THWN-V or equal						
(1) 4/c #14 ($2.5mm^2$)		$210		115,000 Y	$354	
Factor to U.S.		1.00	1.69			0.78
Item weight	46%		0.48			
(2) 7/c #14 ($2.5mm^2$)		$329		180,000 Y	$554	
Factor to U.S.		1.00	1.69			
Item weight	18%		0.18			0.30
		/LF		/M	/LF	
(B) 3/4 in. (22mm) aluminum or galvinized conduit		$0.48		220.0 Y	$0.68	
Factor to U.S.		1.00	1.41			
Item weight	16%		0.16			0.22

(C) Cable tray aluminum or galvanized						
(1) 24 in. w × 4 in. h × 1/8 in. (indoor use) (600mm × 100mm × 2mm)		$4.52		5,600 Y	$17.24	**
Factor to U.S.		1.00	0.00			
Item weight	7%		0.07			0.00
		EA		EA	EA	
(2) Horizontal bend, 90 deg.		$29.80		11,000 Y	$111.11	**
Factor to U.S.		1.00	0.00			
Item weight	2%		0.02			0.00
(D) Lghting (non-explosion type)						
(1) High intensity discharge fixture, HPS 100		$212.58		32,000 Y	$323.23	
Factor to U.S.		1.00	1.52			
Item weight	5%		0.05			0.08
(2) Florescant fixture for office 2-lamp, 40-watt (Troffer type)		$45.13		7,800 Y	$78.79	
Factor to U.S.		1.00	1.75			
Item weight	3%		0.03			0.05
(3) Circuit breaker panel, 24-circuit, 4-wire,120/208 w/150 amp main breaker and 20 amp plug-ins or equivalent. (outdoor use-non explosion)		$800		211,000 Y	$2,131	**
Factor to U.S.		1.00			0.00	
Item Weight	3%		0.03			0.00
Category 10						
Sum, item weighted factors			1.00			1.63

** Did not use to develop factor

location factor for the various types of construction.For this reason, a library of estimates might be maintained to factor depending on the need at that particular time.

The above also illustrates that the base estimate could be 20 years old and it wouldn't matter since we are developing and looking at relative relationships and not absolute dollars. As mentioned earlier, an appropriate level of computer-aided estimating is required.

D. Rolling Costs Up to Project Level

After all the details of the estimate have been factored, it is time to add in all the extra costs such as taxes, import duties, brokers fees, etc. These are included as percentages (requested as such in the survey of data) of one of the elements of the estimate. Duties, ocean freight, and brokers fees can be expressed as a percentage of imports, local freight as a percentage of material/equipment, taxes as a percentage of material and equipment, etc. It is necessary to know at what level each of these percentages must be applied. Applying such allowances incorrectly could have a significant impact on the total estimate. Since a location factor is instantaneous, no escalation of these costs is required.

The next step is to capture the field management costs. It is easier to request only those costs associated with management of the project work in the field and not all of the field indirects. This would include salaries and expenses of the field management team, their supplies, utilities, facilities, and the maintenance of those facilities. Total field indirects are difficult to capture since interpretation can vary with each contractor. Field management is normally estimated by applying a percentage to the total project costs (requested in the survey). Monies for social costs and contractors' overhead and profit must be included at this point if not built into the wage rates. This is usually input as a percent of direct labor.

The final areas to cover are the engineering, design, and procurement. They are also entered as a percent of total project cost. Most of this work is contracted out to FSDCs. The percentages of total project cost will vary by type of project. These percentages are readily available from local contractors. Capital costs required to do any of the up-front engineering by the owner must also be considered. This could include the development of a basic engineering package and/or procurement of proprietary equipment. This effort is also available and input as a percentage of total project cost. Too often the owners' efforts in the field administration and engineering/design and procurement areas are overlooked or underestimated.

E. Comparison at the Summary Level

When the factoring and percentages described above are applied to the base estimate, a parallel estimate in U.S. dollars for Japan is created. The cost relationship between the base estimate and the parallel estimate produces the location factor. The factored estimate will be reflective of the same project scope used for the base estimate. A location factor developed using a factoring method will not add, alter, or delete project scope. The resulting location factor from this comparison is instantaneous at the given exchange rate at a specific point in time. No location factor should be discussed or used without these two qualifiers.

As mentioned earlier, the accuracy of the location factor can be improved by having several surveys filled out for each foreign location. The more that is known about the execution strategy and the local/import content of a specific project, the more the process can be tailored to meet specific needs. Once the factor is developed, it may be desirable to round to the nearest .05 (i.e., 1.03 > 1.05). Although the factor is relatively accurate, it should not be inferred as precise.

VI. MAKING THE FACTORING PROCESS WORK

The greatest difficulty in making the factoring process work lies in the survey. What may be clear and precise in the base location may be hard to interpret in another culture. It takes time and a lot of communication to develop a meaningful survey. It also takes knowledgeable adjustments and interpretations when developing and using the factors. Establishing relationships by sharing the output with the suppliers over a period of time improves the quality of the information.

It usually takes two or three repetitions of the survey before a real understanding is reached. Explaining the method face-to-face is always a good start, but it is only when the resulting analysis of the survey data is used in the factoring process that a true appreciation of what is required hits home. As their confidence and understanding in the method builds over time—and provided they have a need for the results—the accuracy improves.

VII. APPLYING AND UPDATING LOCATION FACTORS

By definition, a location factor is instantaneous and is only good at a specified exchange rate and point in time. A location factor developed from data supplied last year would have to be adjusted for currency and inflation differences between the two countries before it could be used today. Tracking location factors monthly by inputting revised monthly exchange rates and one-twelfth of the forecasted annual inflation will provide updated factors between re-analyses. This is accomplished by using the following formula:

$$\text{new factor} = \text{old factor} \times \frac{\text{new exchange rate}}{\text{old exchange rate \$}} \times \frac{\text{foreign inflation \$}}{\text{base country inflation}}$$

This formula is also used to update material and equipment factors (Table 2). The location factors can be updated for about two years before requiring another complete analysis. (Through periods of significant currency and inflation fluctuations, this timing needs to be shortened).

Location factors help develop the project execution strategy. When the location factor shows that is 25–30% more expensive to build in another country using locally procured material and equipment, the procurement strategy would likely change, since importing and paying the ocean freight and duties may then become feasible. The foreign site could reduce project costs by purchasing material and equipment off-shore.

Project teams should also consider vendor assistance requirements, accessibility to spares, timing for replacement deliveries, and maintenance of installed equipment before electing to procure off-shore. If the decision is made to procure locally in these situations, then the location factor could go beyond the cost of importing. These decisions would have to be made on a project-by-project basis.

VIII. SUMMARY

Location factors are a vital product of any international organization. One thing is for certain—location factors will be challenged. So, not only is it important to have an easily understood and logical method of developing location factors, the process must be supported with hard data from a well-defined survey and a foreign project execution knowledge that only comes through experience.

International markets and politics are constantly changing and those involved with developing location factors must be constantly collecting, analyzing, and understanding the effects created by these changes. Location factor development should not be a mathematical exercise that is done on an as-needed basis, but should be a continuous improvement process. The factoring method of developing location factors is a tool for contributing to that process.

11
Estimating the Cost of Environmental Restoration

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PART ONE: ENVIRONMENTAL COMPLIANCE

I. INTRODUCTION

As the mid-1990s unfold, construction investment for environmental projects is running over $20 billion annually in the United States. The key to successful completion of environmental remediation projects is good sound cost estimating and cost control practices and techniques.

This chapter presents a comprehensive approach to resolving key estimating and hazardous waste issues such as environmental regulation impacts to the cost and schedule; management of hazardous waste projects, estimating environmental restoration projects, hidden costs of remediation, cost growth, risk, and uncertainty analysis.

II. DIFFERENT ENVIRONMENTAL REGULATIONS THAT AFFECT INDUSTRY

A general understanding of the relevant environmental regulations and policies is the first step toward incorporating their impacts into a project plan. Many environmental cleanup activities are mandated by federal, state, and local regulations. Therefore, a project manager must be aware of the regulations that may impact a project and the regulatory agencies that are administering those programs.

There is no Federal, generic environmental statute. Rather, a series of laws has been enacted by Congress to address environmental issues as they have arisen and been recognized as requiring national legislative and regulatory action.

Some of the numerous federal laws that may impact a project are:

Clean Air Act (EPA)—regulates emission of hazardous air pollutants.

Clean Water Act (EPA)—regulates discharge of hazardous pollutants into the nation's surface waters.

Comprehensive Environmental Response, Compensation, and Liability Act (EPA) provides for cleanup of hazardous waste sites.

Resource Conservation and Recovery Act (EPA)—regulates hazardous waste generation, storage, transportation, treatment, and disposal.

Superfund Amendments and Reauthorization Act (EPA)—establishes requirements for Federal, state, and local governments and industry regarding emergency planning and "community right-to-know" reporting on hazardous and toxic chemicals.

In addition to these laws, there are several other Federal, state, and local environmental laws and regulations that can impact a project. Because the regulations and enforcement responsibilities vary from state to state and because the regulations evolve at a very rapid rate, it is beyond the scope of this or any single text to provide a complete up-to-date reference of all environmental regulations that may be applied to a given project. With this in mind, we will concentrate on the above listed regulations with the primary concentration on the federal regulations that will have the most impact on environmental projects: the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). We recommend that if you have questions regarding regulatory compliance that you contact your environmental or legal council. We have also provided a listing of each of the ten EPA regions, primary state regulatory agencies, and other informational contacts in Appendix C for your reference.

There are other statutes that apply to environmental matters that are administered by other governmental entities. For example, the transportation of hazardous waste is regulated principally by the Department of Transportation, surface mining by the Office of Surface Mining, fish and wildlife matters by the Fish and Wildlife Service, oil spills by the Coast Guard, and dredging or filling of wetlands by the Army Corp of Engineers. Where there is shared or correlated responsibility between EPA and these other agencies in carrying out their legislative mandates, memoranda of understanding and cooperative agreements of various kinds generally have been or are being developed to provide coordination and cooperation.

There are a number of aspects that environmental laws administered by EPA generally share. Some of them are:

There generally are national standards regulating the handling, emission, discharge, and disposal of harmful substances.
The statutes are applied either through general rules at the State or Federal level, through permits, or both.
States are given implementing responsibility for most programs (EPA authorizes state program enforcement).
There usually are specific entry and inspection provisions in addition to authority for information requests and demands, monitoring, testing, and reporting.
The EPA generally is given the authority to issue notices of violation and compliance orders.
The EPA usually is able to seek injunctive relief through civil courts or impose it administratively.
The EPA usually can seek administrative penalties or civil or criminal remedies.
The statutes generally provide emergency authority.
The statutes generally enable EPA to eliminate, through assessment of financial penalties, any economic advantage gained by a noncomplying source as a result of its noncompliance.
Most statutes require their substantive requirements (although enforcement is different than for private facilities).
States may take enforcement action under applicable state law, however EPA may also pursue Federal enforcement action.

The following are summaries of the major regulations, listed on page 2 and 3, that provide a general introduction to each regulation and identifies the regulatory actions that need to be considered when developing the preliminary plans of a environmental restoration project.

Clean Air Act

The Clean Air Act is intended to foster the protection and enhancement of the nation's air quality, and to safeguard public health and welfare and the productive capacity of the population. The Act is divided into three titles:

Title I deals with control of pollution from stationary sources.
Title II deals with control of pollution from mobile sources.
Title III addresses general and administrative matters.

The Act requires EPA to promulgate national ambient air quality standards (NAAQS) for certain pollutants to protect the public health (primary NAAQS) and protect the public welfare (secondary NAAQS).

Each State is required to adopt a plan, called a State Implementation Plan (SIP), that limits emissions from air pollution sources to the degree necessary to achieve and maintain the NAAQS. The SIP provides emission limitations, schedules, and timetables for compliance by stationary sources. The Act focuses on "major" stationary sources or major modifications of existing sources. Major sources are defined as sources which emit, or have the potential to emit, more than a prescribed amount of a designated pollutant.

States are also required to adopt measures to prevent significant deterioration of air quality (PSD) in "clean air areas." When an SIP is approved by the Administrator, it is enforceable by both the Federal and State governments.

In addition to the SIP regulatory scheme, the Act establishes two (2) other major regulatory programs for stationary sources. The New Source Performance Standards (NSPS) program establishes stringent emissions limitations for "new" sources in designated industrial categories regardless of the State in which the source is located or the air quality associated with the area.

The second program, the National Emissions Standards for Hazardous Air Pollutants (NESHAP), regulates emissions of pollutants for which no NAAQS is applicable but causes increases in mortality or serious illnesses.

Clean Water Act

The purpose of the Clean Water Act (CWA) is to assure that the nation's waters are safe to the public and support fish and other stream life. These objectives, contained in the statute and commonly known as the "fishable and swimmable" provisions of the Act, were to be achieved by 1985.

In 1972, the Federal Water Pollution Control Act (FWPCA) was significantly amended. Those changes initiated a new regulatory and enforcement approach to cleaning up the nation's waters, combining the setting of state water quality standards based on desired water use objectives (such as cold water fishery) with establishment of individual facility effluent limitations. The amendments called for compliance by all point-source dischargers with technology-based standards implemented through discharge permits. Also, they added Section 404 which established a new permit program to control the discharge of dredged material into water of the U.S., including wetlands.

The major regulatory provisions of the CWA is The National Pollutant Discharge Elimination System (NPDES). This program was established by Section 402 of the CWA and, under it, EPA and approved States have issued more than 60,000 NPDES permits, as of 1992. Permits are required for all point sources from which pollutants are discharged to navigable waters. An NPDES permit is required for any direct discharge from new or existing sources. Indirect discharges through POTWs are regulated under a separate program.

The NPDES permit is issued by EPA or an EPA-authorized state to include those applicable provisions described previously. It is the specific document that provides the reference point for enforcing Federal and State effluent limitations for any particular industrial facility, including:

Limits based on effluent guidelines
New Source Performance Standards
Toxic effluent standards
Limits based on State water quality standards under Section 303 of the CWA, if any are applicable.

CWA Enforceable Provisions. Violations of the Act may be primarily categorized into the following areas:

Direct discharges other than those complying with an NPDES or dredge and fill permit
Indirect discharges in violation of national pretreatment requirements
Failure to perform wastewater monitoring, sampling, or test result reporting that are established by national requirements
Improper discharge or disposal of sewage sludge
Violations of administrative orders
Noncompliance with Section 308 information request letters

Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA, commonly referred to as "Superfund," is the other primary regulatory act that impacts many of the environmental management and hazardous waste projects. The law was enacted in 1980 to give the federal government the authority to clean up hazardous wastes and respond to releases of contaminants that pose a threat to human health and the environment. This law was amended in 1986 as the Superfund Amendments and Reauthorization Act (SARA). One of the major provisions in CERCLA as amended by SARA is the opportunity for the government to conduct site cleanups and determine the potential responsible parties (PRPs) that are liable for paying the costs of the cleanup activities.

The basic procedures to be conducted under Superfund are defined in the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). The NCP establishes steps that the federal government must follow in responding to the release or threat of release of hazardous substances. These procedures include both immediate actions known as *response actions* and long-term cleanups known as *remedial-response actions.*

The Superfund process begins upon discovery of a potentially hazardous site. The situation is reviewed to determine if the conditions require emergency actions or if a long-term action is more appropriate. Removal responses typically are completed in less than 1 year, with remedial responses being extended programs consisting of many steps that may take several years to complete.

The first steps of the remedial response process are site discovery and preliminary evaluation. Any federal, state, or local government agency may identify a site for future evaluation. The federal government then conducts a preliminary investigation to determine the extent of the problem and provide information that will be used to evaluate the priority for conducting remedial actions. Upon completion of this step it may be established that there is no threat or potential threat to human health and the environment and the site may not require any additional remedial action. The information from the preliminary assessment is used to calculate a *hazard ranking system* score to determine the priority for conducting a site cleanup. Depending on the hazard ranking system score a site may be placed on the National Priorities List (NPL) as a site that poses significant threat to human health and the environment and must be remediated.

If a site is placed on the NPL, cleanup actions are evaluated and selected by a remedial investigation and feasibility study (RI/FS) process that is specifically defined in federal guidance documents. This process is an integrated approach that characterizes the site conditions, assess the potential human health and environmental risk resulting from site hazards, identifies numerous cleanup and treatment technologies, and reviews the applicability of these technologies to meet long-term remediation objectives. An RI/FS and site cleanup may be conducted by the PRPs or by the federal or state government and includes a high level of public participation. The recommended remedial action must meet CERCLA requirements but must also comply with other state and federal applicable or relevant and appropriate requirements (ARARs). Upon acceptance of an RI/FS by the EPA a remedial action is recommended and documented in a Record of Decision (ROD); the remedial action is then conducted in accordance with the ROD.

The process described above is a very brief summary of the numerous and sometimes time-consuming steps that are required for remediation of a NPL site. The importance of understanding this process prior to conducting a CERCLA cleanup can not be overstated. There are numerous pitfalls that can delay a project and cost thousands of dollars. It is important to know that if you are working at a site that becomes a NPL site that there are several specific steps that must be followed in order to comply with the federal regulations.

The following is a list of the basic steps that must be considered and incorporated in the project plans when hazardous waste or contaminated soil or ground water are discovered and remedial action is required:

Collect initial site background information
Develop a plan for conducting a site investigation
Obtain regulatory agency approval of the investigation plan
Conduct site investigation
Compile results and review with regulatory agency
Prepare remedial action feasibility study
Obtain both agency approval for cleanup action
Conduct site cleanup
Conduct sampling/analysis and obtain agency sign off on the project

Resource Conservation and Recovery Act

RCRA was signed on October 21, 1976, and subsequently amended in 1980 and 1984. Its major purposes are to provide "cradle to grave" management of hazardous wastes, management of solid wastes, and regulation of underground storage tanks containing chemical and petroleum products.

Hazardous wastes are subject to regulation in their generation, transport, treatment, storage and disposal under Subtitle C. Solid wastes, if land disposed, are regulated through State programs under Subtitle D. The 1984 amendments to RCRA, among other things, added Subtitle I, which enables national regulation of underground storage tanks for the first time.

In addition to the Subtitle C,D, and I provisions of RCRA, other important sections of RCRA include:

Control of Hazardous Waste Injection. Section 7010 prohibits underground injection of hazardous waste into or above any formation that contains an underground source of drinking water within 1/4 mile of the injection well.

Technical Assistance. Section 2003 provides technical assistance to Federal, state, and local governments on solid waste management and resource recovery.

Conservation and Recovery. Sections 2003, 2004, 6002, and Subtitle E direct various activities to promote the conservation and recovery of valuable material and energy resources.

Training, Research, and Application. Subtitle H provides training grants in occupations involving design, operation, and maintenance of solid waste disposal systems; promotes a national research and development program for improved solid waste management and resource conservation techniques and systems that preserve and enhance the quality of air, water, and land resources.

RCRA Enforcement Authorities. Violations may be primarily categorized in the following areas:

Hazardous Wastes

Inspections and Reporting. Section 3007 provides the authority to enter, inspect, copy records of, and obtain samples from facilities that handle hazardous waste.

Federal Enforcement. Section 3008 provides EPA the authority to issue compliance orders, initiate civil litigation for injunctive relief, and assess penalties for violations of Subtitle C requirements, provides for criminal penalties for specified violations.

Monitoring, Testing, and Analysis. Section 3013 provides the authority to issue administrative orders requiring owners and operators of hazardous waste facilities to undertake monitoring, testing, analysis, and reporting regarding their facility whenever EPA determines that the release of any hazardous waste from such facility may present a substantial hazard to human health or the environment.

Solid/Hazardous Wastes

Imminent Hazard. Section 7003 authorizes the Administrator to bring suit against or issue orders to any person contributing to the handling, storing, treating, transporting, or disposing of any solid or hazardous waste in a manner that may present an imminent or substantial endangerment to human health or the environment.

Underground Storage Tanks

Inspections, Monitoring, and Testing. Section 9005 provides that any owner or operator of an underground storage tank, upon request by a duly authorized representative of EPA or a state that has an approved program, shall furnish information relating to such tanks and their contents, and conduct testing and monitoring and grant reasonable access to such representatives.

Federal Enforcement. Section 9006 provides for administrative or judicial enforcement actions and the imposition of civil penalties for failure to comply with notification and other regulatory requirements of the Subtitle.

Citizen Suits.

Section 7002 allows citizen suits against any person, including the U. S., who is alleged to be in violation of any permit, standard, or regulation that has become effective pursuant to RCRA; or against any person, including the U.S., who has contributed or is contributing to the past or present handling, storage, treatment, transportation, or disposal of any solid or hazardous waste that may present an imminent and substantial endangerment to health or the environment.

A. Environmental Regulation Impacts to the Cost and Schedule

Perhaps the most important step in a project, given our current regulatory environment, is to evaluate the environmental conditions of the project, including the history of the site property. This is very important during the property acquisition or selection of a project location. The majority of property transfers and other transactions are now contingent on conducting an environmental site assessment of a property or facility.

Potential project cost and schedule impacts from environmental regulations can be reviewed in a logical sequence by addressing a project in the following three phases: 1) initial property or facility acquisition, 2) site preparation and demolition, and 3) facility construction. This section will look at each of these project phases and identify areas of concern and the potential impact of regulations. In addition, we will review how to negotiate and manage a hazardous waste investigation and remedial action.

Initial Property or Facility Acquisition

There are several environmental regulations that are of concern to a project and should be evaluated before property is purchased or designated for a project. Many of these regulations have to do with existing site conditions or possible contamination that may have originated at the potential site. We will evaluate potential regulations and identify impacts that should be included in the project plan.

Due Diligence

The federal government, along with the majority of states in the country, has established hazardous waste regulations that are designed to protect human health and the environment. Many of these regulations have established extensive lists of contaminants and contaminant concentrations that are considered hazardous. The presence of these contaminants causes concern to the environmental regulatory agencies and may necessitate investigation and cleanup of a site. Current hazardous waste regulations have established that the cost for cleanup must be paid for by both the present and past owners of the site, as well as any parties that generated contaminants or transported them to the site.

There are few defenses that will allow a property owner to avoid paying for cleanup of the site. These expenses can easily cost *millions of dollars*. One of the most common defenses to lessen or defer investigation and cleanup cost is to qualify oneself as an *innocent purchaser*. To meet this defense the purchaser must demonstrate that the contamination occurred prior to this purchase of the site and that he did not know *and had no reason* to know that the site was contaminated. This burden of proof lies with the purchaser of the property. Therefore, when purchasing property or facilities the purchaser must be able to demonstrate that he used *due diligence* to investigate for the presence of hazardous constituents; if he is unable to demonstrate this he will be responsible for cleanup costs.

Based on the potential cost and liability of these statues, property owners, banks, insurance companies, and other lending institutions require environmental site audits to be conducted prior to the transfer of ownership for property or facilities. These audits or assessments vary in cost from $2,000 to $3,000 for small sites that do not require any sampling and analysis, to approximately $100,000 for a large industrial facility that may have numerous potential problems. Typically, audits can be completed within 3 weeks for a small facility or can take several months depending on the complexity of the site and the level of contamination.

Unfortunately there are no rules of thumb that can be universally applied to all sites. The cost and duration of a site audit is dependent on the site history, surrounding areas, and the state and Federal regulatory climate. Each of these factors can easily modify the scope of work. Another significant factor is the amount of time that is allowed for the analysis. Typically, analytical results require 30 to 45 days. This duration is from the time the samples are received until results are available. Another 7 to 21 days need to be added for verification and review of the results. This 1 to 2 months can have a significant impact on a project schedule if this activity has not been included in the project plan. It should be noted that this analysis can be expedited but the costs will be increased by as much as 100% depending on the laboratory schedule and the number of samples analyzed.

There are no environmental regulations that require an owner to conduct a site audit; however, it is recommended that this type of investigation be incorporated into any project plan that will involve newly purchased property or facilities. Site audits should be conducted for projects at locations that you already own but of whose current or past environmental status you are unaware. If the study has been done correctly, the owner should be well aware of any problems that could impact an upcoming project. Typically this type of study will also identify potential problems that may not be in compliance with other environmental regulations. This process is quick and inexpensive, and can save major unforeseen cost and schedule increases.

Site Preparation

There are a variety of Federal and state hazardous waste regulations that may apply to any given site during the construction phase of a project. The primary

Federal regulations are CERCLA/SARA and RCRA that dictate the type of contaminants that are hazardous, the levels of contamination that require cleanup actions to be initiated, and establish cleanup or disposal methods that are acceptable. In addition to the federal regulations, many states have developed regulations that are as restrictive or even more restrictive than the federal regulations. Refer to the second section of this chapter for more information on CERCLA/SARA and RCRA federal regulations.

State and Federal Hazardous Waste Regulations

Because the cleanup or action levels for given contaminants vary from state to state, we have not listed specific cleanup levels. It is recommended that you contact the EPA or local state agency to obtain the most recent information; they will be able to suggest possible actions that may be required to clean up the contaminants at your site. Fortuna and Lennett provide an interpretation of the hazardous waste definition stated in volume 40 of the Code of Federal Regulations (40 CFR) that is helpful in understanding the requirements of the regulations if a material is a hazardous waste. This definition is as follows:

A waste is considered hazardous if it falls within any of the four categories listed below and if it does not qualify for any of the exemptions or exclusions stated in 40 CFR 261:

1. EPA may list a waste, usually from a specific production process, as hazardous, based principally upon the presence of specific hazardous constituents in the waste or because the water consistently exhibits one or more characteristics of a hazardous waste (40 CFR Part 261 Subpart D). EPA may also list a product as hazardous waste if it is discarded in a pure or off-specification form and contains specific constituents.
2. Those solid wastes and waste generation processes that have not been specifically listed by EPA may nevertheless be identified as hazardous solely on the basis that they exhibit one or more of the four characteristics of hazardous waste irrespective of the manufacturing process from which it is generated. The four characteristics are: ignitability (I), corrosivity (C), reactivity (R), or toxicity (EP). Toxicity (EP) means the ability or tendency to leach certain constituents via a specific extraction procedure (40 CFR Part 261 Subpart C).
3. It is mixture of a listed hazardous waste and any other material, or is a mixture of a characteristic waste and any other material, provided the mixture still exhibits characteristic (40 CFR 261.3 (a) (iii) (iv)).
4. It is a residue that is *derived from* the treatment, storage, or disposal of a listed waste (40 CFR 261.3 (c)), such as incinerator ash.

These regulations frequently impact a project during the site preparation phase. Any soils or demolition debris that are being removed from the site must be disposed of properly. If this material is considered hazardous by either state or federal regulations the disposal costs can increase dramatically. For example, soil removed from a site that is not hazardous material may be used as fill at another location, thereby allowing for less excavation and transportation costs, and disposal may be free. If this same material (soil) is deemed a hazardous waste, landfill can easily be as much as $300 per cubic yard, not including sampling and analysis costs to determine the level of contamination. Again, evaluating site conditions prior to beginning site work will identify hazardous material conditions so that they can be included in the project budget.

If there is a significant amount of contamination, the state environmental agency or the EPA will more than likely become involved. This investigation process may take a year or longer to complete and cost between fifty and several hundred thousand dollars depending on the level of contamination. These unplanned costs and schedule delays can greatly impact the initial project plan and economics.

Gain as much information as you can about a site at the initial phase of a project. If there have been underground tanks, transformers, solvent cleaning activities, uncontrolled disposal practices, or other activities, proceed with caution and have a very flexible project schedule and budget.

Facility Construction

During the remaining construction phases of a project environmental regulations should have limited impact with the exception of start up and operation. During these final stages it is very important to have the proper permits (e.g., NPDES or the air quality permit) in place prior to initiating any discharge. Another area of compliance is Superfund Amendments and Reauthorization Act Title III, which deals with the public right-to-know information. This regulation requires notifying local health and safety organizations such as the fire department of hazardous materials that are on site and maintaining records and other information regarding these materials. Most construction organizations and owners are familiar with this act and the coordination of material safety and data sheets (MSDS). This is an ongoing process and should not impact any given project.

Project Strategy

Remember is that the primary purpose of the site investigation, as described in Section 11.3.4, is to gain enough information to prove that a site is not contaminated, or to identify a cleanup process that can be applied. It is important to remember this strategy when developing an investigation plan. It is also important to remember that most hazardous waste projects will need to be accepted by the public. Therefore, the investigation that is conducted should be one that the public will believe is representative of the conditions at that site. Gather data that will be needed to design a cleanup strategy; do not just go through the investigation process hoping not to find any contamination. A well-planned and negotiated investigation will result in a shorter total project schedule and will be more cost effective in gathering field data.

Work with the regulatory agency to determine exactly what their concern with the site are. If they have only one area of concern, address that area only. Good relations with the agencies are not always easy to attain. It is important to educate the regulator about your concerns and reach a mutual understanding of the project requirements.

When conducting the cleanup be sure to gain agency approval throughout the process. There is nothing worse than thinking that you have completed a project only to find that the regulators did not understand what you were doing and want the work to be redone.

Overall there are is a growing number of environmental regulations that will impact projects. Although a project manager may not be able to predict wha t the regulations will be next year, it is likely that they will be equal or more restrictive than the current regulations. It is important to become aware of the regulations incorporate them into your project plans. Ignoring the potential impact of environmental regulations can be very costly and time consuming.

PART TWO: ESTIMATING ENVIRONMENTAL RESTORATION PROJECTS

III. THE THREE LEGS OF ESTIMATING ENVIRONMENTAL RESTORATION PROJECTS

An activity-based estimating approach should be used whenever possible to produce a credible estimate. A diagram for developing activity-based estimates is shown in Figure 1.

A. How to Develop the Scope

Identify the Scope of Work

The scope of work being estimated is defined in terms of technical requirements and specific criteria for performance. The work is described, including its expected end condition, performance methods, measurable deliverables, and any significant exclusions.

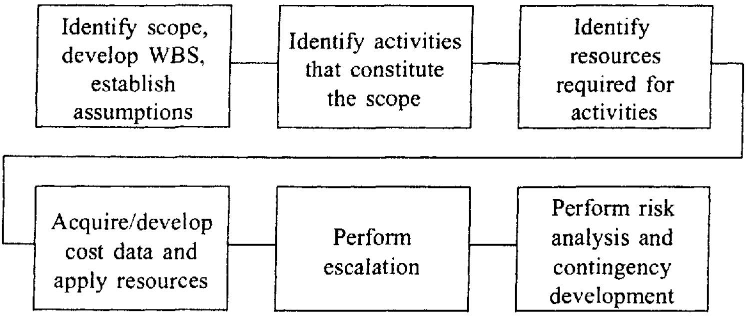

Figure 1 Activity-based estimating approach.

Develop Work Breakdown Structure

The Work Breakdown Structure (WBS), a hierarchical structure subdividing the project work through successive levels of detail, constitutes a formally organized definition of the scope of work. When used for purposes of organizing cost estimate information, the WBS facilitates the development of a hierarchically structured breakdown of costs. An estimate-specific WBS is developed as a tool to logically organize costs and provide insight into how various work elements contribute to project costs.

Establish Technical Approach

In addition to the scope and WBS, assumptions and expected conditions under which work will be performed must be established. Depending on the stage of the project definition and the type of estimate being performed, assumptions may cover information such as the extent or type of contaminants, the expected level of regulator involvement, the remedial technology to be used, and other factors. Assumptions are established at the outset of the estimate and developed as necessary throughout the estimating process. In general, improved project definition results in fewer and better-defined assumptions.

B. How to Develop the Schedule

Activities and Durations

The activity-based approach requires the scope of work to be divided into discrete, measurable units of work for estimating. To the extent possible, the units of work (activities) should have a clearly defined start and finish, including specification of any associated deliverables or other completion criteria. An activity is defined in terms of work output, not labor hours to perform, and should be sufficiently small to support detailed scheduling.

A unit of measure reflecting the basic work output associated with an activity is established in order to quantify the work. For example, if the activity being estimated is soil excavation, the basic unit of work would be *cubic yards of soil excavated.* Much work that has traditionally been estimated as a Level of Effort (LOE) can be analyzed into activities with specific completion criteria and/or deliverables in order to perform an activity-based estimate.

Logical Sequencing

Network logic diagrams are used to begin sequencing the activities at the highest level of the WBS. This is the first scheduling activity and it involves defining and sequencing the activities required. The activities are shown on the WBS. An estimate-specific WBS is developed as a *tool* to logically organize costs and provide insight into how various work elements contribute to project costs. Once activities are identified, a list of resources necessary to accomplish them is developed. Requirements for materials, equipment, facilities, labor, and subcontracted services are established.

When the necessary resources have been identified, an acquisition strategy is developed, indicating when, where, and how resources will be obtained. Resources are then allocated, as practical, to the specific project activities. Shared or common resources are allocated to multiple activities on a *pro-rata* basis or by establishing the distribution of thc resources during preparation of the estimate.

C. How to Develop the Cost Data

Apply Cost Data to Resources. Finally, cost data is acquired and applied to resources. Unit cost data is applied in a manner consistent with the unit of measure identified for each activity. For example, if resources for soil excavation are being estimated, unit cost data for the necessary laborers and equipment would be indicated in "dollars per cubic yard of soil excavated." If the data available is in terms of hours of labor and equipment usage required per cubic yard, the corresponding hourly labor rates and equipment usage rates would be acquired and used to develop unit costs.

Historical unit costs for environmental projects is difficult to obtain and estimate of unit costs are usually refined as more is learned from site investigation. The first estimate of unit costs must be designated and all assumptions should be extensively documented for future reference as a *tool* for developing more accurate unit costs.

Apply Escalation and Contingency

Escalation is performed on all cost estimates from the time of estimate preparation through project completion in order to offset the impact of inflation on projected costs. Unfortunately, there are many sources of cost risk in environmental projects. In almost all cases history has demonstrated the need for additional funding to complete these projects adequately. Furthermore, as many of the easier sites are remediated in the early stages of the large public sector and private sector clean-up programs, many of the more challenging projects must be addressed in thc coming years. This indicates the importance of assuring that the estimate has adequate cost and schedule contingency.

IV. ESTIMATING THE REMEDIATION OF HAZARDOUS WASTE SITES

A. Pre-estimate Activities

The initial work in the development of a hazardous waste estimate is similar to that of general construction with the same procedures and steps followed. Some of these are:

Work plan and Work Breakdown Structure (WBS) development
Identification of direct hire and subcontract work
Determination of local conditions

The development of a work plan is necessary prior to starting the estimate. This plan details the sequencing of the work activities for the project. Each of the activities are defined and any relationship between the activities identified. The crews and equipment that are required for each activity are based on the plan. This document provides the basis for both the project estimate and schedule. The work plan is based on a scope of work for the project which can be the record of decision (ROD) for the project, an early project specification, or a detailed bid document.

The WBS for the project is based on the work plan and is the basis for the estimating account structure. The WBS provides the link between the estimate and the schedule (and accounting system in the execution of the work).

The local conditions affecting cost and schedule must be researched prior to starting the estimate. The location of the project has a major impact on the cost and schedule. If the site is located in an urban or residential area, safety and security precautions are more intense than required for a rural area. Work hours may be curtailed due to noise or congestion for the urban site. A rural site has its own potential cost impacts such as lack of a work force, utility access and the scarcity of material suppliers and temporary living facilities.

The forecast of work in the region of the site must be reviewed for the time of project. The work forecast will identify the impacts to the estimate of the following:

Available work force
Bidding climate
Construction equipment and tools availability

If the forecast is for a lot of work in the area, contractors bidding on the work may bid aggressively enough. The resulting higher overheads and fees will be factored into the estimate. There may not be an adequate work force available for the project and premiums such as overtime or bonuses may be required to attract workers. Construction equipment and tools may not be available or only available at a premium. Conversely, a forecast of low demand will have the contractors develop an aggressive bid with low overheads and fees. A work force can be attracted without premiums. Construction equipment and tools may be available at discounts. The local area may also determine whether the work will be by union or merit shop contractors.

A checklist of local conditions that the estimator must review and answer prior to developing the detailed is included as Table 11.1.

After the site surveys and pre-estimate analysis is complete, the estimator begins the detail costing by the sequence of the project such as:

Premobilization activities
Mobilization including temporary facilities and utilities
Craft labor analysis
Health and safety impacts
Special materials and equipment
Transportation and disposal
Demobilization

B. Premobilization Activities

The premobilization is an important period in the remediation project for the contractor. Work must be completed in order to start on-site. All project related activities are charged against the work scope. The general premobilization activities include plan writing, home office support including procurement and project controls, relocations, worker training, and physicals. All costs that are required to proceed with the work need to be included in the estimate.

After receiving the notice to proceed on the project, the contractor will start the writing of the contract specified plans which can include:

Table 1 Site Checklist

1. Accessibility to site
   a. rail
   b. barge
   c. roads (any bridge limits)
   d. on-site roads
2. Utilities on-site
   a. existing or brought on
   b. what kind of utilities: gas, electric, water
   c. voltage of electric power
   d. name of utilities companies
3. Site conditions
   a. topography
   b. site roads
   c. congestion
   d. access limitations
   e. Health and Safety level required
   f. water problems/table
   g. type of soil
   h. rock
4. Labor force
   a. union/open shop
   b. availability (unemployment in area)
   c. nearness to town (size)
   d. trailer park required?
   e. minority requirements
   f. history of labor in area
5. Material supply
   a. nearness to supply houses
   b. type of supplies required
   c. worked with firms before
6. Subcontractors
   a. client preferred
   b. experience with any in area
   c. Scope of subcontractor work
   d. merit shop/open shop/union
7. Equipment
   a. construction equipment firms in area
   b. supply houses for tools
   c. delivery constraints for engineered equipment due to bridges, road limitations, barge facilities nearby, railroad points
8. Miscellaneous activities
   a. local opposition/support
   b. client interest
   c. competition
   d. weather related/floodplains/etc.

Quality assurance and quality control plans
Site health and safety plan
Work plans
Environmental risk and protection plan

The personnel time required by the contractor to write the plans is estimated including trips to review the plans with the regulatory agencies and publications. Failure by the contractor to provide adequate staff (and budget) for this work can impact the start of the project work at the site. General home office support costs for a project such as procurement, project controls, and management need to be included in the estimate. The home office involvement for hazardous waste projects is usually greater than that for general construction. An important step during the premobilization period is to obtain a trained labor force for the on-site work. All site personnel have to be trained in accordance to OSHA standard 29 CFR 1910.120. This training consists of an initial 40 hours of classwork and then an 8-hour class each year to maintain the certificate. The on-site personnel also must be physically fit to work at the site and pass an annual medical examination.

A contractor may charge costs associated with the OSHA requirements to a project rather than as part of the firm's overhead. The costs include the labor hours, the medical examinations and training courses. A turnover rate will have to be assumed to calculate the expected number of workers that will be examined and trained for the project.

C. Mobilization

The on-site mobilization has steps that must be included in the estimate. These steps may consist of:

Installation of temporary construction facilities
Installation of personnel and vehicle decontamination plants
Onsite environmental controls
Setup of special long term remediation systems, such as a thermal treatment or water treatment system

The first activity in mobilization is the setting up of the site temporary facilities that are similar to those required in general construction. The facilities are erected in the clean area of the site and therefore do not have hazardous waste impacts. Key cost items include: layout of the site, setting of trailers, utility connections to the site, and the construction of roads and parking areas. An area is usually designated and developed for the storage of hazardous waste that will be transported off-site.

The decontamination facilities are erected in the area that is designated the contaminated reduction zone. However, when they are installed, the area is clean. These facilities can include trailers, the equipment decontamination pad, the collection and storage system for the rinse water, and personnel decontamination pad. The project health and safety plan will define the decontamination requirements for the project.

Environmental monitors and controls, which are established on-site during mobilization, are defined in the project's environmental control and health and safety plans. The types of monitoring required will include air and water monitors, erosion controls, and a meteorological station. Costs to install and to initially test the site conditions should be included in the estimate.

The mobilization of a long-term remediation system such as a transportable thermal treatment unit or a water treatment system entails the construction and starting up of the unit.

Prior to starting the remediation work on-site, all on-site workers (both supervisory and manual) may undergo site specific medical examinations and training. The medical examination may consist of a blood test. The on-site training can last several days and may recur as each new phase of the project is begun.

D. Craft Labor Impacts

Craft labor is a major cost component of a remediation estimate. Impacts to the labor which can cause the cost to increase include:

Wearing of personnel protective equipment (PPE)

Table 2 Typical PPE

Level of safety	Equipment required
D Modified	One-piece coverall Disposable outer boots Steel toed boots Tyvek overall Boot covers Inner gloves, surgical Outer gloves Hard hat with face shield
C	Same as D modified Respirator with cartridge
B	Same as D modified Self-contained breathing apparatus
A	Same as B except with a fully encapsulating suit

Table 3 PPE Costs

Equipment required (quantity per day/person)	Useful life	Cost per day ($)
Tyvek overall (2 each)	Once	6.00
Boot covers (2 pair)	Once	10.00
Inner gloves (2 pair)	Once	1.00
Outer gloves (2 pair)	Once	10.00
Work boots (1 pair)	6 months	1.00
Hard hat (1 each)	3 months	0.50
Cotton coverall (1 each)	3 months	0.50
Total cost per person day =		29.00
Total cost per hour (8 hrs/day) =		3.62

Productivity loss in the execution of the work
Wage increases
The requirement for additional personnel

The personal protective equipment (PPE) that the laborers must wear for each phase of the remediation is defined in the project health and safety plan. Each phase of the work may have different PPE requirements. Table 2 lists the typical PPE that the worker must wear working the different levels of safety.

Table 3 presents an example of developing the PPE costs for a Modified Level D project. This example assumes one change of outer garments per day for each worker. Impacts which cause variances to the cost per person day or cost per hour include:

Number of outfit changes per day
Length of workday
Changes in PPE requirements during the work day

In developing the detail estimate, the labor hours are summarized by the length of time that the workers spend in each level of protection. The hourly costs of PPE are developed for each of PPE required for the project. The total hours for each level of protection are then multiplied by the cost per hour for wearing PPE. An example of level D modified (assuming 5,000 hours of level D Modified work):

Level D modified: 5,000 hours × \$3.62/hr = \$18,100

Table 4 Allowable Work Time (min)

	Levels of protection		
Temperature range	B	C	D Modified
Over 90°F (32°C)	10	15	45
80–90°F (27–32°C)	70	60	90
70–80°F (21–32°C)	90	120	150

The costs for the ultimate disposal of the contaminated PPE are to be included in the estimate.

As part of the estimating process, a productivity analysis for craft labor on hazardous waste projects is performed. The analysis is similar to that performed on general construction projects but includes additional impacts such as loss time due to dressing and undressing, weather, and loss of dexterity.

Table 11.4 provides a typical listing of the allowable time a person can spend wearing PPE at various temperatures. Based on the actual activities involved, the length of time can be decreased. The more strenuous the activity, the shorter the time the worker can spend in the PPE.

A productivity analysis for craft labor is shown as Table 11.5. Only the four more common levels of protection analyzed; these are normal conditions, Level B, Level C, and Level D modified. Each level of protection is analyzed for the work activities that impact craft labor. Each project will have unique productivity adjustments based on the conditions presented in the work scope. It is not unusual for distinct activities of a remediation, such as demolition, excavation and capping, to have different productivity adjustment factors.

As shown in Table 5, the "Lost Time" category includes instructions, travel time to the work area, and personal time (lavatory breaks). In the example, 85 minutes is assumed to be lost on a daily basis.

The second activity is "Support Time" which consists of tool management, measurements, and remediation activities such as outfitting and recovery time. The outfitting time is the duration for the worker wearing PPE to dress and undress. The amount of time required for this activity depends on the number of changes that are required each day and the level of protection.

At the end of a shift or the allowable work duration, the worker must recover. The recovery time is dependent on the work assignment, the temperature of the work area, and the PPE worn. As shown in the table, "Support Time" can vary from the normal conditions length of 40 minutes to level "B" duration of 220 minutes.

Table 5 Productivity Adjustments

Activity	Normal conditions (min)	Level B conditions (min)	Level C conditions (min)	Modified level D conditions (min)
Lost time				
Wait for instructions	30	30	30	30
Travel time	15	15	15	15
Personal time	40	40	40	40
Total, lost time	85	85	85	85
Support time				
Pick up tools	30	30	30	30
Measurement	10	10	10	10
Outfitting	0	120	120	30
Recovering	0	60	40	10
Total, support time	40	220	200	80
Direct time on job				
Time	355	175	195	315
Loss due to suits	0.00%	60.00%	30.00%	10.00%
Loss of efficiency	0	105	59	32
Total, available work time	355	70	137	284
Total, daily (8 hours)	480	480	480	480
Percent work/total time	73.96%	14.58%	28.44%	59.06%
Adjustment factor to normal conditions (excludes support craft)	Base	5.07	2.60	1.25

The amount of time available for the laborer to work on the project is called "Direct Time" and is calculated by subtracting the lost time and support time durations from the total work day duration. An example shown for Level C follows:

	min
Total work day	480 (assumes 8 hr day)
Lost time	85
Support time	200
Direct time	195

The direct time on the project is then modified due to the loss in efficiency due to wearing the PPE. Included in this efficiency calculation are impacts caused by loss of dexterity, temperature, and additional health and safety safeguards. For Level C, the efficiency loss is estimated at 30% or another 59 min lost per day. For this example, the actual time the laborer performs work on the project is forecast to be 136 min or about 28% or the total day.

The development of productivity factors is subjective and is unique for each project. The productivity adjustment to "normal conditions" for each level of protection is calculated as follows:

Productivity adjustment = %work PPE/%work normal

As shown in Table 5, for Level C, the productivity adjustment is equal to 73.96%/28.44% or 2.60. For each work activity, the normal construction productivity unit must decreased by 2.6 (it takes a person in level "C" about 2.6 times as long to perform a task as compared to normal conditions).

Due to the low productivity on the project and the lost time due to dressing and undressing, the construction manager tries to maximize the work time available. One approach is to work overtime. The dressing and undressing times occur before or after the work day. The craft worker is usually paid a premium for this overtime. A second wage rate impact is an hourly bonus (or wage rate increases) that are paid to craft labor for working in respirators and self-contained breathing apparatus (i.e., level C, B, and A work). The additional hourly increase can range from 10% to 20% of the base wage rate.

A remediation project requires more personnel than a general construction project. These additional personnel are both supervisory and craft labor. The supervisory staff for a remediation project requires a site health and safety officer and quality assurance engineer. The site health and safety officer is responsible for ensuring the remediation effort follows the project health and safety plan. This person is independent of the site management to help ensure that the project will be run according to plan. The quality assurance engineer verifies that the work is being performed as specified and is responsible for ensuring the integrity of the sampling effort.

The additional craft labor personnel and duties include:

Sampling technicians are necessary to monitor the work. They will obtain all the samples required for the project and ship the samples to the laboratory for analysis.

A full time person to operate the equipment and personnel decontamination pads.

Safety watch personnel who observe the craft laborers working at the site. These people will notify the supervisory staff when an accident occurs. Depending on the activity, the ratio of safety watch personnel to the workers may be as low as one-to-one.

The length of time a laborer can work wearing PPE is limited. For the remediation to operate continuously throughout the workday, a second (or third) shift of workers may be required. While one shift is working, the other shift will be recovering or performing work in the clean areas. Because of this shiftwork, more laborers are required in the work force.

E. Sampling and Analytic Costs

An important activity during a remediation project is sampling and the follow-up analyses. These activities are safeguards for the on-site personnel and the surrounding environment. Typical sampling activities include perimeter monitoring, real time sampling in the work area and final verification of remediation. Environmental monitoring stations are located around the perimeter of the site to monitor the air and water to verify that contaminates are not migrating off the site. Samples are taken from these stations on a periodic basis and are one of the responsibilities of the sampling technicians. As work progresses, the contaminate levels in the work areas change as areas are cleansed or exposed. The sampling technicians are required to be present during the different phases of the work to monitor the levels. Changes to the PPE result as the readings vary. If the levels rise too high, work may be delayed or the area evacuated.

At the completion phase of the remediation, samples are taken from the cleaned areas to verify that the designated level of concentrations has been met. For example, an area being excavated to the prescribed depth will be sampled in several places. The samples have to be analyzed prior to declaring the area clean and backfilling the excavation. The time required for the analysis may be a few days to several weeks. The crew working in the area may need to be moved to another area or demobilized off the site if the analytical delay is lengthy, otherwise the crew can remain at the site. This delay between completing the work and receiving the final analysis verifying the closure must be accounted for in the estimate by the demobilizing and remobilizing of the work crews or the non–work period costs for the crew.

The cost of each sample analysts varies from $25 to over $1,000 depending on the type of analysis required and the turnaround time for the results. In developing the cost of analysis, the estimator must know the quantity of samples that will be required, the analysis for each, and the time in which the results will be needed.

F. Special Materials and Equipment

Many common materials cannot be used for handling hazardous materials due to chemical reactions with the contaminates. An analysis of the contaminates is completed prior to work starting on-site in order to mitigate any problems. A typical occurrence may be the loading of a rubber lined tank truck with a liquid which can react with the lining. As part of the estimate, the estimator must review how the contaminates must be handled. Exotic materials may be required for the project. Both the time to obtain the materials and the higher cost for the material are to be accounted for in the estimate.

The equipment used for remediation has been adapted from general construction (such as backhoes and forklift trucks). The equipment may have modified with an enclosed cab having its own supply of air and a blast shield. The cost of renting or leasing this specialty equipment is higher than general construction. As the work progresses, the equipment is decontaminated as it leaves the site at which time parts may be damaged and have to be replaced. For some projects, the piece of equipment may not be salvageable and have to be disposed of as a hazardous material. The cost of equipment maintenance and repairs are to be included in the estimate.

G. Transportation and Disposal

The transporting and disposal of hazardous waste is an important component of a remediation project and can range to 80% of the entire cost of the remediation. The estimate for this activity is therefore critical in the development of the project cost.

Typical items that are disposed from a remediation include:

Contaminated materials such as soil, concrete, block that is being excavated or removed
Liquid being pumped from the ground
Decontamination liquid from cleaning equipment
Used PPE

The ultimate method of disposal for the contaminated material is regulated by the government depending on the contaminates involved. Types of disposal may include:

Landfilling
Incineration
Deep well injection
Chemical stabilization

The costs for each type of disposal vary depending on the quantity and the contaminates.

The transportation of the materials has to be planned in advance of the on-site work and may impact the schedule. The material cannot be transported to the disposal facility until a laboratory analysis of the contaminated material is performed. Samples are taken at designated intervals based on time or quantity. The time for the analysis delays the shipment. In some instances, the contaminated material is stockpiled on site for months while the analysis is being performed and the disposal facility accepts the waste. Costs for the demurrage of the storage containers are to be included in the estimate. The field crews may have to be remobilized to load the transporting equipment such as trucks or railroad cars.

The cost of transportation and disposal for materials may include:

Hauling costs to the disposal facility
Demurrage costs for the material containers
Sampling and analysis costs
Stabilization and disposal costs including surcharges
Crew demobilization and mobilization costs

H. Demobilization

The demobilization for a remediation project is similar to that for general construction except for the decontamination procedures that are required. The major steps in the demobilization of a hazardous waste project are:

Securing the site
Disposal of the contaminated materials
Removal of the decontamination facilities
Removal of the construction facilities
Final medical tests for the on-site workers

The securing of the site includes fencing in of the site, placement of monitor wells, and the posting of signs around the perimeter of the site. The removal of the decontamination and temporary construction facilities occurs during this final phase. The decontamination facilities may have to be demolished and the debris transported to a hazardous waste disposal site. Temporary construction facilities such as trailers are hauled off the site. The roads and parking area required for the project are removed. The paving material can be considered hazardous and may be transported to a hazardous waste site. When they leave the site, the laborers are often required to undergo medical tests to verify if they have received contamination from working on the site. Costs have to be included for both the medical tests and the labor time involved in the testing. The off-site demobilization will include all the final disposition of the waste handling equipment and the decontamination systems.

V. EXAMPLES OF PROJECTS

A. Alternatives

There are three common approaches for the remediation of a landfill or contaminated area:

Excavate and haul the contaminated material off-site
Impermeable capping of the site
On-site thermal treatment of the contaminated material

The ultimate method chosen depends on various items including the estimated costs, local involvement, and the contaminates. Studies are performed to select the proper technology for the remediation. Other potential options for a soil remediation project are bioremediation and in situ volatilization.

Estimates for each of the three common alternatives are included in the following pages. The costs reflect 1995 prices. General assumption include:

Demolition will not be required
Area of the site = 300,000 sf (about 7 acres)
Area of the contamination = 170,000 sf (about 4 acres)
Depth of contamination = 4 ft average
Approximately 25,000 cy (35,000 tons) of contaminated soil
Suburban location with houses nearby
Ground water is below excavation depth
Excavation will be level "C"
Backfilling will be level "D" modified
Utilities to the perimeter of the site
Average craft wage rate = $35/hr with a $2 premium for "C"

The mobilization activities and productivity analysis is similar for all examples.

B. Excavation and Haul Alternative

During this approach, all contaminated soil will be excavated and placed into 20 cy roll-off containers. All runoff water will be collected and disposed of off-site.

Based on a productivity analysis, the excavation production in level "C" is expected to take twice as long as general construction. The backfilling has a 20% productivity penalty associated with the operation. For the work, the equipment required and production is as follows (each piece has an operator associated with it):

Bulldozers—three each
Front end loaders—two each
20 ton dump trucks—six each
Excavation production—1,000 cy/day

A decontamination person, a flagman/traffic director, and two laborers are assigned to the work force. The laborers are required to assist in loading the roll-offs. The estimated cost for this approach is approximately $20.9 million and the onsite work is expected to last 6 months with the transport off-site of the soil occurring during that time frame.

C. Impermeable Capping

The impermeable capping of the site is based on a membrane liner system. The procedure for this work consists of the following activities:

The contaminated area is cleared and grubbed.
The area is then graded with consolidation of the contaminated material.
A layer of sand is placed over the area to be lined.
The layers of the membrane lining are placed down with backfill as required.
The area is backfilled with soil and topsoil and then seeded.
Monitoring wells are installed on the perimeter of the site to verify that contaminates are not affecting the groundwater.

The estimated cost for this approach is $3.2 million and the forecast construction duration is 6 months.

D. On-Site Thermal Treatment

The thermal treatment of the on-site material using a transportable thermal treatment unit (TTU) is a more lengthy process of remediation. The TTU currently used on projects have a nominal burn rate ranging from 5 ton/hr to over 40 ton/hr. The estimate will assume a "midrange" system capable of treating 15 ton/hr. An on-line factor of 75% is estimated to allow a project specific incineration rate of about 12.5 ton/hr. The unit will operate 24 hours a day, seven days per week. Based on these factors, the 35,000 tons of material will be treated in 126 days.

Each day, three shifts of operators will be required to operate the unit. Overall, including maintenance personnel, 25 people will be required daily at the unit. The average shift will last 9.5 hours due to dressing/undressing time and shift overlap requirements. The estimate is based on 10 hours daily per person to cover the premium portion of overtime that is required to be paid.

Other daily costs for the TTU include chemical, utilities, miscellaneous expenses, and laboratory as well as allowances for depreciation and major maintenance of the system. Typical chemicals consumed during the unit's operation include caustic, carbon, oxygen, and calibration gases. The daily cost for these chemicals are project specific due to reactions with the contaminant. An allowance of $700 per day during operations is assumed for the estimate.

The types and quantities of utilities that are consumed during the operations are based on the TTU design and the composite of the contaminants being treated. Most TTUs use either electricity or gas to produce the high temperatures required for operation. In this example, a gas fired TTU is assumed.

The composite of the contaminants (i.e., the moisture content, type of material, heating value of the material) directly influence the utility usage. A daily cost of $2,800 is assumed for the estimate.

Miscellaneous expenses include all other operating costs that are incurred. These costs include equipment rental (backhoes and loaders); health and safety equipment, supplies, and consumables; office and decontamination trailers; office expenses such as janitorial and copying; home office travel to the site; and incidental repairs. For the example, the estimated daily cost for miscellaneous costs are $4,000.

An important operating cost of an TTU is building a fund for major maintenance that will be required (such as repairing the refractory lining). An allowance for depreciation should be included in the operation costs for the unit. Funding for these items can be part of the overheads for the company or charged directly to the unit. In this example, maintenance and depreciation have been included at a daily allowance of $2,000.

The procedure for installing and operating the TTU at the site is as follows:

The system is transported into the site and erected on concrete foundations.
The system is "shaken down" to verify and correct operating procedures during the test and start procedure.
The system starts to treat the contaminants and is tested by the Environmental Protection Agency (EPA) for stack emissions (the test burn).
The TTU may not operate at full capacity until the EPA approval of the test burn is received (a 2 months duration is assumed).
During this approval time, if the system has performed acceptably in the past, the TTU may operated at a reduced capacity of 75% (interim operations).
Upon receipt of the EPA approval of the test burn, the system will operate at full capacity.

Space needs to be available on the site so soil can be stored until it can be treated. Depending on the size of the area, the excavation procedure will be determined. If the storage area is large enough, all the contaminated soil may be excavated and stored. If only a small area is available, then the contractor will only excavate what can fit within the area.

After the thermal treatment is complete, the soil ash may still considered a hazardous waste and may be placed in a secured landfill. The excavation area can be used or the soil is transported off-site to a secured landfill. The example assumes that the treated soil will be backfilled into the excavated areas and the area capped with a membrane liner system.

The estimated cost for the TTU alternative is $9.4 million and the work duration is 10 months.

Table 6 Comparison of Remediation Techniques

Alternative	Cost	Project duration
Excavate and haul off-site	$20.9 million	6 months
Liner system	$ 3.2 million	6 months
On-site thermal treatment	$ 9.4 million	10 months

E. Comparison

Table 6 is a cost and schedule comparison of the three alternatives. The selection of the remediation method for a site is not based solely on cost or schedule, but also on local needs and long term effects of each alternative. The liner system is the least costly alternative, however, this approach does not remove the contaminants. The site is environmentally safe, but the contaminants still exist.

VI. HIDDEN COSTS OF REMEDIATION

A. Hidden Costs

Remediation work has hidden cost impacts associated with the performance of the work such as:

Unique schedule upsets
Remediation techniques
Bonding restrictions and costs

The estimator has to review these potential impacts and include cost allowances as necessary.

B. Schedule Upsets

The remediation of a hazardous waste site is under scrutiny of several groups including state and Federal regulatory agencies, environmental consultant, construction manager, and local citizen action groups. Many of these organizations review and approve the submittals and oversee the work. Due to this large number of participants, delays in the approval of the submittals may occur or work restrictions may be enacted at the site.

C. Remediation Techniques

The technique proposed for the remediation work may be proprietary to a firm or only a few companies can supply the technique (as is the case with a thermal treatment unit). The estimator developing a budget estimate has to be cognizant of the market conditions for the remediation technique and adjust the overhead and profit margins in the estimate accordingly. The unique techniques may limit the competition on many sites.

The selected technique may be difficult to perform. The constructibility of the project has to be reviewed by the estimator. Additional costs may result due to the creative nature of the remediation.

D. Bonding

Currently, obtaining a performance and payment bond for hazardous waste work is more costly and more restrictive than encountered in general construction. The bonding limits placed on the company for a remediation project may be lower than for other project types. This bonding restriction may limit the number of competitors for projects. The estimator must be cognizant of the limited competition as well as the higher cost for the bond in the development of project estimate.

Example A Conceptual Estimate: Excavation And Transport Off-site Approach

Description	Quantity	Hours	Labor rate	Total labor	Material Unit	Material Total	Subcontracted Unit	Subcontracted Total	Total
SUMMARY									
Total, premobilization activities				36,520		615,650		0	652,170
Total, mobilization				14,459		10,550		40,050	65,059
Total, remediation work				173,320		310,500		14,583,750	15,067,570
Total, indirects				180,480		94,622		0	275,102
Total, demobilization				7,750		500		33,400	41,650
Subtotal				412,529		1,031,822		14,657,200	16,101,551
Contingency	20.00%								3,220,310
Fee	10.00%								1,610,155
Total				412,529		1,031,822		14,657,200	20,932,016
PREMOBILIZATION ACTIVITIES									
Writing of plans									
Site health and safety	1 LS	80	45.00	3,600					3,600
Work plan	1 LS	80	45.00	3,600					3,600
Quality assurance	1 LS	60	45.00	2,700					2,700
Air monitoring	1 LS	60	45.00	2,700					2,700
Site security	1 LS	20	45.00	900					900
Obtain local permits	1 LS	80	45.00	3,600					3,600
Copying/publications	1 LS				2,000	2,000			2,000
Total				17,100		2,000		0	19,100

Example A (Continued)

Description	Quantity	Hours	Labor rate	Total labor	Material		Subcontracted		Total
					Unit	Total	Unit	Total	
Home office services									
Procurement	1 LS	80	33.00	2,640					2,640
Project controls	1 LS	40	33.00	1,320					1,320
General management	1 LS	20	55.00	1,100					51,100
Total				5,000		0		0	5,060
CFR 1910.120 medical/training									
Medical exams	12 ea	48	35.00	1,680	500	6,000			7,680
40 hr training	4 ea	160	35.00	5,600	600	2,400			8,000
8 hr refresher	5 ea	40	35.00	1,400	250	1,250			2,650
Total				8,880		9,650		0	18,330
Preconstruction meetings									
Project manager	1 LS	32	60.00	1,920					1,920
Project engineer	1 LS	48	45.00	2,160					2,160
Site manager	1 LS	32	50.00	1,600					1,600
Allow for travel	1 LS				4,000	4,000			4,000
Total				5,680		4,000		0	9,680
Performance and payment bond									
Allowance for	1 LS					600,000			500,000
Total				36,520		615,650		0	652,170

GENERAL MOBILIZATION ACTIVITIES

Move in and set up trailers									
Office	1 ea	24	35.00	840	250	250	250	250	1,340
Decontamination	1 ea	48	35.00	1,680	300	300	500	500	2,480
Tool/equipment	1 ea	8	35.00	280	150	150	100	100	530
Total				2,800		700		850	4,350
Move in equipment									
Bulldozers	3 ea						250	750	750
Dump and water trucks	7 ea						100	700	700
Front end loaders	2 ea						250	500	500
Roller compactor	2 ea						250	500	500
Total				0		0		2,450	2,450
Set up work zones and initial sitework									
Surveyor	2 day					650	1,300	1,300	
Tapes and stakes	1 LS				150		150		150
Clearing + grubbing	1 LS	36	37.00	1,332	250	250	250	250	1,832
Grading	1 LS	36	37.00	1,332	250	250	250	250	1,832
Gravel paving	200 cy	40	35.00	1,400	12	2,400	0	0	3,800
Electric connections	1 LS	24	35.00	840	1,000	1,000	0	0	1,840
Telephone tie-in	1 LS	24	35.00	840	1,500	1,500	0	0	2,340
Fencing	2,800 lf						12	33,600	33,600
Total				5,744		5,550		35,400	46,694
Decontamination pad									
Grade area	1 LS	24	35.00	840	250	250	0	0	1,090
Install HDPE liner	1 LS	24	35.00	840	1,000	1,000	0	0	1,840
Gravel	50 cy	24	35.00	840	12	5600	0	0	1,440
Piping	1 LS	24	35.00	840	1,500	1,500	0	0	2,340
Set up tanks	2 ea	24	35.00	840	250	500	0	0	1,340
Total				4,200		3,850		0	8,050

Example A (Continued)

Description	Quantity	Hours	Labor rate	Total labor	Material		Subcontracted		Total
					Unit	Total	Unit	Total	
Air monitoring system									
Set up air monitors	2 ea	24	35.00	840	100	200	150	300	1,340
Set up met. station	1 ea	24	35.00	840	100	100	50	50	990
Initial samples	10 ea	1	35.00	35	15	150	100	1,000	1,185
Total				1,715		450		1,350	3,515
Total, mobilization				14,459		10,550		40,050	65,059
Remediation									
Excavation									
Bulldozers (3)	35 day	840	37.00	31,080	0	0	750	26,250	57,330
Front end loaders (2)	35 day	560	37.00	20,720	0	0	900	31,500	52,220
Dump trucks (6)	35 day	1680	37.00	62,160	0	0	600	21,000	83,160
Laborers	35 day	280	37.00	510,360	0	0	0	0	10,360
Total				124,320		0		78,750	203,070
Transportation and disposal									
Roll-off rental	1,750 ea						200	350,000	350,000
Transportation	35,000 tn						50	1.750,000	1,750,000
Disposal	35,000 tn						350	12,250,000	12,250,000
Total	0					0		14,350,000	14,350,000

Backfill									
Bulldozers (3)	25 day	600	35.00	21,000	0	0	750	18,750	39,750
Roller compactor (2)	25 day	400	35.00	14,000	0	0	600	15,000	29,000
Soil, delivered	25,000 cy				12	300,000	0	0	300,000
Water truck	25 day	200	35.00	7,000	0	0	250	6,250	13,250
Laborers	25 day	200	35.00	7,000	0	0	0	0	7,000
Total				49,000		300,000		40,000	389,000
Miscellaneous activites									
Air samples (10/day)	80 day	100				8,000	1,000	80,000	88,000
Misc. diposal, PPE	50 drum	30				1,500	250	12,500	14,000
Compaction tests	30 ea	0				0	250	7,500	7,500
Soil sampling	100 ea	10				1,000	150	15,000	16,000
Total				0		10,500		115,000	125,500
Total, Remediation Work				173,320		310,500		14,583,750	15,067,570
INDIRECT ACTIVITIES									
Health and safety supplies									
Level D mod outfits	250 ea				20	5,000	0	0	5,000
Level C outfits	500 ea				35	17,500	0	0	517,500
Air monitoring equip	6 mo				5,000	30,000	0	0	30,000
Drums	100 ea				30	3,000	0	0	3,000
Small tools/consumables	1 LS				10,000	10,000	0	0	10,000
Total				0		65,500		0	65,500
Trailers and temporary facilities									
Office	6 mo				250	1,500	0	0	51,500
Decontamination	6 mo				900	5,400	0	0	5,400
Equip/tool	6 mo				100	600	0	0	900
Port-a-johns	6 mo				150	900	0	0	900
Signs	1 LS				5,000	5,000	0	0	5,000
Total				0		13,400		0	13,400

Example A (Continued)

Description	Quantity	Hours	Labor rate	Total labor	Material		Subcontracted		Total
					Unit	Total	Unit	Total	
INDIRECT ACTIVITIES (continued)									
Utilities									
Electric	6 mo				500	3,000	0	0	3,000
Water	6 mo				200	1,200	0	0	1,200
Telephone	6 mo				500	3,000	0	0	3,000
Radios	1 LS				2,500	2,500	0	0	2,500
Fuel	6 mo				1,000	6,000	0	0	6,000
Total				0		15,700		0	15,700
Management personnel									
Site manager	1 LS	960	50.00	48,000	10	10	0	0	48,010
Site engineer	1 LS	960	40.00	38,400	6	6	0	0	38,406
Safety/health officer	1 LS	960	38,00	36,480	6	6	0	0	36,486
Decon. person	1 LS	960	35.00	33,600	0	0	0	0	33,600
Sampling technician	1 LS	960	25.00	24,000	0	0	0	0	24,000
Total				180,480		22		0	180,502
Total, Indirects				180,480		94,622		0	275,102

DEMOBILIZATION

Remove trailers									
Personnel	1 ea	24	35.00	840	0	0	250	250	1,090
Decontamination	1 ea	48	35.00	1,680	0	0	250	250	1,930
Equipment/tools	1 ea	16	35.00	560	0	0	150	150	710
Port-a-john	1 LS	0	35.00	0	0	0	100	100	100
Total				3,080		0		750	3,830
Move out equipment									
Decon. equipment	14 ea	54	35.00	2,240	0	0	0	0	2,240
Haul out	7 ea	0	35.00	0	0	0	250	1,750	1,750
Trucks	7 ea	0	35.00	0	0	0	100	700	700
Total				2,240		0		2,450	4,690
Remove decon. facilities									
Remove pad	1 LS	48	35.00	500	500	500	100	100	1,100
Remove piping	1 LS	60	35.00	250	0	0	100	100	350
Dispose of water	10,000 ga	24	35.00	840	0	0	3	30,000	30,840
Remove tanks	1 LS	24	35.00	840	0	0	0	0	840
Total				2,430		500		30,200	33,130
Total, Demobilization				7,750		500		33,400	41,650

Example B Conceptual Estimate—Installatlon of a Landfill Capping System

Description	Quantity	Hours	Labor rate	Total labor	Material		Subcontracted		Total
					Unit	Total	Unit	Total	
SUMMARY									
Total, premobilization activities				536,520		115,650		0	152,170
Total mobilization				13,571		10,550		39,650	63,771
Total remediation work				79,760		253,500		1,645,700	1,978,960
Total, indirects				180,480		67,122		0	247,602
Total, demobilization				6,910		500		18,000	25,410
Subtotal				317,241		447,322		1,703,350	2,467,913
Contingency	20.00%								493,583
Fee	10.00%								246,791
Total				317,241		447,322		1,703,350	3,208,287
PREMOBILIZATION ACTIVITIES									
Writing of plans									
Site health and safety	1 LS	80	45.00	3,600					3,600
Work plan	1 LS	80	4s 00	3,600					3,600
Quality assurance	1 LS	60	45.00	2,700					2,700
Air monitoring	1 LS	60	45.00	2,700					2,700
Site security	1 LS	20	45.00	900					900
Obtain local permits	1 LS	80	45.00	3,600					3,600
Copying/publications	1 LS				2,000	2,000			2,000
Total				17,100		2,000		0	19,100

Home office services								
Procurement	1 LS	80	33.00	2,640				2,640
Project controls	1 LS	40	33.00	1,320				1,320
General management	1 LS	20	55.00	1,100				1,100
Total				5,060		0	0	5,060
CFR 1910.120 medical/training								
Medical exams	12 ea	48	35.00	1,680	500	6,000		7,580
40 hr training	4 ea	160	35.00	5,600	600	2,400		8,000
8 Hr refresher	5 ea	40	35.00	1,400	250	1,250		2,650
Total				8,680		9,650	0	18,330
Preconstruction meetings								
Project manager	1 LS	32	60.00	1,920				1,920
Project engineer	1 LS	48	45.00	2,160				2,160
Site manager	1 LS	32	50.00	1,600				1.600
Allow for travel	1 LS				4,000	4,000		4,000
Total				5,680		4,000	0	9,680
Performance and payment bond								
Allowance for	1 LS					100,000		100,000
Total, premobilization activities				36,520		115,650	0	152,170

Example B (Continued)

Description	Quantity	Hours	Labor rate	Total labor	Material Unit	Material Total	Subcontracted Unit	Subcontracted Total	Total
GENERAL MOBILIZATION ACTIVITIES									
Move in and set up trailers									
Office	1 ea	24	35.00	840	250	250	250	250	1,340
Decontamination	1 ea	48	35.00	1,680	300	300	500	500	2,480
Tool/equipment	1 ea	8	35.00	280	150	150	100	100	530
Total				2,800		700		850	4,350
Move in equipment									
Bulldozers	3 ea						250	750	750
Dump + water trucks	3 ea						100	300	300
Front end loaders	2 ea						250	500	500
Roller compactors	2 ea						250	500	500
Total				0		0		2,050	2,050
Set up work zones and initial sitework									
Surveyor	2 day						650	1,300	1,300
Tapes and stakes	1 LS				150	150			150
Clearing + grubbing	1 LS	24	37.00	888	250	250	250	250	1,388
Grading	1 LS	24	37.00	888	250	250	250	250	1,388
Gravel paving	200 cy	40	35.00	1,400	12	2,400	0	0	3,800
Electric connections	1 LS	24	35.00	840	1,000	1,000	0	0	1,840
Telephone tie-in	1 LS	24	35.00	840	1,500	1,500	0	0	2,340
Fencing	2,800 lf						12	33,600	33,600
Total				4,856		5,550		35,400	45,806

Decontamination pad									
Grade area	1 LS	24	35.00	840	250	250	0	0	1,090
Install hdpe liner	1 LS	24	35.00	840	1,000	1,000	0	0	1,840
Gravel	50 cy	24	35.00	840	12	600	0	0	1,440
Piping	1 LS	24	35.00	840	1,500	1,500	0	0	2,340
Set up tanks	2 ea	24	35.00	840	250	500	0	0	1,340
Total				4,200		3,850		0	8,050
Air monitoring system									
Set up air monitors	2 ea	24	35.00	840	100	200	150	300	1,340
Set up met. station	1 ea	24	35.00	840	100	100	50	50	990
Initial samples	10 ea	1	35.00	35	15	5150	100	1,000	1,185
Total system				1,715		450		1,350	3,515
Total, mobilization				13,571		10,550		39,650	63,771
REMEDIATION									
Excavation									
Bulldozers (3)	10 day	240	37.00	8,880	0	0	750	7,500	16,380
Front end loaders(2)	10 day	160	37.00	5,920	0	0	900	9,000	14,920
Dump trucks (6)	10 day	480	37.00	17,760	0	0	600	6,000	23,760
Laborers	10 day	80	37.00	2,960	0	0	0	0	2,960
Total				35,520		0		22,500	58,020
Backfill, initial cover, 12 in.									
Bulldozers (3)	10 day	240	37.00	8,880	0	0	750	7,500	16,380
Roller compactor (2)	10 day	160	37.00	5,920	0	0	600	6,000	11,920
Soil, delivered	6,500 cy				12	78,000	0	0	78,000
Water truck	10 day	80	37.00	2,960	0	0	250	2,500	5,460
Laborers	10 day	80	37.00	2,960	0	0	0	0	2,960
Total				20,720		78,000		16,000	114,720

Example B (Continued)

Description	Quantity	Hours	Labor rate	Total labor	Material Unit	Material Total	Subcontracted Unit	Subcontracted Total	Total
REMEDIATION (cont.)									
Lining system									
Geo—net	180,000 sf						1.00	180,000	180,000
Fabric filter	180,000 sf						1.50	270,000	270,000
Membrane	180,000 sf						0.75	135,000	135 000
Total				0		0		585,000	585,000
Backfill, final cover, 24 in.									
Bulldozers (3)	12 day	288	35.00	10,080	0	0	750	9,000	19,080
Roller compactor (2)	12 day	192	35.00	6,720	0	0	600	7,200	13,920
Soil, delivered	13,000 cy				12	156,000	0	0	156,000
Water truck	12 day	96	35.00	3,360	0	0	250	3,000	6,360
Laborers	12 day	96	35.00	3,360	0	0	0	0	3,360
Seeding	180,000 sf						0	18,000	18,000
Total				23,520		156,000		37,200	316,720
Miscellaneous activites									
Air samples (10/day)	60 day				100	6,000	1,000	60,000	66,000
Monitoring wells	120 ea				100	12,000	7,500	900,000	912,000
Compaction test	50 ea				0	0	250	12,500	12,500
Misc. diposal, PPE	50 drum				30	1,500	250	12,500	14,000
Total				0		19,500		985,000	1,004,500
Total, Remediation Work				79,760		253,500		1,645,700	1,978,960

INDIRECT ACTIVITIES

Health and safety supplies									
Level D mod outfits	150 ea				20	3,000	0	0	3.000
Level C outfits	100 ea				35	3,500	0	0	3,500
Air monitoring equip	4 mo				5,000	20,000	0	0	20,000
Drums	50 ea				30	1,500	0	0	1,500
Smalltools/consumables	1 LS				10,000	10,000	0	0	10,000
Total				0		38,000		0	38,000
Trailers and temporary facilities									
Office	6 mo				250	1,500	0	0	1,500
Decontamination	6 mo				900	5,400	0	0	5,400
Equipment/tools	6 mo				5100	600	0	0	600
Port-a-johns	6 mo				150	900	0	0	900
Signs	1 LS				5,000	5,000	0	0	5,000
Total				0		13,400		0	13,400
Utilities									
Electric	6 mo				500	3,000	0	0	3,000
Water	6 mo				200	1,200	0	0	1,200
Telephone	6 mo				500	3,000	0	0	3,000
Radios	1 LS				2,500	2,500	0	0	2,500
Fuel	6 mo				1,000	6,000	0	0	6,000
Total				0		15,700		0	15,700
Management personnel									
Site manager	1 LS	960	50.00	48,000	10	10	0	0	48,010
Site engineer	1 LS	960	40.00	38,400	6	6	0	0	38,406
Safety/health officer	1 LS	960	38.00	38,480	6	6	0	0	36,486
Decon. person	1 LS	960	35.00	33,600	0	0	0	0	33,600
Sampling technician	1 LS	960	25.00	24,000	0	0	0	0	24,000
Total				180,480		22		0	180,502
Total, Indirects				180,480		67,122		0	247,602

Example B (Continued)

Description	Quantity	Hours	Labor rate	Total labor	Material Unit	Material Total	Subcontracted Unit	Subcontracted Total	Total
DEMOBILIZATION									
Remove trailers									
Personnel	1 ea	24	35.00	840	0	0	250	250	1,090
Decontamination	1 ea	48	35.00	1,680	0	0	250	250	1,930
Equip/tools	1 ea	16	35.00	560	0	0	150	150	710
Port-a-john	1 LS	35.00	50	0	0	0	100	100	100
Total				3,080		0		750	3,830
Move out equipment									
Decon. equipment	10 ea	40	35.00	1,400	0	0	0	0	1,400
Haul out	7 ea	0	35.00	0	0	0	250	1,750	1,750
Trucks	3 ea	0	35.00	0	0	0	100	300	300
Total				1,400		0		2,050	3,450
Remove decon. facilities									
Remove pad	1 LS	48	35.00	500	500	500	100	100	1,100
Remove piping	1 LS	60	35.00	250	0	0	100	100	350
Dispose of water	5,000 ga	24	35.00	840	0	0	3	15,000	15,840
Remove tanks	1 LS	24	35.00	840	0	0	0	0	840
Total				2,430		500		15,200	18,130
Total, Demobilization				6,910		500		18,000	25,410

Example C Conceptual Estimate—On-Site Thermal Treatment of Contaminants

Description	Quantity	Hours	Labor rate	Total labor	Material Unit	Material Total	Subcontracted Unit	Subcontracted Total	Total
SUMMARY									
Total, premobil. activities				54,520		273,650		0	328,170
Total, general mobilization				14,163		10,550		39,400	64,113
Total thermal system mob.				458 500		272,300		733,700	1,464,500
Total, remediation work				1,349,340		817,050		2,380,900	4,547,290
Total, indirects				300,800		205,522		0	506,322
Total, demobilization				80,410		21,500		207,250	309,160
Subtotal				2,257,733		1,600,572		3,361,250	7,219,555
Contingency	20.00%								1,443,911
Fee	10.00%								721,956
Total, Estimate				2,257,733		1,600,572		3,361,250	9,385,422
PREMOBILIZATION ACTIVITIES									
Writing of plans									
Site health and safely	1 LS	80	45.00	3,600					3,600
Work plan	1 LS	80	45.00	3,600					3,600
Quality assurance	1 LS	60	45.00	2,700					2,700
Air monitoring	1 LS	60	45.00	2,700					2,700
Site security	1 LS	20	45.00	900					900
Obtain local permits	1 LS	80	45.00	3,600					3,600
Test burn report	1 LS	400	45.00	18,000					18,000
Copying/publications	1 LS				10,000	10,000			10,000
Total				35,100		10,000		0	45,100

Example C (Continued)

Description	Quantity	Hours	Labor rate	Total labor	Material		Subcontracted		Total
					Unit	Total	Unit	Total	
PREMOBILIZATION ACTIVITIES									
Home office services									
Procurement	1 LS	80	33.00	2,640					2,640
Project controls	1 LS	40	33.00	1,320					1,320
General management	1 LS	20	55.00	1,100					1,100
Total				5,060		0		0	5,060
CFR 1910.120 medical/training									
Medical exams	12 ea	48	35.00	1,680	500	6,000			7,680
40 hr training	4 ea	160	35.00	5,600	600	2,400			8,000
8 hr refresher	5 ea	40	35.00	1,400	250	1,250			2,650
Total				8,680		9,650		0	18,330
Preconstruction meetings									
Project manager	1 LS	32	60.00	1,920					1,920
Project engineer	1 LS	48	45.00	2,160					2,160
Site manager	1 LS	32	50.00	1,600					1,600
Allow for travel	1 LS				4,000	4,000			4,000
Total				5,680		4,000		0	9,680
Performance and payment bond									
Allowance for	1 LS					250,000			250,000
Total, Premobilization Activities				54,520		273,650		0	328,170

GENERAL MOBILIZATION ACTIVITIES

Move in and set up trailers									
Office	1 ea	24	35.00	840	250	250	250	250	1,340
Decontamination	1 ea	48	35.00	1,580	300	300	500	500	52,480
Tools/equipment	1 ea	8	35.00	280	150	150	100	100	530
Total				2,800		700		850	4,350
Move in equipment									
Bulldozers	3 ea						250	750	750
Dump and water trucks	3 ea						100	300	300
Front end loaders	1 ea						250	250	250
Roller compactor	2 ea						250	500	500
Total				0		0		1,800	1,800
Set up work zones and initial sitework									
Surveyor	2 day						650	1,300	1,300
Tapes and stakes	1 LS				150	150			150
Clearing and grubbing	1 LS	32	37.00	1,184	250	250	250	250	1,684
Grading	1 LS	32	37.00	1,184	250	250	250	250	1,684
Gravel paving	200 cy	40	35.00	1,400	12	2,400	0	0	3,800
Electric connections	1 LS	24	35.00	840	1,000	1,000	0	0	1,840
Telephone tie-in	1 LS	24	35.00	840	1,500	1,500	0	0	2,340
Fencing	2,800 lf						12	33,600	33,600
Total				5,448		5,550		35,400	46,398
Decontamination pad									
Grade area	1 LS	24	35.00	840	250	250	0	0	1,090
Install HDPE liner	1 LS	24	35.00	840	1,000	1,000	0	0	1,840
Gravel	50 cy	24	35.00	840	12	600	0	0	1,440
Piping	1 LS	24	35.00	840	1,500	1,500	0	0	2,340
Set up tanks	2 ea	24	35.00	840	250	500	0	0	1,340
Total				4,200		3,850		0	8,050

Example C (Continued)

Description	Quantity	Hours	Labor rate	Total labor	Material		Subcontracted		Total
					Unit	Total	Unit	Total	
GENERAL MOBILIZATION ACTIVITIES (continued)									
Air monitoring system									
Set up air monitors	2ea	24	35.00	840	100	200	150	300	1,340
Set up met. station	1 ea	24	35.00	840	100	100	50	50	990
Initial samples	10 ea	1	35.00	35	15	150	100	1,000	1,185
Total				1,715		450		1,350	3,515
Total, General Mobilization				514,163		10,550		39,400	64,113
THERMAL SYSTEM MOBILIZATION									
Move TTU on-site and set up									
Freight, trucks	1 LS					6,000	40,000	40,000	46,000
Mechanical work	1 LS	960	35.00	33,600	35,000	35,000	10,000	10,000	78,600
Electrical work	1 LS	640	35.00	22,400	25,000	25,000	5,000	5,000	52,400
Concrete foundations	50 cy	300	35.00	10,500	110	5,500	50	50	16,000
Refractory/misc. repair	1 LS						50,000	50,000	50,000
Total				66,500		71,500		105,000	243,000
Install supporting systems									
Water treatment system	1 LS	480	35.00	16,800	30,000	30,000	0	0	46,800
Cement trailer	1 LS	48	35.00	1,680	10,000	510,000	0	0	511,680
Pollution control system	1 LS	240	35.00	8,400	15,000	15,000	0	0	23,400
Ash handling system	1 LS	240	35.00	8,400	25,000	25,000	0	0	33,400
Material feed system	1 LS	120	35.00	4,200	10,000	10,000	0	0	14,200
Total				39,480		90,000		0	129,480

THERMAL SYSTEM MOBILIZATION

Shakedown/start up the unit									
Personnel	28 day	7,000	35.00	245,000	0	0	0	0	245,000
Utilities	28 day						1,500	42,000	42,000
Misc. expenses	28 day				1,200	33,600	500	14,000	47,600
Chemicals	28 day				250	7,000	100	2,800	9,800
Laboratory	28 day				150	4,200	3,000	84,000	88,200
Depreciation	28 day						3,000	84,000	84,000
Maintenance	28 day						1,000	28,000	28,000
Total				245,000		44,800		254,800	544,600
Trial burn									
Personnel,workers	7 day	1,750	35.00	61,250	0	0	0	0	61,250
Personnel-testing	7 day	700	35.00	24,500	1,300	9,100	0	0	33,600
Utilities	7 day						1,500	10,500	10,500
Misc. expenses	7 day				3,000	21,000	500	3,500	24,500
Chemicals	7 day				250	1,750	100	700	2,450
Laboratory	7 day				150	1,050	5,000	35,000	36,050
Depreciation	7 day						3,000	21,000	21,000
Maintenance	7 day						1,000	7,000	7,000
Special test/analytics	1 LS					100,000		250,000	350,000
Total				85,750		132,900		327,700	546,350
Stand by (hot)									
Personnel, workers	7 day	1,750	35.00	61,250	0	0	0	0	61,250
Utilities	7 day						1,500	10,500	10,500
Misc. expenses	7 day				3,000	21,000	500	3,500	24,500
Chemicals	7 day				250	1,750	100	700	2,450
Laboratory	7 day				50	350	500	3,500	3,850
Depreciation	7 day						3,000	21,000	21,000
Maintenance	7 day						1,000	7,000	7,000
Total				81,250		23,100		46,200	130,550
Total, Thermal System Mobilization				458,500		272,300		733,700	1,464,500

Example C (Continued)

Description	Quantity	Hours	Labor rate	Total labor	Material		Subcontracted		Total
					Unit	Total	Unit	Total	
REMEDIATION									
Interim operations, 75% of capacity									
Personnel, workers	60 day	15,000	35.00	525,000	0	0	0	0	525,000
Utilities	60 day						1,000	60,000	60,000
Misc. expenses	60 day				4,000	240,000	500	30,000	270,000
Chemicals	60 day				500	30,000	100	6,000	36,000
Laboratory	60 day				150	9,000	5,000	300,000	309,000
Depreciation	60 day						3,000	180,000	180,000
Maintenance	60 day						1,000	60,000	60,000
Total				525,000		279,000		636,000	1,440,000
Excavation									
Bulldozers (1)	100 day	800	37.00	29,800	0	0	750	75,000	104,600
Front end l'ders (1)	100 day	800	37.00	29,600	0	0	g00	90,000	119,600
Dump trucks(z)	100day	1600	37.00	59,200	0	0	600	60,000	119,200
Laborers	100 day	800	37.00	29,600	0	0	0	0	29,600
Total				148,000		0		225,000	373,000
Operations of thermal system									
Personnel, workers	66 day	16,500	35.00	577,500	0	0	0	0	577.500
Utilities	66 day						1,800	118,800	118,800
Misc. expenses	66 day	5,000				330,000	500	33,000	363,000
Chemicals	66 day	600				39,600	100	6,600	46,200
Laboratory	66 day	200				13,200	6,000	396,000	409,200
Depreciation	66 day						3,000	198,000	198,000
Maintenance	66 day						1,000	66,000	66,000
Total				577,500		382,800		818,400	1,778,700

Backfill, ash, and final cover									
Bulldozers (3)	45 day	1080	37.00	39,960	0	0	750	33,750	73,710
Roller compactor (2)	45 day	720	37.00	26,640	0	0	600	27,000	53,640
Soil, delivered	6,000 cy				12	72,000	0	0	72,000
Water truck	45 day	360	37.00	13,320	0	0	250	11,250	24,570
Laborers	45 day	360	37.00	13,320	0	0	0	0	513,320
Total				93,240		72,000		72,000	237,240
Lining operation									
Membrane liner	170,000 sf						1	127,500	127,500
Soil base	6,000 cy	160	35.00	5,600	12	72,000			77,600
Geonet/fabric filter	170,000 sf						2.50	425,000	425,000
Total				5,600		72,000		552,500	630,100
Misc. activities									
Air samples (2/day)	135 day				50	6,750	200	27,000	33,750
Compaction test	50 ea				0	0	250	12,500	12,500
Misc. disposal, PPE	150 drum				30	4,500	250	37,500	42,000
Total				0		11,250		77,000	88,250
Total, Remediation Work				1,349,340		817,050		2,380,900	4,547,290
INDIRECT ACTIVITIES									
Health and safety supplies									
Level D mod outfits	3,375 ea				20	67,500	0	0	67,500
Level C outfits	1,000 ea				35	35,000	0	0	35,000
Air monitoring equip	6 mo				5,000	30,000	0	0	30,000
Drums	150 ea				30	4,500	0	0	4,500
Small tools/consumables	1 LS				25,000	25,000	0	0	25,000
Total				0		162,000		0	162,000

Example C (Continued)

Description		Hours	Labor rate	Total labor	Material Unit	Material Total	Subcontracted Unit	Subcontracted Total	Total
INDIRECT ACTIVITIES (continued)									
Trailers and temporary facilities									
Office	10 mo				250	2,500	0	0	2,500
Decontamination	10 mo				900	9,000	0	0	9,000
Equipment/tools	10 mo				100	1,000	0	0	1,000
Port-a-johns	10 mo				150	1,500	0	0	1,500
Signs	1 LS				5,000	5,000	0	0	5,000
Total				0		19,000		0	19,000
Utilities, trailers only									
Electric	10 mo				500	6,000	0	0	5,000
Water	10 mo				200	2,000	0	0	2,000
Telephone	10 mo				500	5,000	0	0	5,000
Radios	1 LS				2,500	2,500	0	0	2,500
Fuel	10 mo				1,000	10,000	0	0	10,000
Total				0		24,500		0	24,500
Management personnel									
Site manager	1 LS	1600	50.00	80,000	10	10	0	0	80,010
Site engineer	1 LS	1600	40.00	64,000	6	6	0	0	64,006
Safety/health officer	1 LS	1600	38.00	560,800	6	6	0	0	60,806
Decon. person	1 LS	1600	35.00	556,000	0	0	0	0	56,000
Sampling technician	1 LS	1600	25.00	40,000	0	0	0	0	40,000
Total				300,800		22		0	300,822
Total, Indirects				300,800		205,522		0	506,322

DEMOBILIZATION

Remove trailers									
Personnel	1 ea	24	35.00	840	0	0	250	250	1,090
Decontamination	1 ea	48	35.00	1,680	0	0	250	250	1,930
Equipment/tools	1 ea	16	35.00	560	0	0	150	150	710
Port-a-john	1 LS	0	35.00	0	0	0	100	100	100
Total				3,080		0		750	3,830
Move out equipment									
Decon. equipment	9 ea	40	35.00	1,400	0	0	0	0	1,400
Haul out equipment	6 ea	0	35.00	0	0	0	250	1,500	1,500
Trucks	3 ea	0	35.00	0	0	0	100	300	300
Total				1,400		0		1,800	3,200
Remove decon. facilities									
Remove pad	1 LS	48	35.00	500	500	500	100	100	1,100
Remove piping	1 LS	60	35.00	250	0	0	100	100	350
Dispose of water	10,000 ga	24	35.00	840	0	0	3	30,000	30,840
Remove tanks	1 LS	24	35.00	840	0	0	0	0	840
Total				2,430		500		30,200	33,130
Decon/demob. TTU									
Personnel, workers	21 day	2,100	35.00	73,500	0	0	0	0	73,500
Mechanical subcont	1 LS						50,000	50,000	50,000
Misc. expenses	21 day				1,000	21,000	500	10,500	31,500
Electric subcontractor	1 LS						30,000	30,000	30,000
Depreciation	21 day						3,000	63,000	63,000
Maintenance	21 day						1,000	21,000	21,000
Total				73,500		21,000		174,500	269,000
Total, Demobilization				80,410		21,500		207,250	309,160

VII. ACRONYM LISTING FOR ENVIRONMENTAL RESTORATION PROJECTS

A	Approval
ACL	Alternative Description Memorandums
ACM	Asbestos-Containing Materials
AD	Associate Director
ADM	Arrow Diagram Method
ADP	Automatic Data Processing
ADPE	Automatic Data Processing Equipment
ADS	Activity Data Sheet
AE	Acquisition Executive
A-E	Architect-Engineer
AEA	Atomic Energy Act
AEC	Atomic Energy Commission
AFP	Approved Financial Plan
AHERA	Asbestos Hazardous Emergency Response Act
AIP	Agreement-in-Principal
AITG	Aquatic Issues Task Group
AL	Albuquerque Field Office
ALARA	As Low As Reasonably Achievable
AMO	Assistant Manager for Operations
AME	Assistant Manager for Environmental Management
AMP	Assistant Manager for Projects
AMT	Assistant Manager for Technical Support
ANSI	American National Standards Institute
ANSP	Academy of Natural Sciences of Philadelphia
AOC	Area of Concern
AP	Activity Package
ARAR	Applicable or Relevent and Appropriate Requirements
ASME	American Society of Mechanical Engineers
ASNE	American Society of Nuclear Engineers
AST	Above Ground Storage Tanks
ATP	Acceptance Test Procedures
ATSDR	Agency for Toxic Substances and Disease Registry
BA	Budget Authorization
B/A	Budget Authority
BAC	Budget At Completion
BACT	Best Available Control Technology
BAT	Best Available Technology
BBC	Balanced Biological Community

BCCB	Baseline Change Control Board
BCP	Baseline Change Proposal
BCY	Bank Cubic Yards
BCWP	Budget Cost of Work Performed
BCWS	Budget Cost of Work Scheduled
BDAT	Best Demonstrated Available Technology
BMP	Best Management Practices
BO	Budget Outlay
BRA	Baseline Risk Assessment
BRC	Budget Review Committee
BY	Budget Year
CA	Corrective Action
CA	Cost Account
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAC	Cost At Completion
CAD	Computer-Aided Design and Drafting
CAM	Cost Account Manager
CAP	Corrective Action Plan
CAPCA	Closure and Post Closure Activities
CCB	Change Control Board
CCE	Certified Cost Engineer
CCWS	Comprehensive Cooling Water Study
CCY	Compacted Cubic Yards
CD	Conceptual Design
CDC	Center for Disease Control
CDS	Construction Data System
CE	Civil Engineer
CEC	Central Environmental Committee
CECEC	Central Environmental Committee Executive Committee
CENRTC	Capitol Equipment Not Related to Construction
CEQ	Council on Environmental Quality
CER	Cost Estimating Relationship
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CF	Cubic Feet
CFC	Chloroflourocarbons
CFR	Code of Federal Regulations
CH	Chicago Field Office
CHE	Chemical Engineer
Ci	Curie

CIF	Consolidated Incineration Facility
CICA	Competition in Contracting Act
CLP	Contract Laboratory Program
CM	Construction Manager
CME	Comprehensive Monitoring Evaluation
CMI	Corrective Measures Implementation
CMI	Corrective Measures Investigation
CMP	Configuration Management Plan
CMP	Corrugated Metal Pipe
CMP	RL Office of Compliance
CMS	Corrective Measures Study
COE	U.S. Army Corps of Engineers
COR	Contracting Officer Representative
CPAF	Cost Performance Report
CPS	Conceptual Project Schedule
CR	Office of the Controller
CR	Community Relations
CRP	Community Relations Plan
CRRFI	Clinch River RCRA Facility Investigation
C/SCS	Cost Schedule Control System
C/SCSC	Cost Schedule Control System Criteria
CTC	Cost to Complete
CV	Cost Variance
CVI	Certified Vendor Information
CWA	Clean Water Act
CX	Categorical Exclusion
CYWP	Current Year Work Plan
D&D	Decontamination and Decommissioning
DE/EM MON	Defense Programs EM Memo of Understanding
DIES	Design Information Exchange System
DNFSB	Defense Nuclear Facility Safety Board
DOD	Department of Defense
DOE	Department of Energy
DOE/GJPO	DOE/ Grand Junction Program Office
DOE/HQ	DOE/Headquarters
DOE/ID	DOE/Idaho Field Office
DOE/SR	DOE/Savannah River Field Office
DOI	Department of Interior
DOL	DepartTnent of Labor
DOT	Department of Transportation
DP	Office of Defense Programs

DQO	Data Quality Objectives
EA	Environmental Assessment
EA	Each
EAC	Environmental Advisory Committee
EAC	Estimate at Completion
E/C	Engineer/Constructor Contractor
ECA	Engineering Cost Analysis
ECD	DOE Environmental Compliance Division
ECN	Engineering Change Notice
ED&I	Engineering Design & Investigation
EE	Electrical Engineer
EE	Environmental Evaluation
EEO	Equal Employment Opportunity
EFPC	East Fork Poplar Creek (OR-Y12)
EH	Office of Environmental Safety and Health
EIP	Environmental Implementation Plan
EIS	Environmental Impact Statement
EM	DOE Environmental Restoration and Waste Management
EMTC	Environmental Management Technical Center (AL-5)
EM-1	Director of the Office of Environmental Restoration & Waste Management
EM-10	Office of Planning and Resource Management
EM-20	Office of Quality Assurance and Quality Control
EM-30	Office of Waste Operations (OWO)
EM-40	Office of Environmental Restoration (OER)
EM-50	Office of Technology Development (OTD)
EOC	Emergency Operation Center
EP	Extraction Procedure
EPA	Environmental Protection Agency
EPB	DOE Environmental Policy Branch
EPCRA	Emergency Planning and Community Right-to-Know Act
EQAB	Environmental Quality Advisory Board
ER	Office of Energy Research
ER	Environmental Restoration
ERA	Expedited Response Action
ERDA	Energy Research and Development Agency
ERP	Environmental Restoration Program
ESA	Endangered Species Act
ESAAB	Energy Systems Acquisition Advisory Board
ES&H	Environmental, Safety and Health
ETC	Estimate to Complete

ETF	Effluent Treatment Facility
4 Cs	Construction, Completion & Cost Closing Statement
FA	Force Account
FDC	Functional Design Criteria
FFA	Federal Facility Agreement
FFCA	Federal Facility Compliance Agreement
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FINPLAN	Financial Plan
FIS	Financial Information System
FIS	Richland Financial Information System
FMD	Richland Financial Management Division
FML	Flexible Membrane Liner
FMPR	Feed Materials Production Center
FMPC	Feed Materials Production Control
FONSI	Finding Of No Significant Impact
FP	FLxed Price
FPM	Federal Personnel Manual
FPMR	Federal Property Management Regulation
FS	Feasibility Study
FSAR	Final Safety Analysis Report
FSP	Field Sampling Plan
FTE	Full-Time Employees
FUSRAP	Formerly Utilized Sites Remedial Action Program
FWS	U.S. Fish and Wildlife Service
FY	Fiscal Year
FYP	Five-Year Plan
G&A	General and Administrative
GC	Office of General Council
GCD	General Containment Disposal
GCEP	Gas Centrifuge Expansion Program (ORNL)
GJ	Grand Junction
GN	Geonet
GOCO	Government Owned, Contractor Operated
gpm	Gallons per minute
GPP	General Plant Project
GT	Geotextile
H&S	Health and Safety
HAZMAT	Hazardous Materials
HAZWRAP	Hazardous Waste Remedial Actions Program
HCFC	Hydrohcloroflourocarbons
HDPE	High Density Polyethylcne

HEPA	High-Efficiency Particulate Air
HHRA	Human Health Risk Assessment
HLLW	High-Level Liquid Waste
HLW	High-Level Waste
HMTA	Hazardous Materials Transportation Act
HNu	Photoionization Detector—Brand Name
HP	Health Protection or Health Physics
HPS	Hanford Plant Standards
HQ	Headquarters
HRS	Hazard Ranking System
HSDP	Hanford Site Development Plan
HSP	Health and Safety Plan
HSWA	Hazardous and Solid Waste Amendments (To RCRA)
HVAC	Heating, Ventilating, and Air Conditioning
HWMF	Hazardous Waste Management Facility
HW/MWDF	Hazardous Waste/Mixed Waste Disposal Facility
HWV	RL Hanford Waste Vitrification Project Division
I	Information
IH	Industrial Hygienist
IAG	Interagency Agreement
IAPP	Interim Action Proposed Plan
IAW	In Accordance With
ID	Idaho Field Office
IHSS	Individual Hazardous Substance Sites
IM	Interim Measures
INEL	Idaho National Engineering Laboratory
IRA	Interim Remedial Action
IRM	Interim Remedial Measure
IT	IT Corporation
ISV	In Site Vitrification
I-T-D	Inception To Date
IVC	Independent Verification Contract
K	Thousands
K-25	Oak Ridge Gaseous Diffusion Plant
KD	Key Decision
L	Liter
LCC	Life Cycle Costs
LCRS	Leachate Collection and Removal System
LDCRS	Leak Detection, Collection, and Removal System
LDR	Land Disposal Restriction
LEL	Lower Explosive Limit

LF	Linear Feet
LI	Line Item Project
LLRWDF	Low-Level Radioactive Waste Disposal Facility
LLW	Low Level Waste
M	Meters
M	Thousands
MAP	Mitigation Action Plan
mL	milliliter
M&O	Management and Operation
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
ME	Mechanical Engineer
MED	Manhattan Engineer District
MM	Millions
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MP	Management Plan
MP	Major Project
MPSA	Marine Protection and Sanctuaries Act
MPR	Management Policies and Requirements
MRAP	Monticello Remedial Action Project
mrem	millirem
MRM	Management Review Meeting
MSA	Major Systems Acquisition
MSDD	Management System Design Description
MSDS	Material Safety Data Sheet
MSWLF	Municipal Solid Waste Landfill
M-T-D	Month-To-Date
MTF	Memorandum to File
MVP	Monticello Vicinity Properties
MW	Mixed Waste
MWMF	Mixed Waste Management Facility
MWSB	Mixed Waste Storage Building
MWTA	Medical Waste Tracking Act
N	Standard Penetration Value in Number of Blows of the Hammer per Foot of Penetration
NAPLS	Nonaqueous Phase Liquid Substance
NAS	National Academy of Science
NASA	National Aeronautics and Space Administration
nCi	Nanocurie
NCP	National Contingency Plan

NCR	Nonconformance Report
NE	Office of Nuclear Energy
NEPA	National Environmental Policy Act
NERP	National Environmental Research Park
NESHAP	National Emissions Standard for Hazardous Air Pollutants
NHPA	National Historic Preservation Act
NHP	New Hope Pond
NMFS	National Marine Fisheries Service
NLT	Not Later Than
NOD	Notice of Deficiency
NOI	Notice of Intent
NOV	Notice of Violation
NOx	Oxides of Nitrogen
NPDES	National Pollutant Discharge Eliminating System
NPL	National Priorities List
NQA-1	Nuclear Quality Assurance-1
NRC	Nuclear Regulatory Commission
NRCC	Natural Resources Coordinating Committee
NRDC	Natural Resources Defense Council
NRT	National Response Team
NRWTP	Nonradiological Waste Treatment Project
NS	Office of Nuclear Safety
NTS	Nevada Test Site
NV	Nevada Field Office
OAC	Official Acceptance of Construction
OC	Operating Contractor (Q&E and R&D Contractors)
OCC	Office of Chief Counsel
ODC	Other Direct Cost
O&E	Operations and Engineering Contractor
OCRWM	Office of Civilian Radioactive Waste Management
OIG	Office of Management and Budget
O&M	Operation and Maintenance
OMB	U.S. Office of Management and Budget
O/O	Owner/Operator
OR	Oak Ridge Field Office
ORAU	Oak Ridge Associated Universities
ORGDP	Oak Ridge Faseous Diffusion Plant (K-25 Site)
ORNL	Oak Ridge National Laboratories
ORO	Oak Ridge Operations
ORR	Operational Readiness Review
OSHA	Occupational Safety and Health Administration

OSWER	Office of Solid Waste and Emergency Response
OTD	Office of Technology Development (EM-50)
OTP	Operations Test Procedures
OU	Operable Unit
OVA	Organic Vapor Analyzer
OWO	Office of Waste Operations (EM-30)
PA	Preliminary Assessment
PA	Project Authorization
P&A	Plug and Abandon
PA/SI	Preliminary Asscssment/Site Inspection
PACE	Plant and Capitol Equipment (Budget)
PB&C	Planning, Budgeting, and Control
PBD	RL Plans and Budget Division
PCB	Polychlorinated Biphenyl
PCE	Perchloroethylene
pCi/g	Picocuries per gram
PCM	Phase Contrast Microscopy
PD	Program Decision
PDS	Project Data Sheet (Schedule 44)
PE	Professional Engineer
PEIS	Preliminary Environmental Impact Study
PFSR	Project Funds Status Report
pH	Potential of Hydrogen (a measure of acidity and alkalinity)
PHS	Public Hcalth Service
PIP	Public Involment Plan
PLM	Polarized Light Microscopy
PM-10	Particulate Matter < 10 μ
PMD	RL Project Management Division
PMP	Program Managment Plan
PMPR	Program Management Policies & Requirements
PMS	Program Management System
POTW	Publicity Owned Treatment Works
PP	Proposed Plan
ppb	Parts per billion
PPE	Personal Protective Equipment
ppm	Parts per million
PRA	Probabilistic Risk Assessment
PRO	RL Procurement Division
PRP	Potentially Responsible Party
PSAR	Preliminary Safety Analysis Report
PSCS	Preliminary Site Characterization Summary

PSD	Prevention of Significant Determination
PSD	Program Summary Document
PSE	Preliminary Safety Evaluation
psi	Pounds per square inch
PSO	Program Secretarial Officer
PSWBS	Program Summary Waste Breakdown Structure
PTS	Project Tracking System
PUF	Polyurethane Foam
PU/U	Plutonium/Uranium
PWA	Process Waste Assessment
PWE	Present Working Estimate
QA	Quality Assurance
QAPD	Quality Assurance Program Description
QAPP	Quality Assurance Project Plan
QC	Quality Control
QPP	Quality Program Plan
R	Review
R&D	Research and Development
RA	Remedial Action
RAA	Remedial Action Agreement
RAFTS	Recommendation and Findings Tracking System
R&HA	River and Harbor Act (COE Permitting Authority)
RAM	Responsibility Assignment Matrix
RAP	Remedial Action Program
RCA	Radiological Controlled Areas
RCD	Reference Conceptual Design
RCRA	Resource Conservation and Recoverry Act
RD	Remedial Design
R&D	Research and Development
RD&D	Research, Development, and Demonstration
RD/RA	Remedial Design/Remedial Action
RDDT&E	Research, Development, Demonstration, Testing, and Evaluation
REA	Radiologic and Engineering Assessment
REC	Request for Engineering Change
rem	Roentgen
RFA	RCRA Facility Assessment
RFD	Reference Dose
RFI	RCRA Facility Investigation
RI	Remedial Investigation
RI/FS	Remedial Investigation Feasibility Study

RL	DOE Field Office, Richland
RLIP	DOE Field Office, Richland Implementing Procedure
ROD	Record of Decision
ROD	Record of Deviation
ROM	Rough Order of Magnitude
RPA	Request for Project Authorization
RPAM	Request for Project Authorization Modification
RPM	Reactive Plum Model
RPM	Remedial Project Manager (CERCLA)
RPM	Revolutions Per Minute
ROOMS	Radioactive Waste Management Site
S&M	Surveilance and Monitoring
SAP	Sampling and Analysis Plan
SARA	Superfund Admendments and Reauthorization Act of 1987
SAS	RL Safeguards and Security Division
SBA	Small Business Act, Section 8(a)
SDWA	Safe Drinking Water Act
SEA	Special Environmental Analysis
SEEP	Groundwater Into Surface Water
SEFES	Southeastern Forest Experiment Station of the U.S. Forest Service
SEMP	System Engineering Management Plan
SKIS	Supplemental Environmental Impact Statement
SER	Site Evaluation Report
SFDS	Short Form Data Sheet
SFMP	Surplus Facilities Management Program
SI	Site Inspection
SID	RL Site Infrastructure Division
SIRIM	Site Item Reportable Issue Management
SITE	Superfund Innovative Technology Evaluation
SMARTS	Specifications and Management Applications for Regulated Tank Systems Program
SOW	Statement of Work
SPDES	State Pollutant Discharge Elimination System
SPCC	Spill Prevention Control and Countermeasures Plan
SRD	Supplemental Design Requirements Document
SP	Small Projects
SR	DOE, Savannah River Field Office
SRS	Savannah River Site
SSDW	Subproject Scope Definition Worksheet
SSP	Site Specific Plans

SST	Single Shelled Tanks
SV	Schedule Variance
SW	Solid Waste
SWDA	Solid Waste Disposal Act
SWMU	Solid Waste Management Unit
SWSA	Solid Waste Storage Area
SWTP	Sanitary Waste Treatment Plant
T	Ton
TAC	Technical Assistance Contractor
TAG	Technical Assistant Grant
TBC	To Be Considered
TCE	Trichloroethylene/Tetrachloroethylene
TCL	Target Compound List
TCLP	Toxicity Characteristic Leachate Procedure
TDHE	Tennessee Department of Health and Environment
TDS	Total Dissolved Solids; Technical Data Summary
TEC	Total Estimated Cost
TECC	Total Estimated Construction Cost
TEM	Transmission Electron Microscopy
TLD	Toxic Lethal Dose
TM	Technical Monitor
TNT	Trinitrotoluene
TPC	Total Project Cost
TPCE	Total Project Cost Estimate
TPD	Tons Per Day
TPY	Tons Per Year
TRC	Total Residual Chlorine
TRU	Transuranic Waste
TSC	Technical Support Center
TSCA	Toxic Substance Control Act
TSD	RL Technical Support Division
TSWMA	Tennessee Waste Managcment Act
T/S/D	Treatment/Storage/Disposal
TSS	Total Suspended Solids
TVA	Tennessee Valley Authority
TWF	Transuranic Waste Facility
UCC	Union Carbide Corporation
UEFPC	Upper East Fork Poplar Creek (ORNL)
UIC	Underground Injection Control
UMTRA	Uranium Mill Tailings Remodiation Act
U.S.C.	U.S. Code of Law

USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
UST	Underground Storage Tank
UTRC	Upper Three Runs Creek
UV	Ultraviolet
VCA	Vanadium Corporation of America
VLF	Vertical Linear Foot
VOC	Volatile Organic Compounds
WA	Waste Authorization
WAG	Waste Area Group
WBS	Work Breakdown Structure
WIPP	Waste Isolation Pilot Plant
WM	Waste Management Operations
WQC	Water Quality Criteria
WWTP	Wastewater Treatment Plant
X-10	Oak Ridge National Lavoratory
Y-T-D	Year To Date
Y-12	Oak Ridge Y-12 Plant

VIII. GLOSSARY TERMS FOR ENVIRONMENTAL RESTORATION PROJECTS

Acceleration Acceleration of the contract occurs when a contractor is forced to perform work in a shorter period of time than called for in the contract. Actual acceleration occurs when the owner directs that the work is to be completed earlier than required by the contract. Constructive acceleration occurs when the contractor has demonstrated that a time extension is required but the owner has denied it, thereby requiring the contractor to complete the work in accordance with a schedule that has not been properly extended.

Abel EPA's computer model for analyzing a violator's ability to pay a civil penalty.

Account structure A formal organization of accounting codes used to collect costs for control account work, which provides needed information, segregated as necessary, for reporting costs.

Activity data sheet (ADS) The ADS provides summary technical, cost, and schedule information at a specified level of the program summary work breakdown structure (WBS). Management activities that are not associated with a specific waste management operation or project are specified on separate ADSs. As a planning document, ADSs reflect the funding requirements for the program. Expended funds, prior-year funds, current-year funds, bud-

get-year funds, and budget year plus one through five funds, and the remaining year funds are shown. As a baseline document, ADS's reflect program baseline in terms of cost, schedule, and technical performance for the approved program.
Activity-based cost (ABC) estimating ABC estimating consists of defining the overall task(s), and providing a unit of measure, quantity, labor-hours required, labor cost, material, subcontract, equipment usage, equipment, and overhead value(s) for that activity.
Activity Estimate activities are defined in sufficient detail to identify components included in the estimate. The activity is defined in terms of a quantity of cost elements (e.g., quantity, labor-hours, labor cost, materials, subcontracts, equipment usage, subcontracts, and overhead percentage).
As-built schedule Schedule prepared at the end of the project (or after) indicating actual completion dates and durations for all activities. The as-built schedule reflects any logic changes, scope additions, resequencing, and delays experienced during the project.
As-planned schedule Schedule, normally made by the contractor at the start of the project. As-planned schedules typically correspond with the contract times, reflect no delays, and describe the initial sequence of work as well as expected durations for all planned activities.
Audit A planned and documented activity performed to determine by investigation, examination, or evaluation of objective evidence the adequacy of and compliance with established procedures, instructions, drawings, and other applicable documents and to determine the effectiveness of implementation. An audit should not be confused with surveillance or inspection activities performed for the sole purpose of process control or product acceptance.
Bar chart A representation of work or activities to be performed. A bar chart is usually time-scaled, where the activities extend horizontally, depicting graphically the appropriate time frame for an activity. A bar chart may provide information at a summary or detailed level. A bar chart is not necessarily a logic-based portrayal of activities.
Baseline A quantitative definition of cost, schedule, and technical performance that serves as a base or standard for measurement and control during the performance of an effort; the established plan against which the status of resources and the effort of the overall program, field program(s), project(s), task(s), or subtask(s) are measured, assessed, and controlled. Once established, baselines are subject to change control procedures.
Certified cost engineer (CCE) The AACE International professional engineering organization certifies cost engineers that meet certain minimum qualifications. If they are graduate engineers, they are certified as certified cost engineers (CCEs). If they are not graduate engineers, they are designated as certified cost consultants (CCCs). Requirements for certification include; eight (8) years verifiable experience, successful completion of a six (6) hour exam,

and authorship of a 2,500 word professional paper. The certification process involves a day-long examination covering all major topics of cost engineering (e.g., estimating, scheduling, controls, cost analysis, project management, value engineering, probability and statistics, etc.).

Change control A documented process applying technical and management review and approval of changes to technical, schedule, and cost baselines.

Check estimate A check estimate is a validating estimate. The development and use is similar to an independent cost estimate, except it is developed by program/project personnel or their supporting contractor. A check estimate should be developed by someone who had no involvement in the original estimate but who may be an advocate of the project.

Computerized cost estimating tools Software-package or computer-based models used for cost estimating. These are usually a relational database model, that allows development of a library or database of costs for various activities. These systems usually allow for multiple sort capabilities.

Contingency The amount budgeted to cover costs that may result from incomplete design, unforeseen and unpredictable conditions, or uncertainties. The amount of the contingency depends on the status of design, procurement, and construction and the complexity and uncertainty of the component parts of the project. Contingency is not to be used to avoid making an accurate assessment of the expected cost.

Cost baseline A budget that has been developed from the cost estimate made at approval of the technical baseline, and the majority of the budget has been time-phased in accordance with the project schedule. The cost baseline is referred to as a baseline, because it is integrated with the technical and schedule baselines and subject to formal change control. The cost baseline normally contains direct and indirect budget, management reserve budget, undistributed budget and higher level budgets, contingency amount, and the amount for fees, as appropriate.

Cost control The application of procedures to follow the progress of design and construction projects as well as manufacturing operations in order to minimize cost with the objective of increasing profitability and assuring efficient operations. (1) Establish optimum condition, i.e., baseline, (2) Measure variation from the baseline, (3) Take corrective action, as needed, to minimize variation from the baseline.

Cost engineer An engineer (with an engineering degree) whose judgment and experience are utilized in the application of scientific principles and techniques to problems of cost estimation, cost control, business planning and management science, profitability analysis, value engineering, project management, planning, and scheduling.

Cost index A number that relates the cost of an item(s) at a specific time to the corresponding cost at some arbitrarily specified time in the past.
Current working estimate This estimate is required for cost control on large projects. The estimate is conducted periodically throughout the life of the project and kept under constant review to assure that it reflects the latest cost and design data available. It also reflects the estimated cost to complete, the allowance for contingency based on the latest detailed contingency analysis, and uncertainties remaining within the project.
Definitive estimate An estimate conducted during the latter stages of a project when engineering may be up to 40% completed. The actual cost should be within plus 15% to –5% of the estimate.
Disputes Disagreement about the interpretation of the contract, including the recognition and pricing of changes.
Escalation The provision in actual or estimated costs for an increase in the cost of equipment, material, labor, etc., over costs specified in the contract or baseline estimate because of continuing price level changes over time. An allowance to offset the impact of monetary inflation through time.
Estimate detail The lowest level of detail that the estimate contains. The estimate detail contains data for all or some of the estimate elements. Also termed estimate activity.
Estimate element Each line item in the estimate may contain information or costs regarding the work breakdown structure (WBS) code, activity number, description, sort code(s), labor-hours, material, subcontract, equipment usage, capital equipment, and overhead.
Fast tracking Project execution strategy whereby normal sequence of design and/or construction activities are overlapped. Projects using this strategy are termed fast-track projects.
Float In critical path method (CPM) scheduling, the amount of slack time between a noncritical activity and the critical path. In contract management, the amount of time between the contractor's forecast for completion and the contract times specified in the contract.
Float suppression Reducing the amount of float time in a CPM schedule through clever network techniques (e.g., preferential sequencing; unusual use of lead/lag restraints; and/or inflated durations for activities.
Force majeure Clauses in contracts that allow time extensions for acts of God or natural disasters.
Fringe benefits Employee welfare benefits, (e.g., expenses of employment not paid directly to the employee, such as holidays, sick leave, supplemental unemployment benefits, social security, insurance, etc.).

Full time equivalent (FTE) A colloquial term that is not used in activity-based estimate preparation. It usually refers to annual labor. FTE has many definitions and hence is not a reliable basis for labor-hour estimation.

Generic cost-estimating tools Tools or models that are typically used for estimating conventional construction costs. They also may shape the capability of estimating costs for environmental restoration projects.

Independent cost estimate (ICE) A documented cost estimate that has the express purpose of serving as an analytical tool to validate, crosscheck, or analyze estimates developed by proponents of a project. An independent cost estimate also serves as a basis for verifying cost risk assessments.

Intermediate estimate An estimate conducted at the intermediate stages of a project or the beginning of the design stage. This estimate is sometimes referred to as budget estimate.

Inspection Examination or measurement to verify whether an item or activity conforms to specified requirements.

Labor factor The ratio between the labor-hours actually required to perform a task under project conditions and labor-hours required to perform an identical task under standard conditions.

Labor-hour Defined as the duration (usually in hours or decimal equivalent, example: 20 min = 20 min/60 min = .333 labor-hours) for the performance of a particular operation.

Level of effort (LOE) Support effort that cannot be measured in terms of discrete accomplishment. LOE is characterized by a sustained rate of activity for a specific period of time.

Life-cycle project planning Life-cycle program planning represents the total planning necessary to achieve program objectives. The total life-cycle is represented by the composite of the life-cycles of the various projects or operations at the installations and management activities that are not applicable to a specific project. Effective planning and control are based on life-cycle events rather than arbitrary time spans having no natural relationship to completing the program. Life-cycle program planning is modified throughout the life of the program as more actual historical information and program experience are obtained.

Liquidated damages Contractual provisions under which the parties agree that unexcused delays will cost the contractor specified sums of money, Normally expressed as a cost per calendar day.

Logic diagram A graphical depiction of a sequence of events that are diagrammed so that the logic of the sequence of events is easily understood (e.g., Activity D cannot start until Activity B is complete. Not necessarily time scaled.)

Lump sum contract A type of contract in which the eost of the work to be performed is shown as an all-inclusive price; also known as *a fixed-price contract.*
Management reserve (MR) The portion of the contract or project budget controlled specifically for management purposes and not designated for the accomplishment of specific tasks; when MR is used it is distributed to specific accounts.
Master schedule Broad based schedule that shows all facets of the project. Master schedules are commonly used in projects with multiple prime contractors to provide an overall roll-up of reporting all of the schedules on one master schedule.
Materials Usually products that are necessary to accomplish a particular task. Also a category of costs (Cost Element) in estimating. Not necessarily a part of the finished project, i.e., formwork may be removed, but it is still material needed.
Memorandum of understanding An agreement between or among two or more federal, state, or local agencies that sets forth basic policies and procedures governing their relationship on matters of mutual interest and responsibility.
Milestone An important or critical event and/or activity that must occur in the project cycle to achieve the project's objective(s).
Network logic diagram (See also "logic diagram" and "time-scaled logic diagram".) Usually a graphic depiction of all relationships within a schedule in a non-time scaled mariner.
Organizational breakdown structure (OBS) The hierarchical arrangement for a company's management organization, graphically depicting the reporting relationships. Normally, the OBS is limited to showing managerial positions, but may depict lower organizational levels. The structure may also show subcontract relationships depending upon the purpose of the OBS.
Overhead A cost or expense inherent in the performing of an operation (e.g., engineering, construction, operating, or manufacturing) that cannot be charged to or identified with a part of the work, product, process, or asset and, therefore, must be allocated on some arbitrary basis believed to be equitable, or handled as an expense independent of the production effort.
Parametric cost estimating relationships Tools that rely on the historical costs of previous operations or remedial actions to build parametric cost estimating relationships. Often referred to as cost-estimating relationships (CER's). Often the costs or quantities are functionally oriented, i.e., costs are examined in terms of production capacity or waste disposal quantities.
Procedure A document that specifies or describes how an activity is to be performed

Procurement document Purchase requisitions, purchase orders, drawings, contracts, contract task orders, specifications, or instructions use to determine requirements for purchase.
Productivity A measure of units of work accomplished per unit of time (e.g., ft^2/hr). Relative measure of labor efficiency, either good or bad, when compared to an established base or norm as determined from an area of great experience. Productivity changes may be either an increase or decrease in cost. Productivity is also defined as the reciprocal of the labor factor. (See "Labor Factor".)
Program An organized set of activities directed toward a common purpose or goal undertaken or proposed in support of an assigned mission area. It is characterized by a strategy for accomplishing a definite objective(s) that identifies the means of accomplishment, particularly in quantitative terms with respect to work force, material, and facility requirements. Programs are typically made up of technology-based activities, projects, and supporting operations.
Project A unique major effort within a program that has a firmly scheduled beginning, intermediate, and ending date milestones; prescribed performance requirements; prescribed costs; and close management, planning, and control. The project is the basic building block in relation to a program that is individually planned, approved, and managed.
Project control system The planning, scheduling, budgeting, estimating, work authorization, cost accumulation, performance measurement, reporting, change control, and other systems used by a company or contractor to plan and control the work.
Quality control All actions necessary to control and verify the features and characteristics of a material, process, product, or service to specified requirements. Quality control is the regulatory process through which we measure actual quality performance, compare it with standards, and act on the difference.
Quality assurance All planned and systematic actions necessary to provide adequate confidence that a facility, structure, system, or component will perform satisfactorily in service.
Record schedule A contemporaneous schedule used to document the actual starts and completions of activities in a project. If done correctly, the final version of the record schedule can also serve as the as-built schedule.
Reimbursable cost contract A type of contract where the cost of the work is determined by actual cost incurred by the contractor. Profit and overhead costs of the contractor can be a fixed amount of a percentage of the actual costs. Also commonly termed as a *time-and-materials* contract.
Requests for information (RFIs) A formal request by the contractor to clarify the technical aspects of the contract.

Risk level The level of complexity and/or uncertainty associated with a project. Examples of risk factors include the number of participants and locations, public/political visibility, regulatory involvement, time frame, and quality requirements.

Schedule

Backward pass The calculation from the end of the network of the durations, lags, and relationships to determine the latest start date possible, given the logic of the network.

Criticality The relevance of an activity or path in the network to cause the network to extend beyond the completion date. Generally the inverse of float; large float = low criticality and low float = high criticality.

Forward pass The calculation from the beginning of the network of the durations, lags, and relationships to determine the earliest completion date possible, given the logic of the network.

Early start The earliest date on which an activity may start, given the logic of the network, as determined by the forward pass.

Float The arithmetic result of early finish minus late finish. This may be negative in the case of a network scheduled to exceed its completion date.

Free float The duration an activity may slip before it impacts any other subsequent activity.

Late start The latest date on which an activity must start to avoid exceeding the completion date, given the logic of the network, as determined by the backward pass.

Path The activities in a chain or sequence having the same float value. The effect on any one activity affects the entire path.

Predecessor activity An activity that must start or finish before another.

Schedule logic The relationship of schedule activities to one another.

Slack See float.

Successor activity An activity that cannot start or finish before another.

Total float The duration an activity may slip before it causes the network as a whole to exceed the end date.

Schedule baseline The time-phased plan with a logical sequence of interdependent activities, milestones, and events necessary to complete the project. The schedule baseline is formally changed during the execution of the project when required.

Schedule relationships

Finish to start (FS) Activity A must be completed before Activity B may begin.

Finish to finish (FF) Activity A must be completed before Activity B may be completed.

Lag The time between activities in addition to the relationship described. A lag may be present with any type of relationship.

Start to start (SS) Activity A must begin before Activity B can begin.

Start to finish (SF) Activity A must begin before Activity B can be completed.

Scope change A change in task objectives, plans (project or field work), or schedule that results in a material difference from the terms of an approval to proceed previously granted by higher authority. Under certain conditions, change in resource application may constitute a change in scope.

Scope of work A statement of definition outlining the parameters of a particular task(s) or project or program.

Site A geographical entity comprising land, buildings, and other facilities required to perform program objectives. Generally a site has, organizationally, all of the required facility management functions (i.e., it is not a satellite of some other site).

Storage Retention and monitoring of waste in a retrievable manner pending disposal.

Substantial completion A contract milestone for completing the work (or a specified portion of the work). At substantial completion the owner has the ability and option to occupy and use the new facilities for their intended purpose. Only minor nonessential work items, such as punch list items or landscaping, remain after substantial completion.

Task description (See "scope of work".)

Time-scaled logic diagram A logic diagram that graphically depicts activities against a time scale. The time scale may be appropriate for the events listed. Some scheduling is performed on a minute-by-minute basis while other schedules are prepared on a yearly time frame.

Unit cost, \$/unit of production Usually total cost divided by units of production, but can consist of smaller elements and their associated unit costs that make up the total unit cost.

Unit price contract A type of contract in which the cost of the work is shown as a schedule of unit prices to be used against a measured set of quantities.

Value engineering A technical review process in which changes to the specified facilities are considered in an effort to reduce the total cost of the project. In the case of a contractor-initiated request for value engineering changes, many contracts allow a sharing of the recovered savings due to the new idea.

Variable costs Raw material costs, byproduct credits, and those processing costs which vary with plant output (such as utilities, catalysts and chemical, packaging, and labor for individual operations).

Variance The difference between planned and actual performance. Variances that exceed established thresholds normally require further review, analysis, or action. Established thresholds should be revised during the life of a project to ensure meaningful analysis.

Work breakdown structure (WBS) A group of alphanumeric characters whose purpose, when associated with other data, is to organize those data into a more meaningful set of information. Usually hierarchical in nature, allows subtotaling at different levels. Each level is associated with a discrete description. Usually used to indicate location or function categories.

Work package Subdivisions of the lowest level WBS element accorded detailed scope, schedule (start and completion points), budget, a description of scope (including activities), and responsible manager.

IX. CONCLUSION

Recent studies have proven that the cost impact of cumulative regulations (OSHA, Mine Safety, Nuclear Regulatory, EPA Regulations as presented in Section 12.2 and 12.3) increased baseline costs by a multiple of three. Although this may not necessarily be representative of all industry, it highlights that industry must continue to pursue innovative initiatives to develop credible baseline estimates for environmental restoration projects. By following the *Three Legs of Estimating Environmental Restoration Projects* and other estimating examples presented in this chapter, realistic estimates of project cost and schedule can be developed.

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12
Risk and Contingency Analysis

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I. INTRODUCTION

Risk is associated with all aspects of a project including the initial capital cost, the project schedule, the ongoing costs to operate the resulting assets, the profits or other benefits derived, etc. *Risk and contingency analysis* applies to every item that is forecasted or estimated. The examples in this chapter relate to the capital cost estimate—but the principles, concepts and methodologies are directly applicable to all of the factors.

Consideration of risk is necessary when preparing estimates and managing projects because there is a probability, not a certainty. that an actual cost will equal the estimate or cost target.

Risk analysis recognizes that it is *uncertainties* in project conditions, scope and pricing that result in cost risks. Uncertainties include events that may impact the project positively, as well as those that threaten the outcome. In other words:

UNCERTAINTY = THREATS + OPPORTUNITIES

where:

Threats are events which *could* adversely effect results.
Opportunities are events which *could* improve results; and
Uncertainty includes the complete range of positive and negative impacts;

Risk refers to the *net impact* of uncertainty, i.e.,

RISK = THREATS – OPPORTUNITIES

Thus *Risk Funds* (contingencies) are based on the consideration of both types of uncertainty and intended to close the gap between them.

When doing Risk Analysis, the engineer must consider all uncertainties (both threats and opportunities). Thus the term risk is synonymous with uncertainty when we talk about *Risk Analysis, Risk Sources, Risk Lists,* etc.

Risk and Contingency Analysis is part of the overall Risk Management process which includes:

Risk Assessment	Identification of risks or uncertainties which may impact a project.
Risk Analysis	Quantification of the effect of all uncertainty (risks) on a project. Usually done by identifying risks and quantifying each risk's probability of occurrence AND potential severity of impact. The impact may be expressed as a range of values, or with a confidence level, or as a probability distribution.
Communicating the Risk Information	The transition between risk analysis and risk control is the communication of the risk information from the estimating function to the execution function.
Risk Management Plan	A list of the action steps to: 1. Eliminate or reduce the probability of a threat occurring; and/or 2. Reduce the impact of the threat if it does occur; and/or 3. Assure or increase the probability of an opportunity occurring; and/or 4. Increase the impact of an opportunity if it does occur. The plan often includes what to monitor and the "trigger points" that, when observed, "trigger" one of the action steps.

Risk mitigation	*Developing* a risk management plan.
Risk control	*Implementation* of the risk management plan.

At the end of this chapter is a glossary of common risk management terms.

Risk and Contingency Analysis includes the first three steps in the process above (Risk Assessment, Risk Analysis, and the Communication of Risk Information). Risk Mitigation and Control is based on the information transmitted and is covered in another section of this text.

II. WATCH OUTS

Experience shows that there the principle reasons Risk and Contingency Analysis fail are:

Key risks are missed (either overlooked or *defined* as outside of the project's scope).
The analysis is complex, but does not provide insights and understandings about the underlying risks or uncertainty necessary to help control risks.
Uncertainty is understated.
Biases, which cause people to understate uncertainty.

The purpose of Risk and Contingency Analysis is to define and communicate how much risk there is in a project, so that Risk Control can be implemented.

The three objectives for Risk and Contingency Analysis are to determine:

1. The accuracy of an estimate.
2. The amount of contingencies (risk funds) needed in an estimate to achieve a desired confidence level.
3. The identification of risk sources that empower management to control risks.

Risk analysis may be done "stand alone" to assess a project at any time. However, Risk and Contingency Analysis is most often done as the final step in estimating the cost of a project.

This chapter provides the principles of Risk and Contingency Analysis, and the core process used to assess risk, analyze its impact, and inform others of the risks inherent in the project.

To produce cost estimates, a quality Risk and Contingency Analysis must be performed. This includes three (3) steps:

1. Risk Assessment
2. Risk Analysis
3. Communication

III. STEP 1—RISK ASSESSMENT

In order for the cost engineer to choose the analysis approach which best fits a specific situation, the risk must first be assessed in broad terms. Risk assessment is the identification of project risks or uncertainties and their characteristics. This includes all uncertainties, *opportunities* as well as *threats*. Risk assessment includes the following actions:

1. Define the critical assumptions
2. List risk sources
3. Determine if risk sources are independent
4. Determine what method to use for Risk Analysis

A. Define the Critical Assumptions

The key assumptions inherent in the estimate that are not certain that could affect the cost of the project by 10% or more, such as:

The exclusion of specific scope, e.g., in providing adjacent manufacturing areas to match the scope in this project; or

The concurrent execution of another project allowing the use of shared resources

B. List Risk Sources

Develop a list of risk sources that could effect the scope or the price of the project. Start with the critical assumptions and add uncertain areas that could affect cost by 10% or more. The list could include items such as:

- Supply and cost of major equipment and bulk construction materials
- Contractor performance
- Construction labor issues (skill shortages, contract expirations, productivity)
- Legal requirements
- Unstable economies or currency exchange rates
- Site underground conditions
- Environmental issues
- Scope likely to change significantly
- Availability of adequate utilities, i.e., power, air, chilled water
- Adverse climate affecting construction's ability to meet tight schedules
- Need to import materials, labor, contractors, and so on

C. Determine If Risk Sources Are Independent

Some risk sources are dependent on each other and some are independent. For example, labor cost is dependent on labor productivity; but labor costs are independent of material costs. If your list includes dependent sources, you must either use complex, probabilistic techniques OR break them down or combine them until you have independent ones.

D. Determine What Method to Use for Risk Analysis

Risk analysis can be done using a variety of methods, ranging from standard checklists to mathematical models. Experience has shown that the each method is appropriate under specific circumstances. Methods fall into three general types:

1. Quantitative (checklists, historical databases of typical risk levels, heuristics, etc.)
2. Risk model (techniques for subdividing the estimate, assigning ranges to each grouping, and determining the total probable impact of the estimate)
3. Probabilistic

Each of these is discussed later.

Table 1 relates risk characteristics to the types of Risk Analysis.

IV. STEP 2—RISK ANALYSIS

Risk Analysis is the quantification of the probability of each risk's occurrence and the potential severity of the impact of each risk upon the project. Once the risks are exposed by the risk assessment phase, the engineer further defines the risks, defines how much Contingency is needed to achieve the Target Cost, and determines the estimate range. This is done by applying the appropriate Risk Analysis technique. All Risk Analysis techniques include:

Defining Risk Sources
Defining the *Contingencies* needed in the Target Cost
Determining Estimate Range of Accuracy.

A. Define Risk Sources

Defining the risk sources means expanding upon the Risk Assessment by quantifying each risk and how the risks relate to the estimated cost (and to each other). Depending on the method selected, the risks are defined as shown in Table 2.

Table 1 Risk Analysis Approach

	Quantitative	Risk model	Probabilistic
Complexity	Reapplication of a process at a single site; minor changes in capacity, size, location, details, etc.	Battery limits expansions of existing process (may be multisite, but in one country)	Multicountry projects; grassroots plant.
Hardware or systems	Off the shelf reapplication of technology	Standard components, designed to fit needs; new application of existing technology	New process; application of new technology.
Cost	Less than typical projects for the business area	Typical, normal projects for the business area	More than typical projects for the business area.
Schedule (pace)	Normal	Rush (up to 25% faster than normal)	Blitz (more than 25% faster than normal).
Number of risk sources (uncertainties or assumptions that could affect cost 10% or more)	There are no more than five key uncertainties	There are five to ten key uncertainties	There are more than ten key initiative or significant defensive actions.
Business impact (on profits)	No direct impact	Minor impact	Major impact

Table 2 Defining Risks

Method of risk analysis	Quantitative	Risk model	Probabilistic
Requires making risk sources independent	Yes	Yes	No
Risk definition	Overall project	Project (estimate) components, e.g., Work structure	Underlying risk sources or elements
Risks are defined	By the percent of contingency or risk funds needed to achieve a 50/50 estimate	By three points (base, top, and bottom of range, where top of range is 90% confidence and bottom of range is 10%)	A probability distribution (could be three points, five points, or a complete curve)

B. Define Target Cost

To define the target cost, the engineer must determine the amount of Contingency (risk funds). To determine the Contingency needed, the engineer must determine what Risk Analysis technique to apply.

This is where the three general approaches differ. Each method and how the target cost is defined is discussed in turn.

Quantitative Approaches

Quantitative approaches assess risk based on project characteristics, e.g., type of work, location, percent engineering completed, etc.

Using historical experience, quantitative methods relate project characteristics directly to the contingency requirements, expressed as a percent of the base estimated costs. The percentages may be developed from checklists or by matching project characteristics to the characteristics of previously completed projects stored in a database.

NOTE: To use a quantitative method the cost engineer must have experience and/or a database. The experience/database provides benchmark information. The cost engineer must relate the current project to the ones that are associated with these benchmarks and make a judgment—should more or less contingency be added to this situation.

Table 3 Generic Risk Check List

Risk area	Factors to consider	Typical adjustment Low	Typical adjustment High	Use
Base amount				5%
Adjustments				
Business needs	Market forces competition	0%	+ 5%	
Product definition	Product/package specs	0%	+ 5%	
	New/innovative products			
System scope	Major equipment	–5%	+ 5%	
	Support facilities			
	Site conditions			
	New/innovative systems			
	Environmental issues			
	Safety issues			
Utilities and auxiliaries	Power supply	–3%	+ 5%	
	Air, water, other needs			
	Building space			
Execution plan	Project team capability	–3%	+ 5%	
	Vendors			
	Contractors			
	Planning and scheduling			
External risks	Economy	–5%	+ 5%	
	Legal & regulatory			
Other risks	List:	–5%	+ 5%	
Total risk				

When the engineer has a database, he or she can compare the specific project's characteristics to the ones described in the database. They try to match the project as closely as possible. The database shows how much contingency was needed for each of the projects described.

One of the most common quantitative methods is the checklist. In most checklist methods, a base value of 5% of defined costs is established to provide a base level of contingency. Then adjustments (positives or negative) are made based on considering how the project relates to the factors in the list.

The engineers relate the uncertainties in the specific project to their own experience of projects, in doing so, asking "where, in the range of values shown, should I place the risk facing this project?"

The engineer estimates the percentage of the defined cost estimate required for each of the risk areas. For each area, the checklist shows a range of typical values. The engineer determines what amount to use for each area and the values are then added to the 5% base allowance.

Table 3 shows a typical checklist. Where possible, a specific checklist should be developed based on the types of risks and their impact typically encountered in your business or industry.

Risk Models. Risk models break the estimate into components and the engineer analyzes risk directly for each component. Typical components are:

1. Estimate categories (Work Breakdown Structure or code of accounts)
2. Parts of the project (systems and/or areas)
3. Equipment, material, labor, overhead, and engineering

The risk model combines the risks mathematically, incorporating statistical adjustments.

There are special programs available for modeling project risk. These programs lead the engineer through the process. The best known program in this field is the *Range Estimating Program©*, developed and marketed by Decision Sciences Corporation. Using these programs often requires special training from the vendor.

For engineers who use spreadsheets to make estimates (or who want to use spreadsheets for risk analysis) there are "add-in" programs which allow the estimator to put ranges around individual cells and use Monte Carlo techniques to transform the spreadsheet into a risk model. The two most common add-in programs are *@Risk©* for Lotus 1-2-3© or EXCEL© (by Palasade) and *Crystal Ball©* for EXCEL (by Decisioneering).

The spreadsheet in Table 4 is a typical basic estimate that could be made in Lotus, EXCEL, etc.

In reality this is a "model." The engineer enters data into the shaded areas including unit costs, quantities, and factors (percents). The model multiplies the amounts entered into the various cells of the spreadsheet. It adds the amounts in the "Estimate" column. This is a "deterministic model." The answer is determined exactly by the amounts entered in the various cells.

With either of the add-in programs, the engineer can change any cell from a single (point) estimate to a probability distribution. The engineer replaces the single amount with a special spreadsheet function that defines the type of probability curve and reference points. The engineer then specifies the output cell (the Total Estimate, cell F117, in the example shown). The model is now transformed from the "deterministic" single outcome spreadsheet to a Risk Model.

Table 4 Typical Basic Estimates

	A	B	C	D	E	F	G
1		Component	Units	Qty	Unit price	Estimate	
2							
3							
110							
111							
112		Subtotal direct costs					
113		Indirect cost component			%		
114		Field overheads					
115		Engineering					
116		Other					
117		Total estimate					

Table 5 Risk Template

	A	B	C	D	E	F	G	H
1		Component	Low	Base	High	Mean	SD	Var
2						X1	Y1	Z1
3						X2	Y2	Z2
4						X3	Y3	Z3
5						X4	Y4	Z4
6						X5	Y5	Z5
7						X6	Y6	Z6
8						X7	Y7	Z7
9						X8	Y8	Z8
10						X9	Y9	Z9
11						X10	Y10	Z10
12		Subtotal		AA				
13		Contingency		BB			TVar=	ZZ
14		Total estimate		CC			TSD=	YY
15								
16		Bottom of range		DD				
17		Top of range		EE				

The add-in program then uses Monte Carlo methods and runs the estimate hundreds or thousands of times to yield a probability distribution of the output cell. This indicates exactly how much contingency is needed to achieve any specific level of confidence. If the target is a 50/50 estimate, the difference between the mean value of the distribution and the initial (deterministic) amount for the estimate is the contingency.

There is a simpler approach that is usable for many estimates. The engineer can use a simple spreadsheet parametric model. This model adds contingency to the estimate sufficient to make the Target Cost (Total Estimate) equal to the mean cost of the probability distribution. The spreadsheet shown in Table 5 is developed as a template. The engineer then uses this template whenever a *Risk and Contingency Analysis* is needed.

NOTE: The basic model was first presented by Dr. Julian Piekarski at a meeting of the Southwestern Ohio chapter of AACE International in the early 1970s. It was modified by S. L. Shafer and R. M. Smith to incorporate the top and bottom of the range and presented at an AACE International technical meeting in 1992. As shown in Table 5, the model is easily applied to any standard spreadsheet program.

1. The shaded area is for user input. The engineer breaks the estimate into 1–10 components and enters the component name, base estimate, and the high and low ranges for each of the components. The low and high estimates are the 10% and 90% confidence estimates for each component, i.e., the low estimate is one that only has a ten percent chance of being underrun; the high value has a ten percent chance of being overrun.
2. The mean value (X1 through X10) is calculated for each component as one fourth of the sum of the low value + 2 times the base value + the high value.

The formula for cell F2 is:

(C2+2*D2+E2)/4 F3 through F11 is similar to F2

3. Y1 through Y10, The SD values (standard deviation) are calculated as the difference between the high value and the low value for each component divided by 2.65.

The formulae for cell G2 is:

(E2-C2)/2.65 G3 through G11 is similar to G2

4. Z1 through Z10, the Var (variance) value is the SD (standard deviation) of each component squared.

The formulae for cell H2 is:

G2^2 H3 through H11 is similar to H2

5. The total variance (ZZ) is the sum of the variances of all of the components (Z1 through Z10).

The formulae for cell H13 is:

@SUM(H2..H11)

6. The total standard deviation (YY) is the square root of the total variance (ZZ).

The formulae for cell H14 is:

(H13)^0.5

7. The subtotal (AA) is the sum of the base values entered.

The formulae for cell D12 is:

@SUM(D2..D11)

8. The Total Estimate (CC) is the sum of the mean values of the components (X1 through X10).

The formulae for cell D14 is:

+D14 – 1.325*H14

9. The Contingency (BB) is the difference between the total (CC) LESS 1.325 times the Total Standard Deviation (YY).

The formulae for cell D13 is:

+D14 – D12

10. The Bottom of the Range is the Estimate Total [the mean] (CC) LESS 1.325 times the Total Standard Deviation (YY)

The formulae for cell D16 is:

+D14-1.325*H14

11. The Top of Range is the Estimate Total [the mean] (CC) PLUS 1.325 times the Total Standard Deviation (YY)

The formulae for cell D17 is:

+D14+1.325*H14

This Risk Model spreadsheet is based on heuristics or rules of thumb:

1. The calculation of the mean is based on experience and is similar to the way PERT calculations of schedule are made. That is the mean is equal to the average of the low estimate, the high estimate plus X times the base estimate

$$\text{Mean} = [\text{Low} + (X \times \text{Base}) + \text{High}]/(2 + X)$$

In the current model, we use X = 2; some users have modified this formulae based on their own experience and set X = 1, 3, or 4.

2. The area bounded by the mean plus or minus 1.325 standard deviations in a normal curve contains 80% of the results. Since the model is based on 10/90 and 90/10 confidence limits, it is intended to include 80% of all occurrences. Therefore, even though the project curve is not expected to be exactly "normal," the constant values of 2.65 standard deviations to determine the standard deviation and 1.325 standard deviations to determine the range are applied as a reasonable approximation. Again, individual users may modify these based on their own experience. Specifically, based on their experience they may skew the curve by having the bottom and the top of range higher (say by using 1.0 and 1.65 standard deviations in the formulae for cells D16 and D17 respectively).

Probabilistic Models

Probabilistic models calculate the actual probability distribution curve for a project either by "constructing" the project numerous times (the Monte-Carlo approach) or by applying sophisticated mathematical techniques (Decision Tree approach).

Like risk models, probabilistic models may start with the direct input of risk associated with components of a project. However, probabilistic models can also accommodate models with risk drivers, each of which can affect more than one component and each component of the project may be affected by more than one risk source.

Probabilistic models require special training and skills and are usually done by consultants or specialty contractors. In any event, the technique is beyond the scope of the methods included in this text.

C. Determine Estimate Range of Accuracy

The range of accuracy is an additional measure of the risk on a project. The accuracy of the estimate is defined by the range of costs into which the final project costs are expected to fall. Normally accuracy is stated with eighty percent confidence; that is the range includes outcomes which have between a 10–90% chance of occurring.

Once the total amount of risk funds is established, the range of accuracy is determined. If a qualitative method was used, the range may be determined by assessing the best/worst case scenarios. This is done by estimating the costs of the worst possible case you can imagine, where every item goes against you. Then, estimate the costs of the best possible case, where none of the base risk funds are needed, all of the opportunities occur, and none of the threats are present.

If a risk model or probabilistic approach was used to determine the estimate target cost, than the range will also be defined by the model used in determining the contingency level and target cost.

V. STEP 3—COMMUNICATION

The final step is to provide information in a way the project leader can use it to manage the project. *In addition to stating the estimate contingency and range of accuracy*:

Document the basis for the estimate contingency.
Include information on how the risk analysis was done and what it uncovered.
Document all critical assumptions and key risks.
Developing a Threat/Opportunities risk list.

A. Allocate the Risk Funds (Optional)

The risk funds may be allocated to the estimate direct cost categories. Note risk adjustments should never be simply prorated. The engineer must allocate the contingencies based on experienced based judgment and knowledge of the specific project and the risks.

B. Develop an Impact-Control Matrix

Additionally, the risk information can be fully communicated by the use of an IMPACT-CONTROL Matrix (also an option). This is usually done as a joint effort with the project manager for the execution phase. Proceed as follows:

1. *List all of the key risks (including critical assumptions that could be wrong).* For each risk assess the severity on the results if the risk happens. This is called the level of IMPACT.
2. Determine the action to be taken to mitigate, eliminate or control a risk. Determine what specific steps will be taken, which could include:

Table 6 Strategies for Risk Control

		Control	
	Impact	Low	High
IMPACT	High	See if there is a way to reduce the impact or increase level of control of these risks. Perhaps the risks can be broken down into components that can be controlled. If not, monitor the risks, but only react where the benefit justifies the costs.	IMPLEMENT THE CONTROL SYSTEM. Monitor as appropriate but, when the trigger point is reached, take the control action.
	Low	IGNORE THESE RISKS The cost of control is not justified by the benefits.	CONTROL WHERE JUSTIFIED Do not use the easy control mechanism unless the cost is clearly less than the benefits.

Reducing Uncertainties: Convert risk to a certainty to be dealt with or reduce the probability of an adverse outcome. Uncertainty can be reduced in ways such as the following:

- Use prototyping, simulating, and modeling.
- Base firm plans on what is certain and have flexible plans to take care of uncertainty.
- Risk Assignment through Firm Price Contracting.

Reducing Consequences of Uncertainties: The consequences of uncertainties may be reduced in ways such as developing parallel (alternative) plans so that if plan "A" fails, plan "B" is ready to implement.

Rank order the actions by how easy or inexpensive vs. difficult or expensive each action step is. This is called level of CONTROL.

3. Develop the matrix. Sort risks into one of the four quadrants based on how much impact the risk could have on results and how easy or difficult it is to control the impact of the risk. This matrix suggests strategies for Risk Control as shown in Table 6.
4. Determine what to monitor (define trigger points). Sometimes you may choose a "preemptive strike" and implement risk plans in anticipation of a risk occurring (i.e. using a lump sum contractor); other times you will have a plan to implement only if the risk happens. In this latter case, you must also determine what needs to be monitored to determine what risk action plan should be implemented and when it should be

implemented (i.e., what observable measure will "trigger" the implementation of the action plan).

VI. A GLOSSARY OF COMMON RISK MANAGEMENT TERMS

Allowances Additional resources included in an estimate to cover the cost of known but undefined requirements.

Condition (uncertain condition) Any specific identifiable *circumstance* (such as the rate of inflation) that might affect the outcome of the project. (See *Event*)

Confidence Level The probability: (1) that results will be *equal to or more favorable than the amount* estimated or quoted; or (2) that the decision made will achieve the desired results; or (3) that the stated conclusion is true. Note: Confidence level may also be expressed as "equal to or *less* favorable." If that is the case, it should be noted ... without such a note, the definition shown is assumed. Note: Confidence level may also be expressed as "equal to or *less* favorable."

Contingency An amount of money or time added to the base estimated amount to: (a) achieve a specific confidence level; or (b) allow for changes that experience shows will likely be required. Contingency may be derived through statistical analyses of past projects; by applying experience; or through a probabilistic assessment of what may occur.

Cumulative (Probability) Distribution A curve whose vertical height is the probability of an amount being equal to or less than the value on the horizontal axis; the vertical axis goes from 0 to 100% (or 0.00 to 1.00). (See *Probability Distribution*)

Event (uncertain event) Any specific identifiable *action* (such as a large government project being started in the same labor area as your project) or an act of nature that might happen and that (if it does happen) could affect the outcome of the project. (See *Condition*)

Expected Value See *Mean*

Mean The sum of all values divided by the number of items in the group. Also known as *the expected value* and as the *weighted average.*

Median The value of the middle item in a list of numbers that have been sorted by amount. If there is an even number of items it is the simple average of the values of the two middle numbers in the list.

Mode See *Most Likely Value*

Most Likely Value The value that occurs most frequently in a set of values. The value on the horizontal curve of a probability distribution curve associated with the highest point on that curve. Also called the *mode.* If there are two values on the distribution curve whose values are equally high (and higher than all other values), the curve is bi-modal; if there are three, it is tri-modal, etc.

Most Probable Amount *An ambiguous term* which frequently refers to the mean value, but sometimes refers to the mode. In a normal curve, the mean, mode and median are all the same so that this ambiguity is no problem; in real life there is a difference and *the reader must ascertain what the author means by "most probable."*

Normal Curve A special "bell shaped" probability distribution which is typical of random events. The characteristics of a normal curve are:

The mode, mean, and median all have the same value which splits the area of the probability distribution curve in half and occurs at the 50% point of the cumulative distribution curve.

There is no skewness, the curve is perfectly symmetrical

The area under the curve is related to the standard deviation, where:

N is the number of standard deviations

the *range* is the Mean *N* Standard Deviations

A, the area the area under the curve, is the percent of the total area of the probability distribution curve that is in the portion of the curve within the *range*.

C, the confidence level is the probability that the observed value will be equal to or less than value of the Mean + *N* Standard Deviations.

N	*A* (Area under the curve)	*C* (Confidence Level)
0.6743	50.0%	75.0%
1.00	68.3%	84.1%
1.65	90.1%	95.1%
2.00	95.5%	97.7%
3.00	99.7%	99.9%

Opportunities Uncertain events which could improve the results OR improve the probability that the desired outcome will happen. (See *Risk, Threats, Uncertainty*)

Overrun (Underrun) The actual costs for the work performed to date minus the estimate or value for that same work. If the actual costs are greater, it is an overrun; if the actual costs are less, it is an underrun.

Probability A measure of how likely a condition or event is to occur Ranges from 0 to 100 % (or 0.00 to 1.00).

Probability Distribution A curve whose vertical height represents the probability of the amount shown on the horizontal axis occurring. (See *Cumulative Distribution*)

The probability distribution shown is skewed to the high end, which is typical for project cost and schedule curves (See *Normal Distribution*)
Range The absolute difference between the maximum and minimum values in a set of values (obtained by subtracting the lowest value from the highest). The simplest measure of the dispersion of a distribution.
Range of Accuracy The values between the top and the bottom of the range. For example if the outcomes might be from $100 to $ 1,000; the Range is $900, while the Range Of Accuracy is $100–$1,000. Usually the Range of Accuracy has defined upper and lower limits (such as 10% confidence and 90% confidence; known as 10/90 Range of Accuracy).
Risk An ambiguous term, that can mean any of the following:

All *uncertainty* (threats and opportunities; OR
Downside uncertainty (a.k.a. "*Threats*"); OR
The *net* impact or effect of uncertainty [threats – opportunities]. The convention used in any paper should be clearly stated to avoid misunderstanding. (See *Opportunities, Events, Conditions, Threats, and Uncertainty*)

Risk Analysis The second phase of Risk Management, which includes the quantification of the effect of all uncertainty (risks) on a project. Usually done by identifying risks and quantifying each risk's probability of occurrence AND potential severity of impact. *Note: the impact may be expressed as a range of values, or with a confidence level, or as a probability distribution.*
Risk Analysis Methods The technique used to analyze the risks associated with a project or program. Specific categories of Risk Analysis methods are:

Qualitative—based on project characteristics and historical data (check lists, scenarios, etc.)
Risk Models—combination of risks assigned to parts of the estimate or project to define the risk of the total project
Probabilistic Models—combining risks from various sources and events (Monte Carlo, Latin Hypercube, Decision Tree, Influence Diagrams, etc.)

Risk Assessment The first phase of Risk Management, which includes the identification of risks or uncertainties which may impact a project.
Risk Control *Implementation* of the Risk Management Plan. (The last phase of Risk Management)
Risk Management All of the steps (phases) associated with managing risks—Risk Assessment, Risk Analysis, Risk Mitigation, Risk Control. (See *Risk Analysis, Risk Assessment, Risk Management Plan, Risk Mitigation, and Risk Control*)
Risk Management Plan The product of Risk Mitigation (which is the third phase of Risk Management), a list of the action steps to:

1. Eliminate or reduce the probability of a threat occurring; and/or
2. Eliminate or reduce the impact of the threat if it does occur (mitigate the threat); and/or
3. Assure or increase the probability of an opportunity occurring; and/or
4. Increase the impact of an opportunity if it does occur.

The plan includes predefined action steps to be taken and the "trigger points" that will indicate when they are to be executed to mitigate risks. The plan also defines what to monitor to determine the "trigger points." The steps may include, holding portion of funds and/or scope in reserve, until outcome is more certain; trading cost risk for schedule or quality risk; and/or buying "insurance" (such as lump sum, firm price subcontracts).

Risk Mitigation The third phase of Risk Management, *Developing* a Risk Management Plan.

Risk Sources Events or conditions that have been defined that might affect the outcome of a project. Risk sources are frequently subdivided into the following groups, based on the underlying source of the source:

Business needs risks
Results definition risks
Scope definition risks
Execution plan, mastery and processes risks
External risks (See *Conditions* and *Events*)

Risk Types Another means of characterizing risk sources is by the type of risk:

Inherited—derived from preceding stages of project
Economic—associated with availability and costs of resources
Commercial—associated with customers needs and wants, competition, etc.
Technological—associated with ability to achieve desired results, produce products, etc. life of current or new technology and compatibility of new technologies
Implementation—ability to meet project plan and commitments due to human behavior or organizational factors.

Scenario A description of specific events and their probable outcome. Usually limited to likely or probable scenarios versus all possible ones. Frequently "most likely," "best case" and "worst case" scenarios are used to define the most probable outcome and the range of outcomes.

Sensitivity When the outcome is dependent on more than one risk source, the sensitivity to any specific one of those risks is the degree to which that specific risk (event or condition) affects the outcome or value.

Standard Deviation The most widely used measure of dispersion of a probability (frequency) distribution. Calculated by summing squared deviations from the mean, dividing by the number of items in the group and taking the square root of the quotient. The square root of the variance. (See *Variance* and *Normal Curves*)

Threats Uncertain events which are potentially negative OR reduce the probability that the desired outcome will happen. (See *Risks, Opportunities, Risk and Uncertainty*)

Underrun See *Overrun (Underrun)*

Uncertainty The total range of events that may happen and produce *risks* (including both *threats* and *opportunities*) affecting a project. (See *Opportunities, Events, Conditions, Risks and Threats*)

[Uncertainty = Threats + Opportunities]

13

Profitability Analysis

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I. INTRODUCTION

This chapter gives those who make decisions and recommendations about money the concepts and techniques of economic analysis. The use of standard conventions allows management to allocate scarce corporate resources of people and dollars on a reasonable basis.

A company's financial performance is tied to the selection of attractive investment opportunities. One of the objectives has always been to maintain a strong financial position in order to be a long-term competitor. In order to accomplish this objective, we want to allocate funds to those business areas that offer the highest probability of achieving returns from capital employed that are better than the competitors.

Economic analysis deals with the question of resource allocation and choosing among alternatives in a systematic way. It involves the application of measuring techniques to determine the relative attractiveness of a range of investment proposals. It requires the analysis of more than one indicator to get the total economic picture for a project.

II. INTEREST FACTORS AND TABLES

Economic analysis begins with the definition of compound interest factors. Most interest tables in engineering economics textbooks are divided into two patterns of cash flow: single payment and uniform series. These patterns are derived from one basic formula, the single payment compound amount:

$$(1 + i)^n$$

The following symbols are used:

i	=	interest rate per period
n	=	number of interest periods
P	=	present sum of money
F	=	future sum of money at the end of period n
A	=	uniform end-of-period payment or receipt continuing for the coming n periods

There are, in fact, several methods as shown below:

A. Formulas for Calculating Compound Interest Factors

1.	Single Payment–Compound Amount Factor (F/P, i%, n)	$(1 + i)^n$
2.	Single Payment–Present Worth Factor (P/F, i%, n)	$\frac{1}{(1 + i)^n}$
3.	Sinking Fund Factor (A/F, i%, n)	$\frac{i}{(1 + i)^n - 1}$
4.	Uniform Series–Compound Amount Factor (F/A, i%, n)	$\frac{(1 + i)^n - 1}{i}$
5.	Capital Recovery Factor (A/P, i%, n)	$\frac{i(1 + i)^n}{(1 + i)^n - 1}$
6.	Uniform Series–Present Worth Factor (P/A, i%, n)	$\frac{(1 + i)^n - 1}{i(1 + i)^n}$

Appendix A shows three interest factors commonly used in working time value problems: single payment present worth factor (P/F), uniform series compound amount factor (F/A), and uniform series present worth factor (P/A). The other three factors—single payment compound amount, sinking fund, and capital recovery factors—are reciprocals, as the tables show. This means that formulas 1 and 2, 3 and 4, and 5, and 6 are reciprocals of each other.

III. DEPRECIATION

Economic analysis must, in most cases, include depreciation. Depreciation rates provide cash for asset replacement and to encourage new investment. The investor is allowed to recover the original investment over time from cash earnings as a deduction from taxable income. Most assets are depreciated for U.S. tax purposes using the 200% declining balance method, converting to straight line. Appendix B shows depreciation schedules for different types of assets. Note that a "5 year schedule" is 6 years long. This is because the IRS permits only 50% of the available depreciation in the year the asset is placed in service.

IV. ECONOMIC ANALYSIS METHODS

Projects vary greatly. A project might expand business, meet new environmental requirements, or sustain profit for a business. Consistent financial risk and return indicators are required, if alternative project investments are to be compared.

This section describes basic financial indicators of net cash flow (NCF), payout, net present value (NPV), and rate of return (ROR).

A. Net Cash Flow (NCF)

In economic analysis, cash flow is an expression of the annual or cumulative cash effect on the Company from investing capital in a particular project. That is, money which enters or leaves the Company as a result of the investment proposal.

The characteristics of NCF are:

- Usually presented as a cumulative NCF versus time.
- Gives a clear overview of the proposal.
- Cumulative NCF for project (end point of the plot) shows how much money the project made but not whether it was a good investment.

B. Payout

Payout is the time required for the accumulated cash flow generated by an investment to equal the amount invested. Payout is normally measured from either the time of first expenditures or the time of project startup.

The characteristics of payout are:

- Easily calculated.
- Easily understood.
- Indicates length of investment "exposure."
- Ignores the timing of cash flow.

- Gives no indication of cash flow past the payout time.
- Early economic attractiveness indicator.

C. Net Present Value (NPV)

NPV is the sum of the present values of all positive and negative cash flows associated with an investment proposal, using an appropriate discount rate.The characteristics of NPV are:

- Takes into account timing of future cash flows.
- Cash flows occurring in different time periods are discounted to a single "lump sum" present value.
- Provides a means of comparing two or more projects.
- Favors large projects over smaller projects.
- NPV is an indication of the size of a project, but gives no indication of investment efficiency.

A weakness of NPV is that although Project "2" provides more value per dollar of investment, NPV cannot distinguish it from Project 1 in the following example:

	Project 1	Project 2
NPV of revenues	$2,500,000	$300,000
Less initial investment	–2,400,000	–200,000
NPV profit	$ 100,000	$100,000

D. Rate of Return (ROR)

ROR is the discount rate which equates the present value of a project's future cash return to the present value of a project's investment outlays.

The characteristics of ROR are:

- Requires knowledge of the appropriate (risk-related) discount rate to use as a hurdle rate.
- Tends to favor high-initial-earnings projects over long-lived projects.
- Can produce multiple RORs if cash flow signs change more than once.
- Most popular indicator of investment efficiency.

In order to illustrate the application of various measuring techniques, we will work through a sample project step by step.

Project "A" is a proposal to build a new facility to make and sell plastic containers. Initial investment is estimated to be $7,650,000 ($1,500,000 at Time 0 and $6,150,000 in Year 1). The salvage value of the plant at the end of the seven year useful life is estimated at $500,000.

Table 1 shows given information on investment, revenues and operating expenses for Project "A." Table 2 shows how depreciation and taxes are calculated for Project "A." Table 3 shows how net cash flow and payout are computed for Project "A." Figure 1 is a plot of the cumulative net cash flow over the life of this project. Table 4 and Figure 2 show how NPV and ROR are calculated and plotted for Project "A."

V. COMPARING ALTERNATIVE INVESTMENTS

Now let's assume there is an alternative, Project "B." Instead of building a grassroots facility like Project "A," we can buy the equipment off the shelf on a turnkey basis. Project "B" costs more than Project "A" but there is no construction delay and the operating expenses are expected to be lower. The sales forecast remains the same.

The economic indicators for Project "B" are summarized on Table 5. Based on this data, which project would you select (Project "A" or Project "B") and why? In order to answer this question, we need to do an incremental rate of return analysis between Project "A" and Project "B." Figure 3 shows the NPV for both projects at various discount rates.

If the incremental ROR is greater than the hurdle rate (or the cost of money), we should select Project "B" over Project "A" even though Project "B" has a lower ROR than Project "A." However, in a company which is capital-constrained, we may have to select Project "A" over Project "B" due to limited availability of capital.

VI. ECONOMIC PERFORMANCE INDICATORS SUMMARY

- More than one economic indicator is needed to describe a project
- Some indicators describe "how big," some describe "how efficient."
- All indicators have pluses and minuses.
- Payout, net present value, and rate of return are the indicators most in use in the industry.

REFERENCES

1. *Skills and Knowledge of Cost Engineering*, a special publication of AACE International, 1992.
2. Chevron Economic Analysis Manual, 1991.

Table 1 Project "A" Investment, Revenues, and Operating Expenses (in $1,000's)

Year	Investment (and sales)	Sales volume (1000's)	Revenue		Operating expense			
			Unit price	Total revenue	Unit cost	Total variable cost	Fixed cost	Total operating expense
	A	B	C	D=B×C	E	F=B×E	G	H=F+G
0	1,500.00							
1	6,150.00	1,000	4.00	4,000.00	0.20	200.00	1,200.00	1,400.00
2		1,050	4.00	4,200.00	0.20	210.00	1,320.00	1,530.00
3		1,080	4.10	4,428.00	0.22	237.60	1,450.00	1,687.60
4		1,110	4.10	4,551.00	0.22	244.20	1,600.00	1,844.20
5		1,140	4.25	4,845.00	0.25	285.00	1,760.00	2,045.00
6		1,170	4.25	4,972.50	0.25	292.50	1,930.00	2,222.50
7	(500.00)							
Totals	7,150.00	6,550		26,996.50		1,469.30	9,260.00	10,729.30

Table 2 Project "A" Depreciation and Taxes (in $1,000's)[a]

Year	Total revenue	Total operating expense	Depreciable investment	Depreciation[a] rate (%)	Depreciation	Asset sales	Total taxable income	Tax rate	Taxes
	A	B	C	D	E=C×D	F	G= A–B–E	H	I=G×H
0			1,500.00						
1	4,000.00	1,400.00	6,150.00	20.00	1,530.00		1,070.00	35%	374.50
2	4,200.00	1,530.00		32.00	2,448.00		222.00	35%	77.70
3	4,428.00	1,687.60		19.20	1,468.80		1,271.60	35%	445.06
4	4,551.00	1,844.20		11.52	881.28		1,825.52	35%	638.93
5	4,845.00	2,045.00		11.52	881.28		1,918.72	35%	671.55
6	4,972.50	2,222.50		5.76	440.64		2,309.36	35%	808.28
7						500.00	500.00	35%	175.00
Totals	26,996.50	10,729.30	7,650.00	100.00	7,650.00	500.00	9,117.20		3,191.02

[a] from Appendix B

Table 3 Project "A" Net Cash Flow and Payout (in $1,000's)

Year	Total revenue	Total operating expense	Investment (and sale)	Taxes	Net cash flow (NCF)	Cumulative NCF
	A	B	C	D	E=A–B–C–D	
0			1,500.00		(1,500.00)	(1,500.00)
1	4,000.00	1,400.00	6,150.00	374.50	(3,924.50)	(5,424.50)
2	4,200.00	1,530.00		77.70	2,592.30	(2,832.20)
3	4,428,00	1,687.60		445.06	2,295.34	(536.86)
4	4,551.00	1,844.20		638.93	2,067.87	1,531.01
5	4,845.00	2,045.00		671.55	2,128.45	3,659.46
6	4,972.50	2,222.50		808.28	1,941.72	5,601.18
7			(500.00)	175.00	325.00	5,926.18
Totals	26,996.50	10,729.30	7,150.00	3,191.02	5,926.18	

Project "A" NCF = $5,926.18

$$\text{Payout, years} = 3 + \frac{536.86}{2{,}067.87} = 3.26$$

Table 4 Project "A" Net Present Value (NPV) and Rate of Return (ROR) (in $1,000's)

Year	Net after-tax cash flow	Net present value of net cash flow					
		10%		20%		30%	
		P/F factor	$	P/F factor	$	P/F factor	$
0	(1,500.00)	1.0000	(1,500.00)	1.0000	(1,500.00)	1.0000	(1,500.00)
1	(3,924.50)	0.9091	(3,567.76)	0.8333	(3,270.29)	0.7692	(3,018.73)
2	2,592.30	0.8264	2,142.28	0.6944	1,800.09	0.5917	1,533.86
3	2,295.34	0.7513	1,724.49	0.5787	1,328.31	0.4552	1,044.84
4	2,067.87	0.6830	1,412.36	0.4823	997.33	0.3501	724.96
5	2,128.45	0.6209	1,321.55	0.4019	855.42	0.2693	573.19
6	1,941.72	0.5645	1,096.10	0.3349	650.28	0.2072	402.32
7	325.00	0.5132	166.79	0.2791	90.71	0.1594	51.81
Total	5,926.18		2,795.81		951.85		(187.75)

NPV @ 10% = $2,795.81
ROR ~28% (From Figure 2)

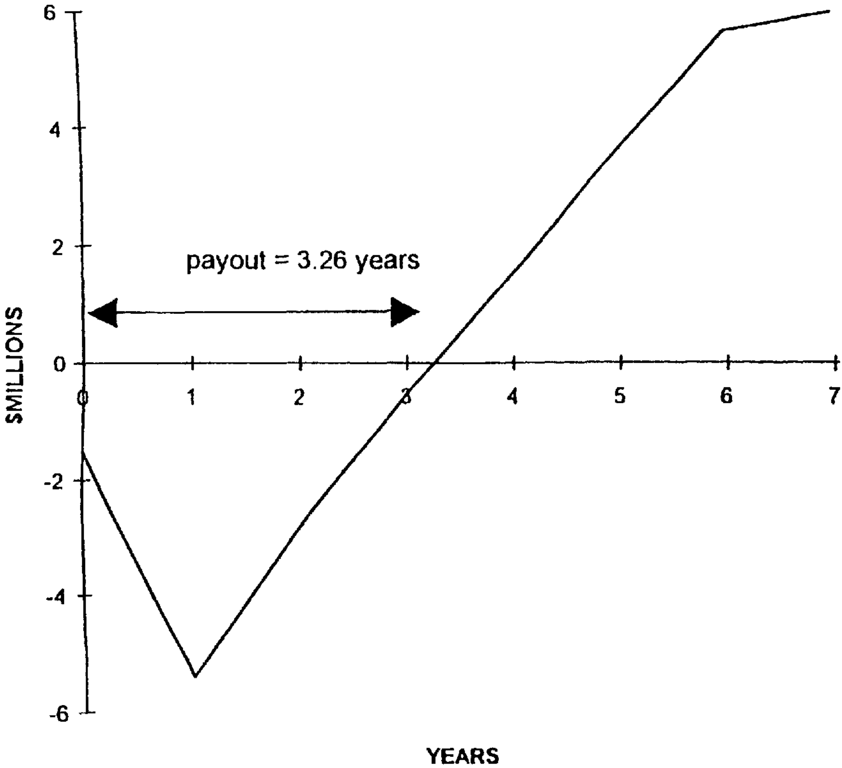


Figure 1 Project "A" Cumulative Net Cash Flow (NCF).

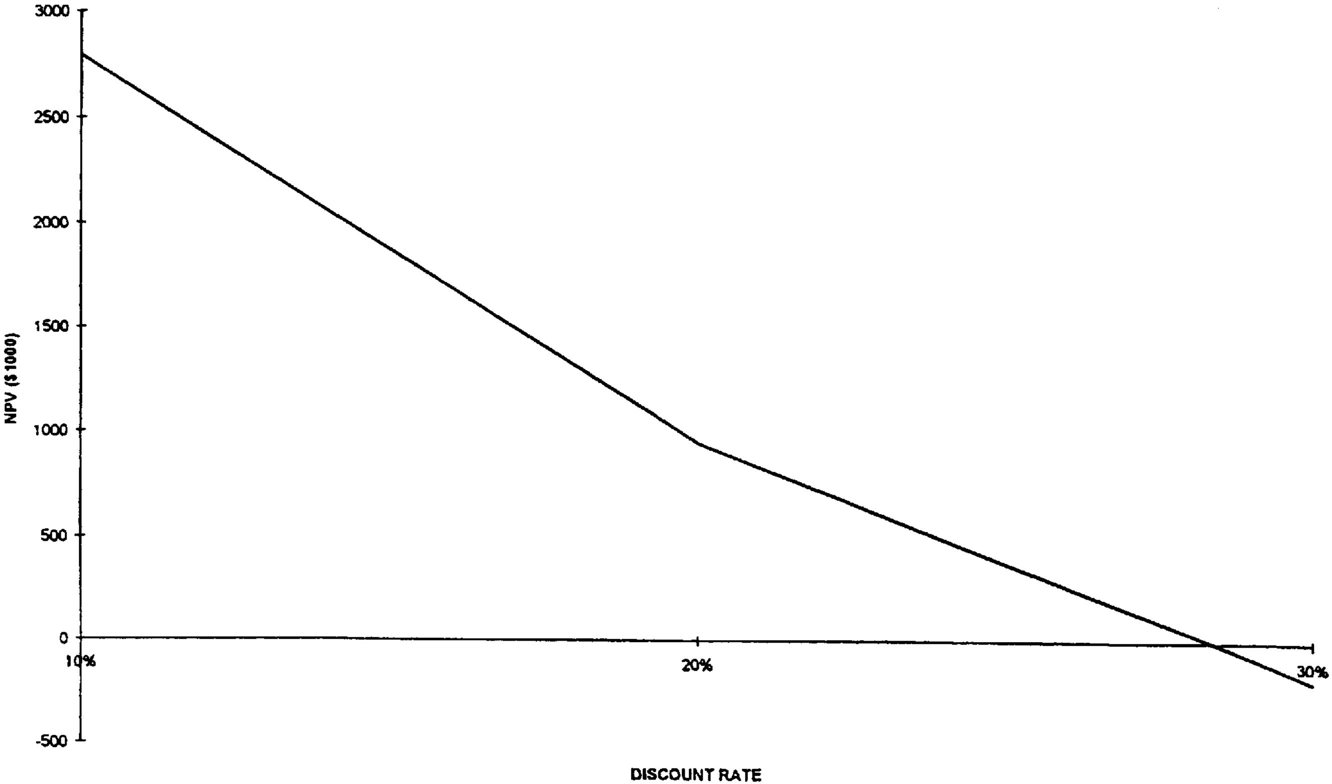


Figure 2 Project "A" Net Present Value (NPV) and Rate of Return (ROR).

Table 5 Project "B" Economic Indicators (in $1,000's)

			Net present value of net cash flow					
			10%		20%		30%	
Year	Investment	Net after-tax cash flow	P/F factor	$	P/F factor	$	P/F factor	$
0	10,000.00	(10,000.00)	1.0000	(10,000.00)	1.0000	(10,000.00)	1.0000	(10,000.00)
1		2,845.00	0.9091	2,586.39	0.8333	2,370.74	0.7692	2,118.37
2		3,349.50	0.8264	2,768.03	0.6944	2,325.89	0.5917	1,981.90
3		3,006.80	0.7513	2,259.01	0.5787	1,740.04	0.4552	1,368.70
4		2,775.10	0.6830	1,895.39	0.4823	1,338.43	0.3501	971.56
5		2,953.30	0.6209	1,833.70	0.4019	1,186.93	0.2693	795.32
6		2,761.60	0.5645	1,558.92	0.3349	924.86	0.2072	572.20
7		1,300.00	0.5132	667.16	0.2791	362.83	0.1594	207.22
Total	10,000.00	8,991.30		3,568.60		249.72		(1,984.73)

Project "B" NCF = $8,991.30

$$\text{Payout, years} = 3 + \frac{798.70}{2,775.10} = 3.29$$

NPV at 10% = $3,568.60
ROR ~21% (From Figure 3)

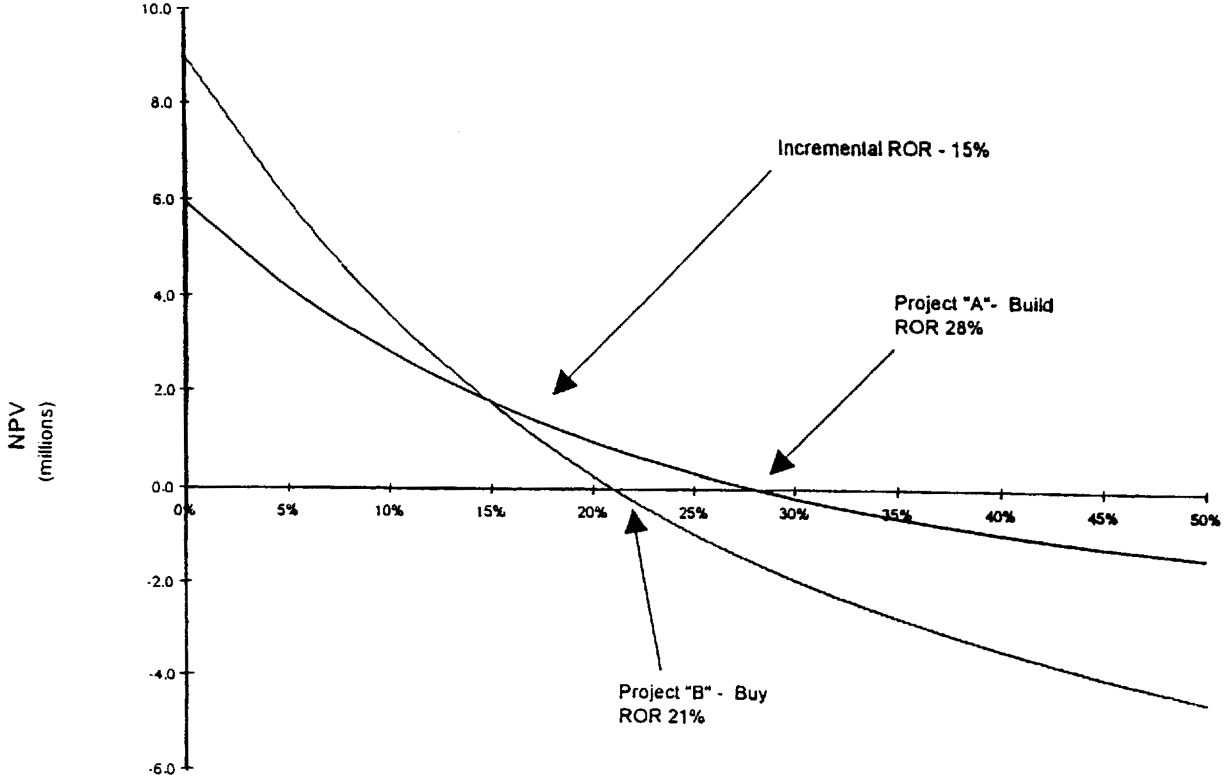


Figure 3 Project "A" and Project "B" NPV and ROR.

APPENDIX A—INTEREST FACTOR TABLES

Table A1 Single Payment Present Worth Factor—P/F. (Note: Single payment compound amount factor F/P is the reciprocal of the numbers shown below.)

Number of periods (e.g., years)	Interest rates						
	5%	10%	15%	20%	25%	30%	35%
1	0.9524	0.9091	0.8696	0.8333	0.8000	0.7692	0.7407
2	0.9070	0.8264	0.7561	0.6944	0.6400	0.5917	0.5487
3	0.8638	0.7513	0.6575	0.5787	0.5120	0.4552	0.4064
4	0.8227	0.6830	0.5718	0.4823	0.4096	0.3501	0.3011
5	0.7835	0.6209	0.4972	0.4019	0.3277	0.2693	0.2230
6	0.7462	0.5645	0.4323	0.3349	0.2621	0.2072	0.1652
7	0.7107	0.5132	0.3759	0.2791	0.2097	0.1594	0.1224
8	0.6768	0.4665	0.3269	0.2326	0.1678	0.1226	0.0906
9	0.6446	0.4241	0.2843	0.1938	0.1342	0.0943	0.0671
10	0.6139	0.3855	0.2472	0.1615	0.1074	0.0725	0.0497
11	0.5847	0.3505	0.2149	0.1346	0.0859	0.0558	0.0368
12	0.5568	0.3186	0.1869	0.1122	0.0687	0.0429	0.0273
13	0.5303	0.2897	0.1625	0.0935	0.0550	0.0330	0.0202
14	0.5051	0.2633	0.1413	0.0779	0.0440	0.0254	0.0150
15	0.4810	0.2394	0.1229	0.0649	0.0352	0.0195	0.0111
16	0.4581	0.2176	0.1069	0.0541	0.0281	0.0150	0.0082
17	0.4363	0.1978	0.0929	0.0451	0.0225	0.0116	0.0061
18	0.4155	0.1799	0.0808	0.0376	0.0180	0.0089	0.0045
19	0.3957	0.1635	0.0703	0.0313	0.0144	0.0068	0.0033
20	0.3769	0.1486	0.0611	0.0261	0.0115	0.0053	0.0025
21	0 3589	0.1351	0.0531	0.0217	0.0092	0.0040	0.0018
22	0.3418	0.1228	0.0462	0.0181	0.0074	0.0031	0.0014
23	0.3256	0.1117	0.0402	0.0151	0.0059	0.0024	0.0010
24	0.3101	0.1015	0.0349	0.0126	0.0047	0.0018	0.0007
25	0.2953	0.0923	0.0304	0.0105	0.0038	0.0014	0.0006
26	0.2812	0.0839	0.0264	0.0087	0 0030	0.0011	0.0004
27	0.2678	0.0763	0.0230	0.0073	0.0024	0.0008	0.0003
28	0.2551	0.0693	0.0200	0.0061	0.0019	0.0006	0.0002
29	0.2429	0.0630	0.0174	0.0051	0.0015	0.0005	0.0002
30	0.2314	0.0573	0.0151	0.0042	0.0012	0.0004	0.0001

$$\text{Single Payment–Compound Amount Factor (F/P)} = (1 + i)^n$$

$$\text{Single Payment–Present Worth Factor (P/F)} = \frac{1}{(1 + i)^n}$$

Table A2 Uniform Series Compound Factor—F/A. (Note: sinking fund factor A/F is the reciprocal of the numbers shown below.)

Number of periods (e.g., years)	Interest rates						
	5%	10%	15%	20%	25%	30%	35%
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	2.050	2.100	2.150	2.200	2.250	2.300	2.350
3	3.153	3.310	3.473	3.640	3.813	3.990	4.173
4	4.310	4.641	4.993	5.368	5.766	6.187	6.633
5	5.526	6.105	6.742	7.442	8.207	9.043	9.954
6	6.802	7.716	8.754	9.930	11.259	12.756	14.438
7	8.142	9.487	11.067	12.916	15.073	17.583	20.492
8	9.549	11.436	13.727	16.499	19.842	23.858	28.664
9	11.027	13.579	16.786	20.799	25.802	32.015	39.696
10	12.578	15.937	20.304	25.959	33.253	42.619	54 590
11	14.207	18.531	24.349	32.150	42.566	56.405	74.697
12	15.917	21.384	29.002	39.581	54.208	74.327	101.841
13	17.713	24.523	34.352	48.497	68.760	97.625	138.485
14	19.599	27.975	40.505	59.196	86.949	127.913	187.954
15	21.579	31.772	47.580	72.035	109.687	167.286	254.738
16	23.657	35.950	55.717	87.442	138.109	218.472	344.897
17	25.840	40 545	65.075	105.931	173.636	285.014	466.611
18	28.132	45.599	75.836	128.117	218.045	371.518	630.925
19	30.539	51.159	88.212	154.740	273.556	483.973	852.748
20	33.066	57.275	102.444	186.688	342.945	630.165	1152.210
21	35.719	64.002	118.810	225.026	429.681	820.215	1556.484
22	38.505	71.403	137.632	271.031	538.101	1067.280	2102.253
23	41.430	79.543	159.276	326.237	673.626	1388.464	2839.042
24	44.502	88.497	184.168	392.484	843.033	1806.003	3833.706
25	47.727	98.347	212.793	471.981	1054.791	2348.803	5176.504
26	51.113	109.182	245.712	567.377	1319.489	3054.444	6989.280
27	54.669	121.100	283.569	681.853	1650.361	3971.778	9436.528
28	58.403	134.210	327.104	819.223	2063.952	5164.311	12740.313
29	62.323	148.631	377.170	984.068	2580.939	6714.604	17200.422
30	66.439	164.494	434.745	1181.882	3227.174	8729.985	23221.570

$$\text{Sinking Fund Factor (A/F)} = \frac{i}{(1+i)^n - 1}$$

$$\text{Uniform Series–Compound Amount Factor (F/A)} = \frac{(1+i)^n - 1}{i}$$

Table A3 Uniform Series Present Worth Factor—P/A. (Note: capital recovery factor A/P is the reciprocal of the numbers shown below)

Number of periods (e.g., years)	Interest rates						
	5%	10%	15%	20%	25%	30%	35%
1	0.952	0.909	0.870	0.833	0.800	0.769	0.741
2	1.859	1.736	1.626	1.528	1.440	1.361	1.289
3	2.723	2.487	2.283	2.106	1.952	1.816	1.696
4	3.546	3.170	2.855	2.589	2.362	2.166	1.997
5	4.329	3.791	3.352	2.991	2.689	2.436	2.220
6	5.076	4.355	3.784	3.326	2.951	2.643	2.385
7	5.786	4.868	4.160	3.605	3.161	2.802	2.508
8	6.463	5.335	4.487	3.837	3.329	2.925	2.598
9	7.108	5.759	4.772	4.031	3.463	3.019	2.665
10	7.722	6.145	5.019	4.192	3.571	3.092	2.715
11	8.306	6.495	5.234	4.327	3.656	3.147	2.752
12	8.863	6.814	5.421	4.439	3.725	3.190	2.779
13	9.394	7.103	5.583	4.533	3.780	3.223	2.799
14	9.899	7.367	5.724	4.611	3.824	3.249	2.814
15	10.380	7.606	5.847	4.675	3.859	3.268	2.825
16	10.838	7.824	5.954	4.730	3.887	3.283	2.834
17	11.274	8.022	6.047	4.775	3.910	3.295	2.840
18	11.690	8.201	6.128	4.812	3.928	3.304	2.844
19	12.085	8.365	6.198	4.843	3.942	3.311	2.848
20	12.462	8.514	6.259	4.870	3.954	3.316	2.850
21	12.821	8.649	6.312	4.891	3.963	3.320	2.852
22	13.163	8.772	6.359	4.909	3.970	3.323	2.853
23	13.489	8.883	6.399	4.925	3.976	3.325	2.854
24	13.799	8.985	6.434	4.937	3.981	3.327	2.855
25	14.094	9.077	6.464	4.948	3.985	3.329	2.856
26	14.375	9.161	6.491	4.956	3.988	3.330	2.856
27	14.643	9.237	6.514	4.964	3.990	3.331	2.856
28	14.898	9 307	6.534	4.970	3.992	3.331	2.857
29	15.141	9.370	6.551	4.975	3.994	3.332	2.857
30	15.372	9.427	6.566	4.979	3.995	3.332	2.857

$$\text{Capital Recovery Factor (A/P)} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

$$\text{Uniform Series–Present Worth Factor (P/A)} = \frac{(1+i)^n - 1}{i(1+i)^n}$$

APPENDIX B—DEPRECIATION SCHEDULES AND ASSET TYPES

Table B1 Depreciation Life and Class

Designation	DDB-5	DDB-7	DDB-10	DB-15	DB-20	SL-27.5	SL-31.5
Year	5 year 200%	7 year 200%	10 year 200%	15 year 150%	20 year 150%	27.5 year SL	31.5 year SL
1	20.00	14.29	10.00	5.00	3.75	1.82	1.59
2	32.00	24.49	18.00	9.50	7.22	3.64	3.17
3	19.20	17.49	14.40	8.55	6.68	3.64	3.17
4	11.52	12.49	11.52	7.70	6.18	3.64	3.17
5	11.52	8.92	9.22	6.93	5.71	3.64	3.17
6	5.76	8.92	7.37	6.23	5.28	3.64	3.17
7		8.92	6.55	5.90	4.89	3.64	3.17
8		4.48	6.55	5.90	4.52	3.64	3.17
9			6.55	5.90	4.46	3.64	3.17
10			6.55	5.90	4.46	3.64	3.17
11			3.29	5.90	4.46	3.64	3.17
12				5.90	4.46	3.64	3.17
13				5.90	4.46	3.64	3.17
14				5.90	4.46	3.64	3.17
15				5.90	4.46	3.64	3.17
16				2.99	4.46	3.64	3.17
17					4.46	3.64	3.17
18					4.46	3.64	3.17
19					4.46	3.64	3.17
20					4.46	3.64	3.17
21					2.25	3.64	3.17
22						3.64	3.17
23						3.64	3.17
24						3.64	3.17
25						3.64	3.17
26						3.64	3.17
27						3.64	3.17
28						3.64	3.17
29							3.17
30							3.17
31							3.17
32							3.17
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table B2 Asset Types

DDB-5	DDB-7	DDB-10	DB-15
Computers	Producing	Refining	Service station
Telephone switch	Mining	Ships	Pipelines
Autos	Natural gas		LNG
Trucks	Geothermal		Land improvements
Chemicals	Railcars		
Drilling			
Renew energy			
Aircraft			
Marketing equipment			

DB-20	SL-27.5	SL-31.5
Utilities	Residential Rental	Commercial Building

Legend:
DDB = double declining balance
DB = declining balance
SL = straight line

APPENDIX C—GLOSSARY

Accounting Deals with the presentation of the results of an ongoing business to the stockholders, e.g., profitability.

Accounts payable A cash obligation to a supplier of goods or services. It partially offsets cash due from accounts receivable.

Accounts receivable Cash tied up in a commercial operation to cover the time between the sale of goods or services and the receipt of payments from the customer.

After tax Cash flow or income after payment of income taxes.

Amortization Similar to depreciation. Used to describe the write-off of special types of expenses and intangible assets. Also describes loan repayment.

Background inflation Refers to a general increase in the prices of goods and services as measured by a broad index such as the GNP Deflator. (The Consumer Price Index is based on a narrower basket of goods and services but generally tracks the GNP Deflator.)

Balance sheet An accounting evaluation of the firm's assets and the claims on the assets.

Basis For tax purposes, the depreciated value of an asset.
Before tax Cash flow or income before payment of income taxes.
Capital Money that a company uses to fund its various activities or investment proposals. Obtained either from stockholders who invest in the company (equity capital) or by borrowing money from lenders (debt).
Capital gain The difference between the sales price of an asset and the tax basis (up to the original cost) is taxable as ordinary income; the excess (if any) in the sales price over the original cost is taxable as Capital Gain income.
Capitalizing The act of defining a newly acquired asset as a capital item that will be written off over time (see depreciation, depletion, and amortization). Different from "expensing," where expenditures are written off directly against taxable income in the year they occur, e.g., operating expenses for power, materials, and labor.
Cash flow In economic analysis, an expression of the annual or cumulative cash effect on the company from investing capital in a particular project. That is, money that enters or leaves the company as a result of the investment proposal.
Compounding The growth of a cash investment over time through continuing reinvestment of the original cash amount plus all cash earnings. For example, investment of \$100 in an account paying 10% annual interest will grow (compound) in three years to $\$100\ (1.10)^3 = \$133.10$ (before taxes).
Cost of capital Normally has the same meaning as minimum hurdle rate or value of money when applied to individual investment proposals. In a broader sense, measures a company's weighted average cost of obtaining funds from both lenders and investors.
Cumulative cash flow The summation of all project cash flows (positive or negative) up to a given point of time.
Depletion Analogous to depreciation; an allowance that enables a producer of a natural resource to "write off" the cost of the resource as it is produced (depleted) in order to reduce taxable income.
Depreciation A method of "writing down" or spreading the cost of an asset over its life as it wears out. Depreciation is a noncash charge used only to calculate book income or to calculate taxable income.
Discounting The reciprocal of compounding; reducing a cash amount (to a smaller value in an earlier time period) by a certain rate each year.
Discount rate The rate used in discounting a cash flow, e.g., 15%.
Dividends Cash payments to the stockholders of a company or cash from a subsidiary to its parent company.
Economics analysis The application of various cash flow measuring techniques to determine the attractiveness of a given investment proposal.
End-of-year discounting Discounting when annual cash flows are assumed to occur at year-end.

Equity The sum of money invested by stockholders in a company plus retained earnings (total assets of the company minus liabilities).

Escalation The rate of price increase of a given item.

Fixed assets An accounting description of long-lived assets acquired for use in the operation of a business, e.g., land, buildings, machinery. More commonly referred to as property, plant, and equipment on financial statements.

Fixed costs Those out-of-pocket costs incurred more or less independently of the number of units sold or produced. (For example, property tax, labor, overhead, and administration.)

Future worth The value of a cash amount or cash flow stream compounded to some future time period.

Hurdle rate Hurdle rates reflect both project risk and the inflationary environment. The minimum rate of return for an investment proposal is usually equal to the cost of obtaining capital plus a risk premium.

Interest rate The rate of money growth when the return is expressed in then current dollars before any tax considerations.

Leverage To use borrowed money to supplement equity funding for a project, typically in an effort to enhance the return on owner's equity. Usually measured by a debt/equity ratio.

Line of credit An arrangement between the bank and its customer which specifies the amount of credit available to the customer.

Liquidity The ability of a firm to meet its current liabilities and potential cash outflows.

Maturity The term of duration of a loan arrangement.

Net present value (NPV) The sum of the present values of all positive and negative cash flows associated with an investment proposal using an appropriate discount rate.

Net worth The liquidation value of a business less obligations to nonowners.

Operating income Cash income before depletion, depreciation, amortization, and income tax, but after operating costs, royalties, and direct taxes. Also known as cash income before tax.

Payout The time required for the accumulated cash flow generated by an investment to equal the amount invested. Payout is normally measured from either the time of first expenditures or the time of project startup.

Present value (or present worth) The value of a future amount or cash flows discounted to a certain point in time specified by the analyst (typically, but not necessarily, the present).

Prime rate A reference rate of interest commercial banks charge large, financially strong corporations. Banks lend money at rates above or below Prime Rate based on their perception of risk.

Profit An accounting presentation of financial performance which does not accurately reflect cash flow. Profit before taxes is typically equal to cash earnings minus certain noncash costs (such as depreciation or depletion).
Project life In economic analysis, project Life means the economic life of the project (not the physical life of plant and equipment).
Rate of return (ROR) The discount rate which equates the present value of a project's future cash return to the present value of a project's investment outlays. Also known as the internal rate of return (IRR), discounted cash flow rate of return (DCFROR), return on investment (ROI), actuarial rate of return (AROR) and project rate of return (PROR). In economic analysis, Rate of Return means the then-current dollar rate of return.
Real interest rate The difference between the nominal or quoted interest rate and the background inflation rate.
Replacement value The cash cost of replacing an existing facility with new equipment. Not related to economic value, i.e., replacing the asset may or may not be economically justified.
Retained earnings An accounting statement of after-tax profits reinvested in a company after payment of dividends to the stockholders.
Risk Risk is viewed as a possible decrease in investment wealth due to uncertainty in investment returns.
Risk premium The theoretical difference between the required rate of return on a risky investment and the rate of return on a riskless investment that produces a certain cash flow with the same expected life.
Royalty Compensation for the use of a property, usually a patent, copyrighted material, or natural resource; often expressed as a percentage of receipts from using the property.
Salvage value The market value of a capital asset at the time it is retired (often assumed to be zero in economic analysis).
Sensitivity analysis Analysis of the variation of economic results with variations in individual input parameters; for example, operating costs.
Service life The useful life of an asset.
Start up The point in a project where construction has been essentially completed and the facilities are started up, thereby generating revenues.
Stockholder An investment group or individual holding legal ownership of a business by virtue of investing equity capital and entitled to any profits generated.
Stockholder equity Funds invested in the company by the stockholders plus the company's retained earnings.
Straight line (SL) depreciation Provides that an asset be depreciated in equal annual installments over its useful (book) life or its tax life.
Sunk costs Prior expenditures; typically excluded from economic analysis.

Tariff A fee per unit throughput, e.g., barrel, for use of an operating unit or facility.
Taxable income Cash earnings minus cash expense minus noncash expenses for depreciation, depletion, or amortization.
Taxes Cash payments to governmental agencies, including excise taxes, property taxes, capital gains taxes, and income taxes.
Then-current dollars Dollars with whatever buying power they have in the year in question (vary in purchasing power with inflation).
Time value of money Recognizes that money shifts in purchasing power over time to reflect inflation and uncertainty in investment returns. Equivalent to discount rate which is the preferred terminology. A discount rate that is selected and based on an evaluation of project risk and inflation is the project hurdle rate.
Time zero A single reference point in time set by the analyst as a starting point for economic analysis.
Variable costs Cash costs that vary directly with the number of units sold or produced, e.g., raw material, fuel, electricity, chemicals.
Working capital Cash that is tied up in an operation in addition to capital invested in facilities. Includes cash cost of inventories, net accounts receivable, spare parts or supplies, and cash-on-hand.
Write-off Any charge against taxable income. Can be either current cash costs or noncash costs such as depreciation, depletion, or amortization. A special write-off can occur when the value of an asset is reduced to zero and it is abandoned.

APPENDIX D—COMPUTER PROGRAM AND DISK

A. General Information

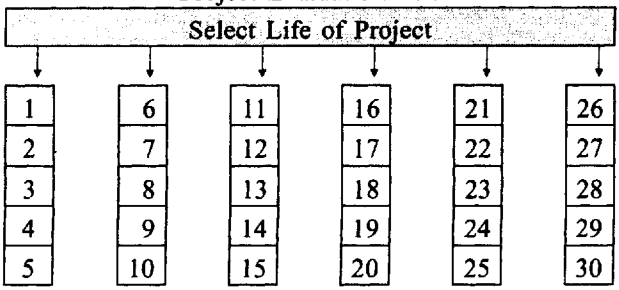
This section presents an example of a spreadsheet application for evaluating projects. The computer model is based on an Excel 5.0 sheadsheet. Several macro buttons are available for moving between inputs and also for printing. Flagged arrows indicate where input is required on the different input sheets.

B. Input Steps

I. Summary Page Inputs
   a) *Project Title* in green box
   b) *Tax rate* as a decimal in green box
   c) *Discount Rate* as a decimal in green box

II. Press "Button" on summary sheet for inputting *Project Life*. From selection sheet, select life of project (1–30) by pushing button on for years of the project.

Project Evaluation Life



Note. The Excel file "Model" is used in the macros for selecting project life. Changing the file name will cause macro to fail. After life of project is set, file name can be changed to save file.

III. Press "Button" on summary sheet for Inputting *Investment* amounts. Enter only investment values on sheet and press "Return" button.

IV. Enter *Revenues* by Pressing "Button" on summary sheet

a) On revenue sheet enter
   1. Sales volume by year
   2. Unit sales price by year
   3. Asset sale at end of project if any

b) Press "Return" button to go back to summary sheet

Revenue

Input Values

Year	Sales Volume	Unit Price ($)	Asset Sale ($)	Total Revenue ($)
	A	B	C	A × B + C
0				
1	1000	4.00		4,000.00
2	1050	4.00		4,200.00
3	1080	4.10		4,428.00
4	1110	4.10		4,551.00
5	1140	4.25		4,845.00
6	1170	4.25		4,972.50
7			500.00	500.00

V. Enter *Cost* by pressing on button on summary sheet
   a) On Cost Sheet enter
      1. Variable cost per unit by year
      2. Fixed cost per year
   b) Press "Return" button to go back to summary sheet

Operating Expense

Input Values (→ Unit Cost, Fixed Cost)

	Sales Volume	Unit Cost ($)	Total Variable Cost ($)	Fixed Cost ($)	Total Operating Cost ($)
	A	B	C = A × B	D	E = C + D
0					
1	1000	0.20	200.00	1,200.00	1,400.00
2	1050	0.20	210.00	1,320.00	1,530.00
3	1080	0.22	237.60	1,450.00	1,687.60
4	1110	0.22	244.20	1,600.00	1,844.20
5	1140	0.25	285.00	1,760.00	2,045.00
6	1170	0.25	292.50	1,930.00	2,222.50
7	0	0.00	0.00	0.00	0.00

VI. Select *Depreciation* schedule by pressing on "button" on summary sheet. Select depreciation schedule by pressing on button for one of the options of schedules to be used.

Depreciation and Taxes

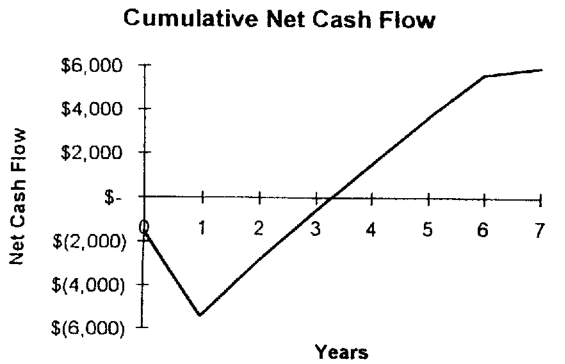
Input Values (→ Investment)

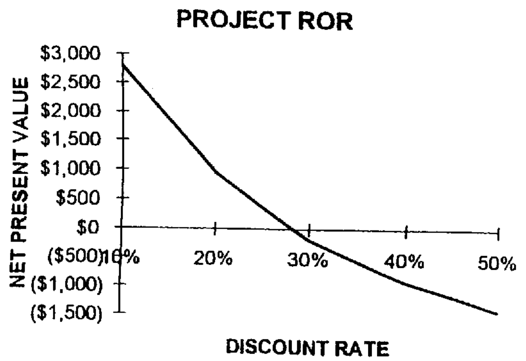
Yr	Total Revenue ($)	Total Operating Expense ($)	Investment ($)	Depr. Rate (%)	Depr. ($)	Total Taxable Income ($)	Tax Rate (%)	Taxes ($)
0			1,500					
1	4,000	1,400	6,150	20.00	1530	1,070	35	374.5
2	4,200	1,530		32.00	2448	222	35	77.7
3	4,428	1,688		19.20	1468.8	1,272	35	445.06
4	4,551	1,844		11.52	881.28	1,826	35	638.932
5	4,845	2,045		11.52	881.28	1,919	35	671.552
6	4,973	2,223		5.76	440.64	2,309	35	808.276
7		0	(500)			500	35	175

Depreciation Schedules

Yr	DDB-5	DDB-7	DDB-10	DB-15	DB-20	SL-27.5	SL-31.5
1	20.00	14.29	10.00	5.00	3.75	1.82	1.59
2	32.00	24.49	18.00	9.50	7.22	3.64	3.17
3	19.20	17.49	14.40	8.55	6.68	3.64	3.17
4	11.52	12.49	11.52	7.70	6.18	3.64	3.17
5	11.52	8.92	9.22	6.93	5.71	3.64	3.17
6	5.76	8.92	7.37	6.23	5.28	3.64	3.17
7		8.92	6.55	5.90	4.89	3.64	3.17
8		4.48	6.55	5.90	4.52	3.64	3.17
9			6.55	5.90	4.46	3.64	3.17
10			6.55	5.90	4.46	3.64	3.17
11			3.29	5.90	4.46	3.64	3.17
12				5.90	4.46	3.64	3.17
13				5.90	4.46	3.64	3.17
14				5.90	4.46	3.64	3.17
15				5.90	4.46	3.64	3.17
16				2.99	4.46	3.64	3.17
17					4.46	3.64	3.17
18					4.46	3.64	3.17
19					4.46	3.64	3.17
20					4.46	3.64	3.17
21					2.25	3.64	3.17
22						3.64	3.17
23						3.64	3.17
24						3.64	3.17
25						3.64	3.17
26						3.64	3.17
27						3.64	3.17
28						3.64	3.17
29							3.17
30							3.17
31							3.17
32							3.17

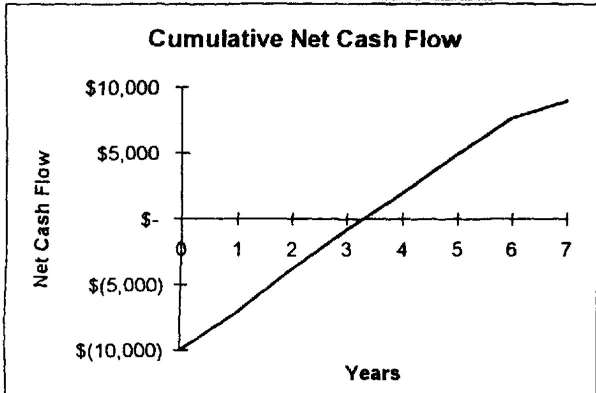
PROJECT :	Project A	*DISCOUNT RATE*	10%
PROJECT EVALUATION	7 *YEARS*	*TAX RATE*	35%

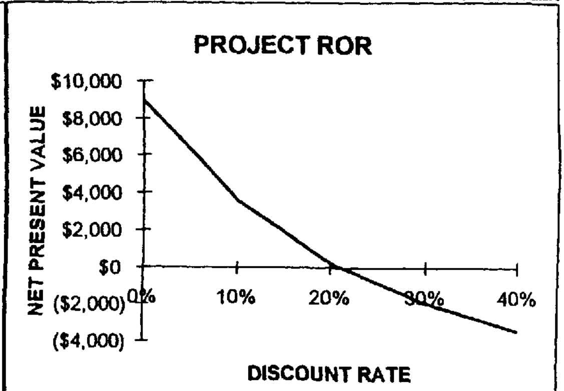




Payout	3.26	*Net Present Value*	$2,796	*Project Rate of Return*	28%

PROJECT :	Project B	*DISCOUNT RATE*	10%
PROJECT EVALUATION	7 *YEARS*	*TAX RATE*	35%





Payout	3.29	*Net Present Value*	$3,569	*Project Rate of Return*	21%

C. Printing

Press "Button" on summary sheet to print graphs of Net Present Value and Rate of Return. Individual sheets can be printed by using the Excel button for printing.

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14
Investment Decision-Making

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> Nothing is more difficult, and therefore more precious, than to be able to decide. Napoleon Bonaparte (*Maxims*, 1804)

What qualities make a high-performing manager? Surveys consistently rank good decision-making at or near the top of the list. Engineers, like most professionals, spend most of their time preparing information for others to use, to act upon in making decisions. Further, in design work where choices are often left to the professional, the quality of the work product depends upon the capacity for making good decisions.

This chapter is about investment decision-making. Where are resources best applied so as to most benefit the organization? Money is usually the foremost concern. Certain resources may be costly or in short supply, including people, time, materials, and capacity.

Decision analysis is the discipline that helps decision makers choose wisely under uncertainty [1]. Logical, consistent decisions—*good decisions*—result from using the data available in assessing value in a systematic way. Most decisions involve risks, and judgments about uncertainty are explicitly incorporated into the analysis as probability distributions.

This chapter shows how decision analysis improves upon the more traditional evaluation approaches. The compelling advantages of these new techniques include:

1. Clarifying the objective and how to measure value in the context of that objective
2. Clearly communicating the influence and amounts of risk and uncertainty
3. Providing greater accuracy in the evaluation result

Increasingly, the well-rounded engineer is expected to be holistic. It is no longer sufficient to be merely good in one's technical field. An outward focus is expected. Effects on the business, including customers and suppliers, should be considered in decisions. Cost/benefit/risk assessments are becoming the norm when presenting recommendations. This is both good and appropriate. The goal of this chapter is to present a solid and modern approach for engineering evaluations.

The chapter is organized so as to build upon important, fundamental concepts. The major sections are:

I. The Approach: Problem-solving steps and types of problems
II. Project Value: Appraisal approach, quantifying value under uncertainty
III. Preferences: Components of decision or evaluation policy: objective, time value, and risk attitude; multicriteria decisions
IV. Investment Decision Process: Credible analysis; evaluation report elements
V. Decision Analysis Process: Sequence of steps, roles, and suggestions
VI. Example Evaluations: Activity acceleration; plant investment, solved three ways; value of information
VII. Summary

I. THE APPROACH

Foremost in any evaluation is the need to be clear about the objective. What is the *mission* of the business enterprise? Most organizations have one overarching objective. For a business, the common objective is to maximize shareholder value. For a government, the stated objective might be to maximize the quality of life for its citizens. The attractiveness of decision alternatives should always be in the context of the objective.

A. Problem Solving

Evaluations are performed as part of solving problems. A typical problem-solving process is:

1. Something happens that brings a matter to our attention. This might be the outcome of a "gap analysis," i.e., the organization recognizes a gap between where it is now and where it wants to be.
2. Alternatives are generated and screened. Brainstorming is often employed. Some proactive organizations, or individuals, routinely generate decision alternatives without waiting for something to happen (Step 1).
3. Viable alternatives are evaluated in the context of the organization. Which alternative is expected to provide the most progress or value toward reaching the organization's objective?
4. The best alternative is implemented.

B. Problem Types

Evaluation problems always seem to fit into one of three categories:

Ranking alternatives according to preference.
Appraising the value of a project, strategy, or asset. For example, how much value will this project add to corporate net worth?
Optimizing one or more decision variables. These variables are controllable. For example, what plant capacity provides the most value to the corporation?

Conveniently, an *appraisal approach* can be applied, universally, to any type problem. Decision alternatives are appraised, in turn, and the one providing the greatest value is selected.

II. PROJECT VALUE

The appraisal approach is represented by the conceptual *value meter* shown in Figure 1. All three problem types, in the previous section, can be solved by reading the meter. The decision maker wants the alternative or combination of decision variables that provides the highest value. For an appraisal analysis, the evaluation is analogous to reading the meter.

A. Quantitative Methods

Analysis of complex, important problems is best done quantitatively. Numbers are not inherently more accurate than word descriptors. However, *numbers are unambiguous*. Further, we know many useful ways to combine numbers mathematically, which makes possible analyses of large, multicomponent problems.

Forecasting is the most important, and valuable, analytic problem in business. All decisions presuppose a forecast. Most often, the outcome forecast is driven by separate forecasts of several input variables. The inputs drive the

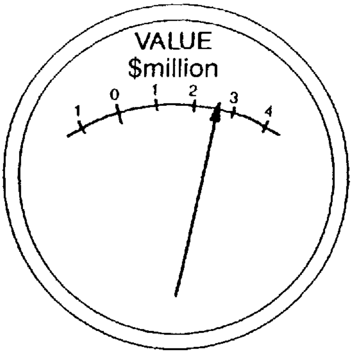

Figure 1 A conceptual meter measures value in the eyes of the decision maker. The scale is most often calibrated in dollars. Alternatively, the scale may be in arbitrary utility units, often called *utiles* or *utils*.

outcome, and the engineer's understanding of the system embodying the relationships is expressed in a mathematical model.

The most popular form of forecasting model is the ubiquitous computer spreadsheet. Most evaluation professionals now have this tool on their desks. Spreadsheet programs have done much to demystify forecasting models and to empower the ordinary professional who wants to perform analyses.

In a *deterministic* analysis, every input to the model is the best estimate of the respective parameter. Each input is singly determined. If we know the outcome value for each alternative, it is a simple matter to make the best choice. This is seldom the case, because there are uncertainties about what will occur.

A *stochastic* or *probabilistic* analysis recognizes that some of the input parameters are uncertain. These are represented as probability distributions. Probability is the language of uncertainty. If one or more inputs to a model is a probability distribution, the output value will also be a probability distribution.

B. Quantitative Value

A *value function* is needed to measure goodness in reference to the organization's objective(s). This function is embodied in a company's evaluation and decision policy.

Probability is the formal, unambiguous language of uncertainty. A *probability distribution* shows the relative likelihood of different values occurring. By *probability*, we are referring to a number, ranging 0–1, representing the likelihood of something happening. These fractions may be expressed as percents, if desired. Being numeric, probabilities are concise and useful in calculations. Most often, the source of the probability is someone's judgment, based on experience, intuition, understanding of the system, and, perhaps, historical data. A probability distribution clearly and completely represents a person's judgment about an uncertain variable.

C. Value Under Uncertainty

A straightforward way to measure value under uncertainty is to convert the outcome probability distribution into a single number. The simplest way to do this is to determine the probability-weighted outcome value. This is called *expected value* (EV). Statisticians call this the *mean* of the distribution. Expressed mathematically,

$$\text{Expected value} = \text{EV} = \int_{-\infty}^{\infty} x\, p(x)\, dx$$

where x is the outcome value and $p(x)$ is the probability (density) function of x. While this calculus equation may appear foreboding, one seldom does a mathematical integration in practice. For a discrete distribution, where there are a finite number of possible outcomes, *EV* is simply

$$\text{EV} = \sum_{n}^{i=1} x_i\, p(x_i)$$

For example, suppose your project has only three possible outcomes: "Failure," "Success," and "Huge Success." Suppose the outcome values (x_i) and their likelihood of occurrence ($p(x_i)$) are as shown in Table 1.

The right-most column shows the expected value calculation. The outcome values are simply weighted with their probabilities of occurrence. The sum

Table 1 Possible Outcomes and Associated Probabilities, Used to Calculate EMV.

Outcome	Outcome \$ x_i	Probability $p(x_i)$	Expected value (\$)
Failure	–500,000	0.30	–150,000
Success	1,000,000	0.50	500,000
Huge success	2,000,000	0.20	400,000
		1.00	750,000

of the components is the *expected monetary value* (EMV). We usually use EMV, instead of EV, when the outcome is measured in monetary units.

The EMV for this project is $750,000. This is an *objective*, i.e., unbiased, assessment for the project's value so long as (1) the outcomes are objective value measures for the purpose at hand and (2) the probability judgments are objective (unbiased). For a risk-neutral decision maker, he or she would be indifferent between (a) having this project and (b) having $750,000 cash with certainty.

In this chapter, "decision maker" is a general reference to the entity represented. The manager making decisions on behalf of her organization is implementing the decision policy crafted for the organization. This policy is usually intended to best represent the interests and desires of the company's stockholders.

Often, as in this case, the EMV is not a possible outcome. The "expected" label in EV, or EMV, is unfortunate because "expected value" is not what we actually expect. The EV is merely the probability-weighted outcome value. The name "expected value" derives from what mathematicians call *expectation theory*.

Consider another example. Suppose your project cost analysis results in the probability distribution shown as Figure 2. The curve communicates your full judgment about project cost to your client. However, many situations, such as business appraisal, require a single, best estimate. That is where EV is useful. EV translates this distribution curve into a single number.

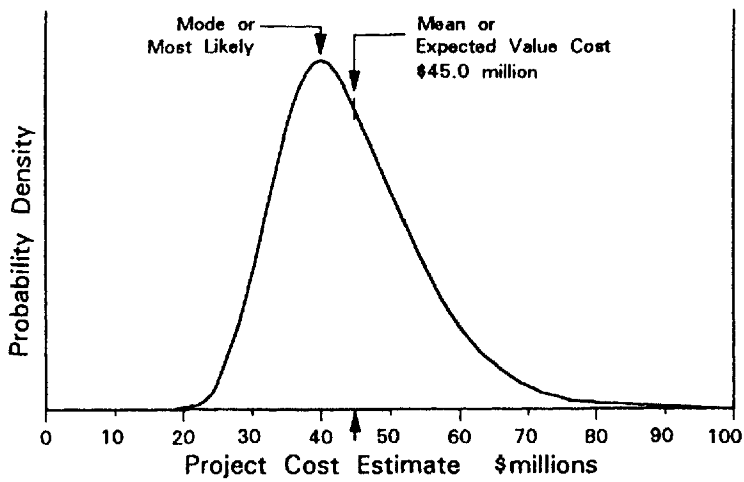

Figure 2 Example project cost distribution. The height of the curve represents the relative likelihood for the outcomes along the *x*-axis.

EV says nothing about uncertainty. However, to the risk-neutral decision maker, value (EV or EMV) is all that matters. In this case, the $45 million value is the *objective* estimate of project cost. Because the distribution is positively skewed, there is a greater probability that actual project cost will be below $45 million. This probability is the portion of the area under the curve to the left of $45 million. If a group of engineers is well-calibrated, a history of their projects estimated with EVs will have an average error converging toward zero over time. That is, random errors are diluted with additional samples.

D. Expected Value Calculations

Decision tree analysis and Monte Carlo simulation are the two most popular, robust ways to calculate expected value in an evaluation analysis. There are other techniques, but most are limited to simple probabilistic situations.

Decision trees are evaluated using the discrete distribution calculation,

$$\mathrm{EV} = \sum_{n}^{i=1} x_i \, p(x_i)$$

as in the last example.

Monte Carlo simulation uses a somewhat different approach to solve the integral,

$$\mathrm{EV} = \int_{-\infty}^{\infty} x \, p(x) \, dx$$

Simulation averages many randomly-generated scenarios, called trials, to effectively solve the equation. At the start of each trail, a *random sample* value is obtained for each uncertain input variable. Figure 3 illustrates one way this sampling process can be done. A *random number generator* provides uniformly-distributed values between 0 and 1. The random number provides the parameter to sample the cumulative probability distribution. On one trial, the random number generator provided a 0.68513 value. This is used to enter the graph at the y-axis. The corresponding x-axis value is 12.6 weeks. This value is used as the completion time for this activity for this trial.

Similarly, other input variables are sampled, each with its own curve and a different random number. The project model is solved with these input values and the outcomes recorded. Averaging the trial values provides an approximation to the EV equation. This simple, yet elegant, random sampling process actually performs the integration. Usually at least several hundred trials are necessary for sufficient accuracy.

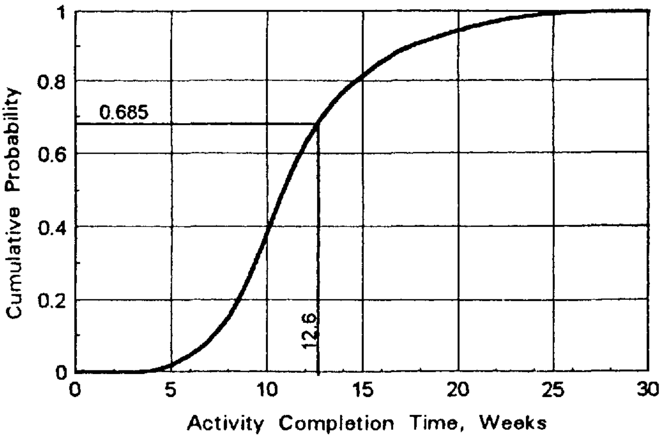

Figure 3 Input judgment about the completion time for a particular activity.

III. PREFERENCES

How are project outcomes to be valued? This is the purpose of evaluation, or decision, policy. A *value function* represents a mathematical calculation of value. Crafting the value function is sometimes done by decomposing value according to three *preferences*. These preferences are attitudes about facets of the problem, representing the organization's objective and beliefs.

A. Attitude Toward Different Objectives

In business, it is axiomatic that we strive to make money for the stockholders: *The driving objective is usually to maximize the monetary value of the firm.* The decision rule that maximizes shareholder value is to choose the alternative having the greatest dollar value (or other monetary units). Sometimes, considerations other than money enter the evaluation. Examples include:

Operating in socially acceptable ways
- Operating legally
- Providing a quality product or service
- Protecting the environment
- Creating and protecting jobs
- Protecting the community
- Recognizing the interests of customers and suppliers

Doing business with companies, countries, and people whom we like.

These considerations ultimately affect the monetary value of the business. The simplest way to deal with nonmonetary effects is to express them in money-equivalents. For example, suppose your company has a policy of being environmentally responsible. The issue is, sometimes, "How much altruism and at what cost?" One consistent way to deal with pollution is to establish a dollar value for each quantity of pollution avoided or released.

Another interesting and emotional trade-off involves human life. How much should be invested in safety? A person feeling uncomfortable placing a value on human life may consider how investments can save lives elsewhere. EV lives lost can be equated to EV lives saved elsewhere. This allows a reasonably objective, quantitative analysis of very emotional situations.

It is sometimes inconvenient or inappropriate to measure value in monetary terms. Most often, this situation represents a *multicriteria decision* problem where several objectives or subobjectives are being optimized. This is especially true of public sector decisions. Using decision analysis for such problems involves constructing a multicriteria objective function to measure value. A project multicriteria decision example is described later in Multicriteria Decisions.

B. Attitude Toward Time Value of Money

Most people recognize that there is value to receiving benefits sooner rather than later. Conversely, we would like to defer payments and other obligations. *Present value* (PV) discounting is the generally accepted method to recognize time preference. Usually, we are dealing with inflows and outflows of money, but the approach is applicable also to nonmonetary measures.

Chapter 13, Profitability Analysis, described discounted cash flow (DCF) analysis. This is the basis for most modern financial analysis. It is essential that the time value of money be represented when costs and benefits will be realized across a time period exceeding a few months.

The general PV equation, and *the one that always works*, is:

$$PV = \frac{CF}{(1 + i)^t}$$

where

PV = present value of the future cash flow
CF = a future cash flow amount realized at future time t
i = discount rate, expressed as an "interest rate" per year
t = the time, in years, between the effective, or as-of date, and when the cash flow is realized

The discount rate (i) represents the organization's attitude toward time value of money. This is a fundamental part of decision policy. This is usually a fixed rate tied to the forecast for cost of capital. The discount rate need not be fixed, although most companies set a constant rate as a matter of policy. Alternatively, the discount rate may be different for different future periods according to a time-varying outlook for inflation and capital markets.

Unless specified otherwise, exacted monetary value (EMV) represents EV PV. Equivalent, and useful in certain complex situations, is the decision policy to choose the alternative having the highest EV *future value* (FV) of the company. This also maximizes EMV becuase PV and FV are related. In the previous equation, substituting FV for CF yields,

$$FV = PV(1 + i)^t$$

Financing costs are rarely included in project projections. The cost of funding a project is accounted for by the PV discount rate. An objective attitude toward the time value of money will use a discount rate representing the marginal (incremental) cost of capital for the company. When using probabilities to deal with uncertainty, the author advocates a discount rate near the risk-free cost of capital [2]. *Do not adjust the discount rate for unique project risk.* A slight adjustment is appropriate for market (systematic, undiversifiable) risk. A guideline to the appropriate rate is: What discount rate will be used in a postanalysis to determine how much value was added to the company by the project?

The value of a business is its ability to generate cash. Be careful that overhead burdens are legitimately incremental. Since corporate income taxes must be paid, it is the project's impact on *after-tax* net corporate cash flow that determines project value. This cash is available to repay creditors, dividend stockholders, or reinvest in the business. If the analysis is done properly, project PV represents the PV of dividends to stockholders possible as a result of the project. That is, project PV corresponds to incremental shareholder value before personal income taxes.

The *scope* encompassed by the model is important. The project analyzed may be all or part of an industry, business, project or transaction. The scope usually needs to consider the full remaining life cycle of the project. Sometimes managers concern themselves only with the construction or development phase. This is usually inadequate. Completion time and asset performance impact value, also, as illustrated in Figure 4. Decision analysis techniques are fully general, and their application applies to nonconstruction projects equally well. All important details and aspects of the problem should be incorporated into the model.

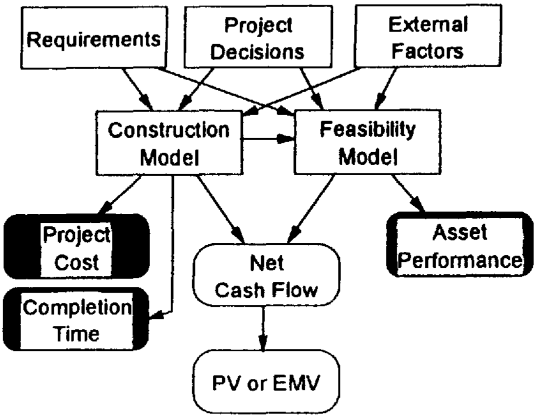

Figure 4 The scope of the project model usually includes the full life cycle of whatever asset is being built. Project cost, completion time, and performance are key drivers for the ultimate outcome value.

Here are several analysis areas where mistakes are often made:

Discount time periods do not match the project. Be careful about the assumed timing of cash flow receipts and disbursements. The as-of date for PV calculations is usually the date of the commitment decision. Most practitioners use midperiod discounting. For example, if evaluating a 10-year project with a projection in annual time periods, all cash flows can be assumed to occur in the middle of respective project years.

Inappropriate fixed or overhead costs in cash flow projections. The intent is to forecast incremental corporate net cash flow. Usually, fixed costs are not allocated to a project. However, in the long run, all costs are variable. For example, adding one computer workstation to a network server may only cost for the connection. However, as more and more workstations are added, the system response will slow to a point where server capacity will eventually have to be expanded. Thus, a portion of the future upgrade cost would be appropriate to add when costing the additional workstation connection.

Including sunk costs and benefits. These are usually ignored in an analysis. Today's decision or evaluation should not be influenced by prior investments. The exception is when taxes and contractual terms are affected by what has happened before. The forecast cash flow model should consider any future effects from prior transactions.

C. Attitude Toward Risk

Risk attitude, or preference, is perhaps the most fascinating area of decision analysis. Most people, unknowingly, make choices that are inconsistent with their objective. Project evaluations, decisions, and negotiations can be improved with an understanding of the concept of risk preference.

The uninitiated tend to be overly-conservative. For example, consider the middle manager in a large public corporation who would give up a chance to invest \$1 million to gain a 50% chance at \$10 million in present value (PV) benefits. For the project,

$$\begin{aligned} \text{EMV} &= -\$1 \text{ million} + [0.5(\$10 \text{ million}) + .5(\$0)] \\ &= 0.5(\text{low outcome}) + 0.5(\text{high outcome}) \\ &= 0.5(-\$1 \text{ million}) + 0.5(\$9 \text{ million}) = \$4 \text{ million} \end{aligned}$$

An investment like this example will, on average, add \$4 million to the company's net worth. Thus, the rejecting manager loses an opportunity to add value to the corporation. This behavior may seem more rational if his or her department has a small budget. However, the proper perspective is to consider project outcomes in relation to the size of the corporation. Or, better, compare this investment to the collective net worth of the company's stockholders.

A decision maker who is *risk neutral* would be indifferent between (1) having \$4 million cash in hand and (2) having an opportunity to do this project. Conservative decision makers, however, would willingly accept less if the certainty is reduced or removed.

Most people will make their future decisions more objectively, once they realize the implications of their conservative actions. That is, they learn to adjust less for risk. Choosing to fund this example project would be a good decision in a portfolio of many similarly-sized decisions. If the company's value is large in comparison to the outcomes of a particular decision, generally the company will want to be objective toward risk. For most decisions, risk neutrality is a reasonable assumption.

Maximizing Utility

The rest of this section applies only to readers who want to apply a consistent, conservative risk policy. Conservative individuals making personal decisions, and conservative organizations, will want to have their decision policy reflect their risk aversion. There is a straightforward way to do this. A *utility function* is crafted to represent the decision maker's risk policy. This function defines how the company makes trade-offs between dollar value and risk. This clever concept is the only way the author knows of for making logical, consistent trade-offs between risks and rewards.

Instead of maximizing EMV, conservative investors want to maximize the *utility* of their portfolio. This embodies the centuries-old concept of the diminishing marginal value (utility) of addition amounts of money. Most textbooks on decision analysis [3] describe the use of a utility function for calculating *expected utility* (EU). EU is calculated the same way as EMV except that the outcome PVs are first converted into utility units using the utility function.

Equivalent to maximizing EU is the idea of maximizing the *certainty equivalent* (CE). This is functionally identical to maximizing EU, but results in an answer expressed in actual dollars. The fundamental relationship for conservative decision-making is:

$$\text{CE} = \text{EMV} - \text{Risk Premium}$$

CE can be considered EMV adjusted for risk attitude. Decisions are made to maximize the CE of the portfolio.

The risk premium, as a fraction of the investment amount, is small for modest-sized investment decisions. However, when the possible outcomes are large in comparison to the investor's net worth, the adjustment can be substantial. The author favors the utility equation of form:

$$\text{Utility} = r(1 - e^{-\text{PV}/r}) \qquad \text{(in } \textit{risk-neutral (RN) dollars}\text{)}$$

where r is a *risk tolerance coefficient* unique to the individual or organization. Highly risk-averse decision makers have small values of r. It is often about 1/5 of the individual's net worth and can change across time as net worth and dollar value changes. A risk-neutral decision maker has $r = \infty$.

In decision tree analysis, the utility of each terminal branch outcome is converted into utility units. Then, the tree is back-solved for EU. Similarly, the outcome of every trial in a Monte Carlo simulation is converted and recorded in utility units; the results are averaged to get EU. In both techniques, EU can then be inverse-transformed into CE.

Consider the previous project example:

$$\text{EMV} = 0.5(\text{low outcome}) + 0.5(\text{high outcome})$$

$$= 0.5(-\$1 \text{ million PV}) + 0.5(\$9 \text{ million PV}) = \$4 \text{ million}$$

Assume the project opportunity is owned by a small, closely held business. Suppose the company's risk policy is expressed as r = \$5 million. This might be a \$25 million net worth business representing the principal asset of 50 descendants of the original company founders. The utilities (in "risk-neutral dollars") of the two possible project outcomes are:

$$U_{\text{low}} = (5 \times 10^6)(1 - e^{--10^6/5 \times 10^6}) = \text{RN\$} -1{,}107{,}014$$

$$U_{high} = (5 \times 10^6)(1 - e^{-9 \times 10^6/5 \times 10^6}) = \text{RN\$4,173,506}$$

Calculating expected utility,

$$\text{EU} = 0.5(-1{,}107{,}014) + 0.5(4{,}173{,}506) = \text{RN\$1,533,246}$$

Converting EU into CE requires the inverse of the utility equation,

$$\text{CE} = -r \log_e\left(1 - \frac{\text{EU}}{r}\right) = (-5 \times 10^6) \log_e\left(1 - \frac{1{,}533{,}246}{5 \times 10^6}\right)$$

$$= \$1{,}831{,}096$$

Additional digits were retained to show the calculations and should not be interpreted as inordinate precision.

The company would clearly fund the project, because the "do nothing" alternative has CE = EU = \$0. Further, this company would be indifferent between (1) keeping and funding the project and (2) selling the unfunded project for \$1.8 million.

D. Decision Policy

Conceptually, any project with PV > 0, discounting at the marginal cost of capital, adds value to the company. Again, with uncertainty, we are calculating EV PV, which is EMV.

The *EMV decision rule* is a complete decision policy suitable for most business situations: *Choose the alternative having the greatest EMV.* This is the optimal decision policy assuming that (1) capital is available at the PV discount rate and (2) the objective is to maximize the EMV of the company.

Sometimes there are constraints which preclude all economic projects from being undertaken. Most often, companies plan as if there is a shortage of capital. Ideally, all possible combinations would be considered to see which combinations satisfy the capital constraint. Quantitative methods such as *goal programming* and *branch-and-bound techniques* consider all feasible possibilities. However, there is a simpler method that suffices for most situations.

Bang-for-the-buck ranking easily determines a nearly optimal project portfolio. The name derives from the metaphor of a child, with a certain amount of money in hand, who wants to buy the best portfolio (biggest bang) of firecrackers for his money. Investment opportunities are ranked by the ratio,

$$\text{Bang–for–the–buck} = \frac{\text{Noise (in decibels, perhaps)}}{\text{Unit cost}}$$

The child merely buys firecrackers, in sequence according this ratio, until all his money is spent. In capital budgeting [4], many companies use, instead,

$$\text{Discounted return on investment (DROI)} = \frac{\text{PV}}{\text{PV(Investment)}}$$

or

$$\text{Profitability index (PI)} = \frac{\text{PV}}{\text{Investment}}$$

Of course, the numerators should be EMVs in the probabilistic case. The denominators can be EVs as well. Although rarely seen, the author recommends using *undiscounted investment* in the denominator (he knows of no company that discounts budget dollars). If something other than money is the controlling constraint, then that measure should replace investment in the denominator.

Ranking projects for selection under a capital constraint has a long history. Ranking or screening for shortest payout has been around for centuries but is too primitive. *Internal rate of return* (IRR) was a favorite ranking index in the 1960s. The DROI and PI ratios, above, are now recognized as more theoretically correct.

The process of ranking to fit within a constraint should be recognized for the management expedient [5] that it is. There is no shortage of capital in the world, only a shortage of enough good projects. If a properly analyzed project has a positive EMV, then it should be funded except in unusual circumstances. If the decision maker thinks otherwise, then perhaps the discount rate assumption is wrong.

Sometimes a decision involves only or mostly costs. Then, the decision rule is to choose the alternative having the minimum EV costs. Only the sign has changed, and this is exactly equivalent to maximizing EMV.

If the company is intentionally conservative and uses a utility function to express its risk policy, then the decision rule is to choose the alternative with the highest CE. If projects are reasonably independent, this rule maximizes the CE of the company. Correlated projects must be analyzed as a portfolio rather than individually. CE can be used instead of EMV in the DROI or PI ratio.

E. Multicriteria Decisions

Monetary value is a convenient measure for comparing decision alternatives. Most people already recognize corporate value in terms of dollars. Increasingly, decisions in government and not-for-profit organization are also based upon monetary-equivalents. *This section is for readers whose situation is incompatible with valuing outcomes in monetary units.*

Sometimes, outcomes must be measured in several dimensions. For example, a city makes trade-offs among safety, transportation, and recreational opportunities [6]. There may be a complex relationship of objectives, often

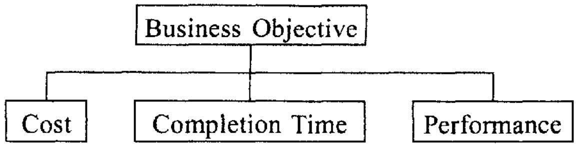

Figure 5 Simple hierarchy of objectives. These structures can extend many layers below the top objective.

represented as a hierarchy, such as Figure 5. A recently popular way of constructing the hierarchy is the *analytic hierarchy process* [7]. This quantitative technique uses pair-wise comparisons to determine the weights of decision criteria and the criteria scores for decision alternatives. Composite score values are then easily determined for every alternative. (In for-profit situations, the interrelationships could, and probably should, be modeled to produce the EMV valuation.)

Consider a software project manager thinking in terms of cost, schedule, and performance. Wanting to be systematic in thinking, the manager develops a utility scale for each dimension, as shown in Figure 6. The y-axis of each scale represents "goodness" or value in the context of the respective attribute. The x-axes are scaled according to the possibilities in this project.

The utility axes have arbitrary scales. Each function is unique to the subobjective and can incorporate the decision maker's attitude toward risk.

Once the manager has relevant quantitative value measures, she can weight each attribute. The combination is a single *objective function*, often in the additive form:

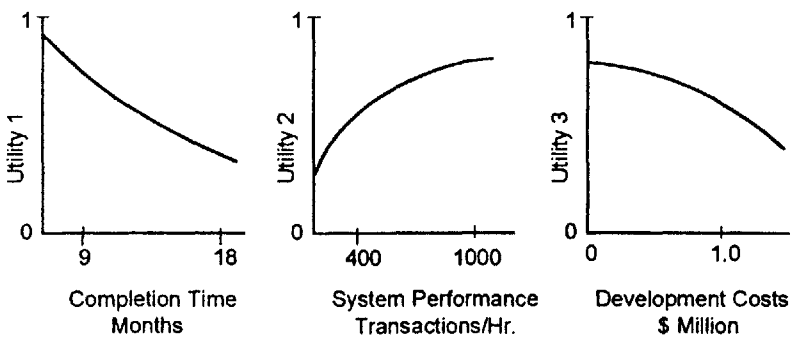

Figure 6 Three utility scales measuring dimensions of the problem.

$$\text{Utility} = \text{wt}_1 \times \text{Utility}_1 + \text{wt}_2 \times \text{Utility}_2 + \text{wt}_3 \times \text{Utility}_3$$

where weights (wt_i) are chosen so that the value behaves according to her intuition about the problem. A linear, additive form is most often chosen for the value equation. Other forms, such using multiplicative terms, have been found useful.

This valuation approach is obviously highly subjective. The strength of the process is providing a structure that helps keep the process reasonably logical and complete. With a way to measure value, the project manager can analyze problems as they arise during the project. To recognize uncertainty, outcome values are weighed with probabilities in EU calculations, and the choice is always to pick the alternative having the greatest EU.

IV. INVESTMENT DECISION PROCESS

A workable definition of a *credible analysis* is: *one that gets used.* The goal of evaluation work is to provide value assessments that are relied upon as the basis for decisions. Here, *evaluation* is a generic word representing engineering evaluation, cost estimation, project assessment, feasibility analysis, asset appraisal, and all other types of analyses related to decisions. This section describes the decision analysis process.

A. Excellence in Evaluation

If your job includes analysis, how do you feel about the quality of your evaluations? Users of your reports will, most likely, recognize two principal desirable characteristics:

Objectivity: Lack of bias. On average, over a number of projects, estimates proving neither too high nor too low.
Precision: Reasonable closeness of the estimates to outcome values; a low amount of random "noise" in the estimates.

Forecast *accuracy* is a composite of low bias *and* high precision. Suppose actual outcomes versus estimates are tracked by the ratio, Actual/Estimate, as shown in Figure 7. *Objectivity* tells us about the estimate quality regarding *where* the values are located on a scale. If the estimators are well-calibrated, the sample mean of this distribution will be close to one. *Precision* refers to the *dispersion* of values about the central location and is often measured by the *standard deviation*. In competitive situations, precision is critical. However, for most internal purposes, objectivity is more important. Understanding the EV concept is essential to objective evaluations under uncertainty.

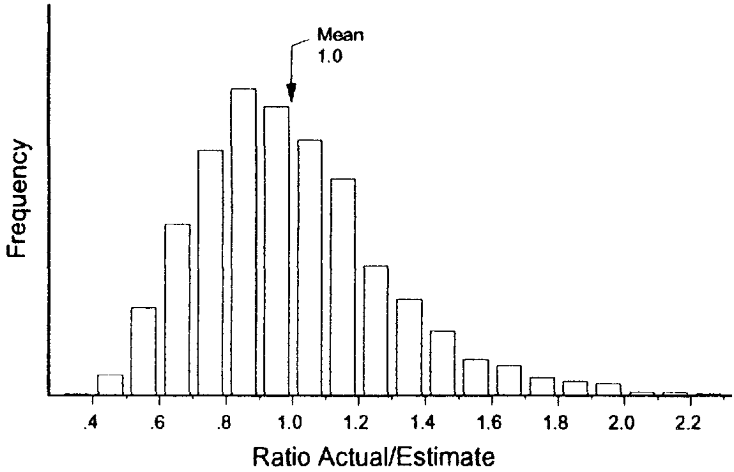

Figure 7 Frequency histogram showing project estimation Actual/Estimate ratios.

B. Credible Evaluations

A decision maker has a right to expect quality evaluations. The author favors pushing decisions down the organization. In companies that do so, the actual approval process may be a formality. In many companies, a chicken-and-egg syndrome persists. Evaluations are often habitually optimistic, as evidenced by post-evaluations. Decision makers therefore learn to trim expectations. This is manifest in layers of reviews, high hurdle rates, and conservative economic assumptions.

Professionals need to be relentless in reducing bias in their estimations. This is done naturally by providing individual performance feedback within a nonpunitive environment. Most engineers work in a conservative culture. If several people having input to an evaluation are individually conservative, the analysis ends up being *extremely* conservative. In this case, the information arriving at the decision maker is nearly worthless. If the organization wants to be conservative, then risk attitude is best reserved for the last stage of analysis:

- The decision maker can examine cumulative probability, such as Figure 8, to determine which alternative has the best risk versus value profile.

or, less commonly,

- The outcome PVs can be translated into utility units, and EU or CE computed (see Attitude Toward Risk).

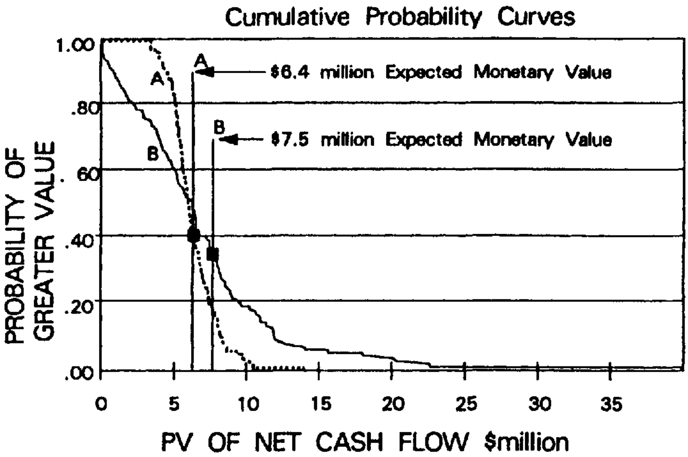

Figure 8 Probability curves generated by a Monte Carlo simulation. Alternative B (solid line) is more risky (wider) than Alternative B. However, B has the greater EMV. Which alternative is better?

Credible evaluations have several hallmarks:

- Suited to purpose
- Objective
- Recognizes risks and uncertainties
- Understood by the decision maker
- Result from an established evaluation process

These features are expanded as follows:

Suited to Purpose

Defining the *correct problem.*
Encompassing all significant impacts on the organization, including other projects, in the *scope of the evaluation.*
Timely evaluation results.
Incorporating *implementation plans*, contingencies, and contingency responses into the evaluation.

Objective

Value measure clearly and logically relates to the organization's objective.
Unbiased except for any biases that are purposefully inherent in the decision policy (e.g., conservative risk policy).

All decisions are based upon forecasts of the future. The projection models providing these forecasts are *valid* and *correctly perform all calculations.*

Recognizes Risks and Uncertainties

Probabilities and *probability distributions* explicitly represent risks and uncertainties in the analysis.
Expected value (EV) calculations combine multiple possible outcome values into single values.
Judgmental inputs are assessed by qualified persons. All data in possession are considered.

Understood by the Decision Maker

The *projection model* closely corresponds to the way the decision maker views the problem.
All key elements of the problem are included in the decision model, in appropriate detail and relevant to the decision at hand.
Any evaluation element can be *examined in detail* and readily understood.

Result from an Established Evaluation Process

An established, tested *evaluation process* that warrants confidence.
Post-evaluations and other *feedback* processes are used to improve the quality of subsequent evaluations.
Decision policy is communicated clearly and is recognized as relating directly to the organization's purpose.

C. Evaluation Report Elements

Conceptually, the decision maker only needs to know the EMV of each alternative. The author recommends that the transmittal letter begin with language such as: "We recommend funding Project X because we estimate it will add ($ EMV) to the company's value."

A typical evaluation report contains these elements:

- Summary and conclusion, including a recommendation if alternatives were evaluated. This should include the estimated value added (or cost avoided) by accepting the recommendation. *Value (or cost) versus risk profiles for key alternatives are often displayed as cumulative probability curves* (e.g., Figure 8).
- Statement of the problem, background, scope, and approach.
- Discussion of the search for alternatives and those considered. Rationale for early eliminations.
- Description of the project and project model.

- Discussion of input assumptions and sources.
- Reference to the decision policy, or description of the valuation formula.

It is often appropriate to provide evaluations for three viable alternatives. These strategies are typically optimized, i.e., the best solution within each general strategy. The decision maker then has some choice. Certainly, all important alternatives should be addressed.

If the manager believes that an evaluation is credible, he or she will usually act in accordance with the results as presented. However, the manager is part of the business control system. He or she will judge the competence of the analysis team and the quality of their work. The values may be adjusted, explicitly or not, or the analysis team may be asked to redo the work.

Conceptually, the analysis should be performed as if the decision maker had done the work personally. The decision maker should be involved, if possible, in the formulation of the model and is responsible for communicating decision policy so that the calculations reflect value. The decision maker can either provide the judgments that go into the model or delegate who will provide which variable assessments.

All details that are important to the problem should be incorporated into the model. It is inappropriate to do formal analysis on a part of the problem and leave everything else to a subjective "windage" adjustment. For example, some organizations use formal, quantitative analysis for the "hard" financial numbers and leave other "soft" costs and benefits to an intuitive adjustment. This defeats the integrity of the decision analysis approach.

The decision maker, unless intimately involved with the evaluation, brings important, additional intuition to the problem. How good are the model and the judgments that went into it? Were all viable alternatives identified and considered? What should be done when the model does not agree with the decision maker's intuition? That is, what if the "head" does not agree with the "gut"? Something is clearly wrong, and the error should be found. Often, something is missing from the model or a logic error has been made in calculation. Other times, importantly, the decision maker may be poorly calibrated for the new type of problem at hand. The decision maker and analysts should work together until the discrepancy is eliminated.

V. DECISION ANALYSIS PROCESS

One characteristic of a professional is good habits. For work of a repeating nature, such as most evaluations, the professional usually develops a systematic process. The evaluation engineer can think of herself as an analysis factory, and set up a production system to fit the situation.

Having an evaluation *process* should not be at the expense of creativity and flexibility, for these are clearly important. However, consider the dentist as a metaphor. When you are having a tooth filled, you do not want the dentist to be brainstorming and experimenting with new techniques. You want a tried and proven process that has been successfully applied many times before. Similarly, the user of an evaluation report will want it to be the product of logical, consistent analysis process.

A. Sequence of Steps

Here is a typical sequence of steps in a decision analysis:

1. Define what decision is to be made.

Must a decision be made?
Who has to make it?
When is the decision needed?
What is the scope of the problem and analysis?
Develop a problem statement.
Gather background and historical examples.
Pick a well-conceived title for the problem.

2. Determine what factors to use in the decision. These should be quantitative to facilitate comparison. The factor(s) should reflect decision policy. This step is often merely an affirmation of the policy.

3. Identify the decision alternatives.

New or combination alternatives will likely surface as the analysis progresses.
Constantly seek to prune the list of poorer alternatives.
Recognize any truly limiting factors; consider ways to relax or eliminate these constraints.

4. Identify possible outcomes from each alternative.

What are the drivers of value?
What are the risks and uncertainties?

5. Develop one or more models that can be used to evaluate every possible outcome.

Some techniques that are helpful:

- Causal network diagram (influence or relevance diagrams)
- Flow diagrams of the system process and model logic
- Balance equations: energy, material, income and cash flow
- Sensitivity analysis (to identify which variables are important in the problem)

Validate the model (work should be thoroughly reviewed by at least one other person or verified by other independent means).

6. Capture expert judgments.

Determine values for fixed (deterministic) variables in the model.
Capture judgments about risks and uncertainties as probabilities and probability distributions.
Validate the data and judgments in the model.
Ensure that the model is valid over the range and all combinations of input variables. Check, especially, extreme (outlier) values.

7. Calculate EV outcomes for each alternative. Usually, this is EMV (EV PV). Decision tree analysis and Monte Carlo simulation are the most popular calculation techniques that propagate the probability distributions through the calculations.

8. Choose the alternative with the highest EMV (or highest utility if risk-averse or if working with multiple decision criteria).

9. Rethink the problem.

Test the robustness of the model by examining sensitivities.
Seek insights about model behavior and clarity.
Is further study warranted? (*value of information* problem)
Is the model *robust*, i.e., how sensitive are the model conclusions to different parameters?

10. Implement the solution (best alternative). Be sure to act! Sometimes, the best choice is to wait; if so, arrive at this conclusion by reason, not by default.

11. Do a post-audit of the decision.

Review the project, possibly at several stages, to assess the effectiveness of the decision analysis process.
Provide outcome feedback to the experts who provided the input assessments.

Although the process appears sequential, it seldom is entirely so in execution. The insights gained about the problem are, perhaps, as important as the numerical result. Often, the analysis team will want to backtrack to a previous step after discovering some new information.

B. Roles and Analyst's Effort

One advantage of decision analysis is that a framework is provided that holds many features of a complex problem. This facilitates a multidisciplined team working on a problem. Accountability is possible because everyone knows

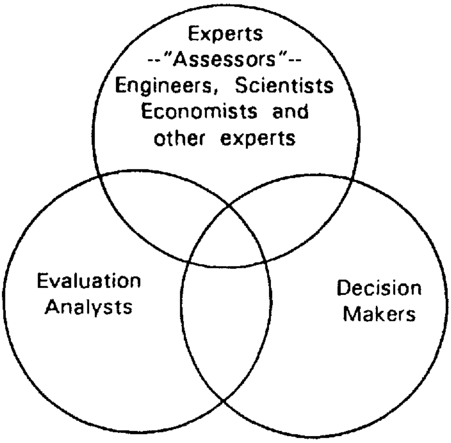

Figure 9 Three roles in the decision process.

and understands the contributions to the analysis. Three principal roles are played, as shown in Figure 9.

Many times, the same person will assume more than one role in an evaluation. Because economic evaluation is a discipline, the organization will often have staff persons designated as analysts. They often go by alternative titles, such as economist, evaluation engineer, or planner. The analysts have the principal responsibility of constructing the evaluation model. They often interview the experts who will provide the judgmental inputs to the model. The analyst also interviews the decision maker, as appropriate, to define decision policy (criteria), the scope of the analysis, and the solution approach.

Unless the problem type is routine, most of the analyst's effort is usually devoted to constructing the decision model. Here are typical proportions:

10%	Defining the problem
50%	Developing the deterministic model
15%	Interviewing experts and encoding judgments
10%	Modifying the deterministic model for simulation or decision tree
15%	Documenting the analysis approach and results
100%	of the analyst's effort

C. Analysis Suggestions

Here are several suggestions to help in the analysis process:

Think and rethink about the *problem definition*. Avoid solving the wrong problem. Often eliminating a root cause is better than treating a symptom.

The model should forecast *incremental company net cash flow*. Consider all impacts on the corporation, such as effects on other departments or divisions; sometimes, the model scope needs to be expanded. Be careful when including any fixed and overhead expenses.

Further information and analysis only adds value when it has the potential to change the present choice. Routinely assess whether further analysis is justified. Marginal decisions generally warrant the greater analysis effort.

Decompose the problem into manageable pieces—"divide and conquer."

Simplify wherever you can. "Less is more." The appropriate model detail depends upon the decision at hand. Consider which details to capture in the model and which can be omitted. Be specific about the details that matter. However, nothing important should be left out. Usually, the top 3 to 5 variables are responsible for over 90% of the outcome value uncertainty.

Iterate back through the analysis steps sequence, seeking new insights about the problem.

- Clarify or perhaps redefine the problem.
- Add or refine alternatives.
- Refine probability assessments.
- Continue ruthless pruning of unimportant details.
- Revise, expand, and re-solve outcomes.

Although most problems are unique, decision analysis is a straightforward, structured process. The decision model should be an evolving and permanent feature of project planning and project documentation. It should reflect the current scope definition and be updated for new information and project developments as they unfold.

VI. EXAMPLE EVALUATION MODELS

Several examples illustrate the decision analysis approach.

A. Project Activity Acceleration Problem

Joe Wilson is managing a small but important project and wants to control costs and risks. Quality (performance) is not an issue, because the product must be reworked, as required, to meet standards. However, schedule is important because there is a $5,000 per day incentive (or penalty). This $5,000 adequately relates schedule to cost for this analysis.

Joe has two qualified vendors, A and B, who can perform a particular activity, "Machine Castings." Vendor B is expected to complete the activity

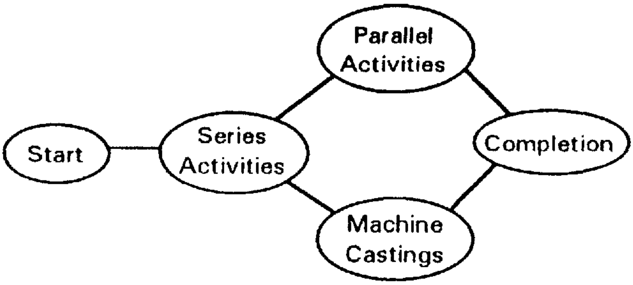

Figure 10 Simplified activity network for the vendor analysis.

in less time, but will charge another $900. The decision at hand is which subcontractor to choose for this activity. Joe develops a simple model of the project, shown as Figure 10, to analyze this vendor decision. All activities parallel to Machine Castings are consolidated into the "Parallel" node. All leading and trailing activities are consolidated into the "Series" node. Joe has previously done a *critical path method* (CPM) analysis. Machine Castings is not on the deterministic *critical path*. However, Joe recognizes that forecast completion times are uncertain. Events may unfold such that Machine Castings *is* an element of the actual critical path and affects the project completion schedule.

With his best judgment, using vendor data and other inputs, Joe assesses the distributions in Table 2 for completion times. Lognormal distributions are often suitable in situations where the distribution is positively skewed (i.e., a tail in the positive, or right, direction); when things go badly, they often turn out very bad. The graphs in Figure 11 show the shapes of these distributions.

Because Machine Castings will be similar regardless of vendor selected, Joe believes there is a strong correlation between the time to complete this activity for both vendors. He assesses a 0.50 correlation coefficient [8] to

Table 2 Judgments About the Uncertainties in the Simplified Project Model

Activity	Distribution type	Mean (days)	Standard deviation (days)
Series activities	Lognormal	83	7
Parallel activities	Lognormal	10	3
Vendor A, machine castings	Lognormal	9	3
Vendor B, machine castings	Lognormal	8	2.5

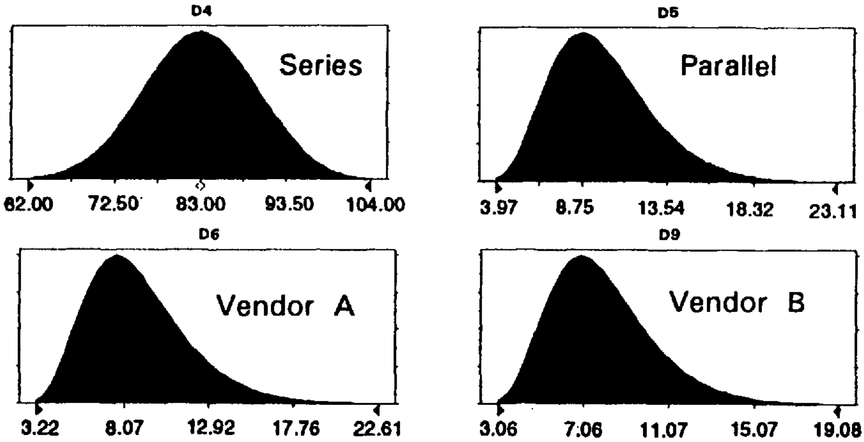

Figure 11 Input probability distributions.

represent this association. Joe set up a simple Monte Carlo simulation model to evaluate his options for this activity. Figure 12 shows the spreadsheet model which was written in Microsoft Excel® using Crystal Ball® [9]. After running 10,000 trials in a simulation run, Joe finds that the EMV improvement for engaging Vendor B, instead of Vendor A, is $1,520 ± 121 [10]. The $900 additional vendor cost has already been deducted. He finds the choice clear: The project has a (rounded) $1,500 higher pretax value to Joe's company if Vendor B is used instead of A.

Projdemo.xls		Evaluating Machine Castings Activity Acceleration					
Activities	Mean	SD	Lognormal	Days	$5,000	/day Schedule Delay	
Series	83	7	83.00		$900	Vendor B add'l cost	
Parallel	10	3	10.00	Completion			
MachCastA	9	3	9.00	93.00	0	Probability On CP	
Alternative Vendor Case				Completion			
MachCastB	8	2.5	8.00	93.00	0	Probability On CP	
				Difference			
			Days saved	0.00	($900)	Improvement EMV	

Figure 12 The shaded cells in the fourth column are input or "assumption" cells. The shaded cells in the sixth column are output or "forecast" cells.

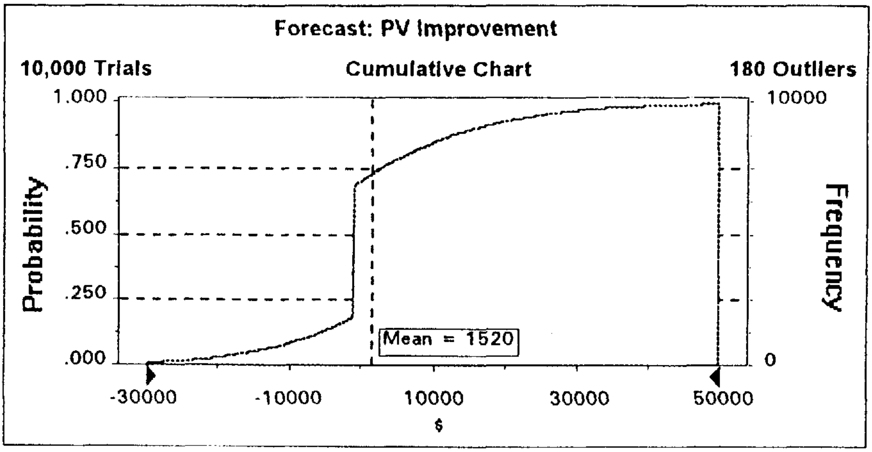

Figure 13 Cumulative probability distribution for the impact on the project if Vendor B is chosen as opposed to Vendor A. The vertical cliff is at –$900, the additional cost charged by Vendor B. There is only about a 31% probability that engaging Vendor B will add value to the project, but that value might be considerable.

The EMV difference is all Joe needs to know to make an informed decision between the two alternatives. However, he also learns from the simulation:

If Vendor A is used, Machine Castings has a 40% probability of being on the critical path, i.e., it affects total project completion time. The probability drops to 29% if Vendor B is used.

Even with the strong correlation between vendor performances, there is a huge range, from about –$74,000 to $90,000, of possible impact on the project due to Machine Castings vendor selection.

There is a 50% probability that switching vendors will have no impact on the project completion time, as shown in Figure 13. There is a 17% probability that the project completion time will be *worse* with Vendor B than if Vendor A is used. And, there is a 31% chance that project completion time will be *improved* by choosing Vendor B over Vendor A.

B. Deterministic Solution of a Plant Problem

Consider a feasibility study of an opportunity to enter a new business line. Pursuing this venture requires building a new plant to manufacture the product. The company is a diversified, publicly-held manufacturing corporation. The market capitalization (net worth) of the company is $50 million. The business is stable with a history of earnings progression. The new venture requires $1.8 million investment in plant and equipment plus another $0.8 million in initial working capital. The economic life of the facility and product type is about 20 years. The deterministic analysis [11] is shown as Table 3. Assume the corporation's after-tax cost of capital is 10%/year. Although the payout is almost 10 years, the 14% rate of return is acceptable. The present value of $1.034 million is the apparent value added to the company, and its stockholders, by funding the venture.

In a *base case*, usually the best estimate is used for each input variable. If there is uncertainty about a variable, its best estimate is its EV. For contingency events that may or may not occur, usually the base case uses the most likely outcome. The base case is dangerous to use for decision-making, as shown by the different results obtained in the next two sections.

C. Monte Carlo Solution of the Plant Problem

Continuing the plant decision problem, we now recognize that several key input variables are uncertain. It is desirable to represent these as probability distributions. Examples include: Sales Escalation, Life of Sales Growth, and Operating Cost Escalation.

The deterministic spreadsheet model was converted into a Monte Carlo simulation. The software tools used for this analysis were Lotus® 1-2-3® for DOS and @RISK® [12]. Conceptually, all that was required was to substitute probability distributions for uncertain variables. Table 4 shows the uncertainties that were recognized in the example simulation model.

Triangle distributions were used for this example, although there are many possible distribution shapes. With @RISK, probability sampling functions are supplemental @ ("at") functions like those that come with standard Lotus 1-2-3. For example, the 1-2-3 cell for Initial Sales contains the function, @TRIANG (2000, 3000, 7000).

After 400 trials, the new business line value was determined:

EMV = $4.24 million ± 0.37 million [13]   *Correct* value

This compares with:

Deterministic value: $1.034 million   *Wrong* value

The $3.2 million difference is the *stochastic variance* resulting from the more correct calculation with probabilities. The improved accuracy is a key reason for using decision analysis in evaluations. This more accurate valuation is the result of correctly carrying the probability distributions through the calculation model. The big impact in this situation is the unequal treatment of upside and downside scenarios. There is considerable upside profit potential. However,

Table 3 Deterministic Economic Analysis for Investing in Plant and Equipment to Produce a New Product. Dollar Amounts are in 000s

Year	0.06515 Sales	0.055 Operating costs	Gross margin – fixed expenses	Plant & equipment inventory (salvage)	Depreciation	0.50 Plant & equipment end balance	0.75 Working capital investment (recovery)	0.40 Income taxes	Net cash flow
1				1,800		1,800	400	0	–2,200
2	4,000	3,700	300	0	90	1,710	400	84	–184
3	4,260	3,904	357	0	90	1,620	52	107	198
4	4,537	4,118	419	0	90	1,530	55	131	232
5	4,832	4,345	487	0	90	1,440	59	159	269
6	5,146	4,584	562	350	99	1,691	63	185	–36
7	5,480	4,836	645	0	108	1,584	67	215	363
8	5,837	5,102	735	0	108	1,476	71	251	413
9	6,216	5,382	834	0	108	1,369	76	290	467
10	6,620	5,678	942	0	108	1,261	81	334	527
11	7,050	5,991	1,060	0	108	1,154	86	381	593
12	7,509	6,320	1,188	0	108	1,046	92	432	664
13	7,997	6,668	1,329	0	108	939	98	489	743
14	8,516	7,034	1,482	0	108	831	104	550	828
15	9,070	7,421	1,649	0	108	724	111	616	921
16	9,659	7,830	1,830	0	108	616	118	689	1,023
17	9,659	8,260	1,399	0	108	509	–0	517	883
18	9,659	8,714	945	0	108	401	0	335	610
19	9,659	9,194	466	0	108	294	0	143	322
20	9,659	9,699	–40	–147	147	0	–1449	–268	1,824
	135,367	118,780	16,587	2,003	2,003	21,995	483	5,640	8,460

@IRR: 0.141 or 14.1% PV.10: 1034
Payout: 9.9 yrs
Discounted payout: 14.3 yrs

Table 4 Distributions for Judgments About Uncertainties

Input variable	Distribution type and parameters
Initial sales $000	Triangle (2000, 3000, 7000)
Years sales growth	Discrete (0.2, 12; 0.6, 15; 0.2, 18)
Sales growth rate	Triangle (0.05, 0.06, 0.085)
Initial operating cost $000	Triangle (2000, 2800, 6300)
Operating cost growth rate	Triangle (0.04, 0.05, 0.075)
Initial plant investment $000	Triangle (1600, 1800, 2000)
Subsequent plant investment $000	Triangle (250, 350, 450)
Plant salvage fraction	Triangle (0.35, 0.45, 0.70)
Income tax rate	Triangle (0.38, 0.40, 0.42)
Working capital, fraction of sales	Triangle (0.16, 0.19, 0.25)
Working capital recovery	Triangle (0.6, 0.7, 0.95)

if the business doesn't work out, the company would simply terminate operations and salvage the assets, thus limiting its downside exposure.

In many organizations, EMV would be sufficient to approve the project. The author recommends that the analysis presentation also include a distribution of outcome value, such as Figure 14. This graph is easy to obtain from a Monte Carlo simulation. The "Do Nothing" alternative, with which to compare, is the vertical x = $0 line. Several alternatives can be compared

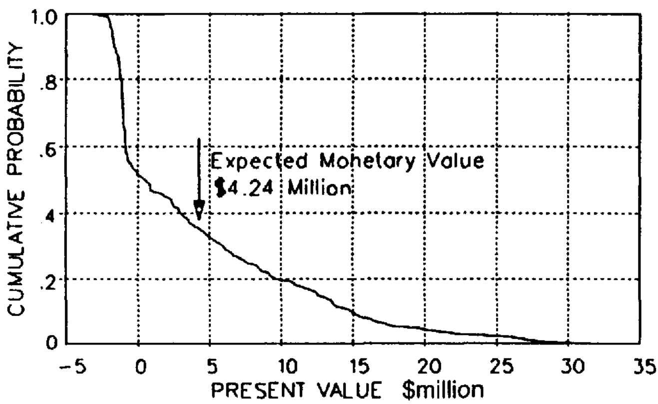

Figure 14 Cumulative probability distribution for plant outcome PV, obtained from Monte Carlo simulation.

with superimposed curves, and the decision maker can decide which alternative has the best value versus risk profile.

Many people looking at curves such as Figure 14 are alarmed at the high probability—almost 50% in this case—of losing money on a project. This would certainly be an unacceptable risk if all the eggs are in this one project. However, if this is only one business unit of a much larger corporation or if the stock is widely-held, this risk is diluted and acceptable. Simulation is a powerful tool for evaluating a portfolio of projects.

D. Decision Tree Solution of the Plant Problem

A sensitivity analysis of the plant problem would show that initial sales and initial operating costs account for most of the outcome PV uncertainty. Fcr decision tree analysis, continuous probability distributions, such as the triangle type, first need to be converted into discrete distributions. The author chose to approximate these two events as 3-level distributions, shown in Figure 15 and as follows:

Initial Sales

triangle(2000,3000,7000) ⇒ discrete(.23,2800; .41,3400; .36,5400)

Initial Operating Costs

triangle(2000,2800,6300) ⇒ discrete(.26,2700; .39,3300; .35,4900)

These *discretized* distributions are then used in constructing a decision tree for the plant problem. The decision tree model is shown as Figure 16. Fol-

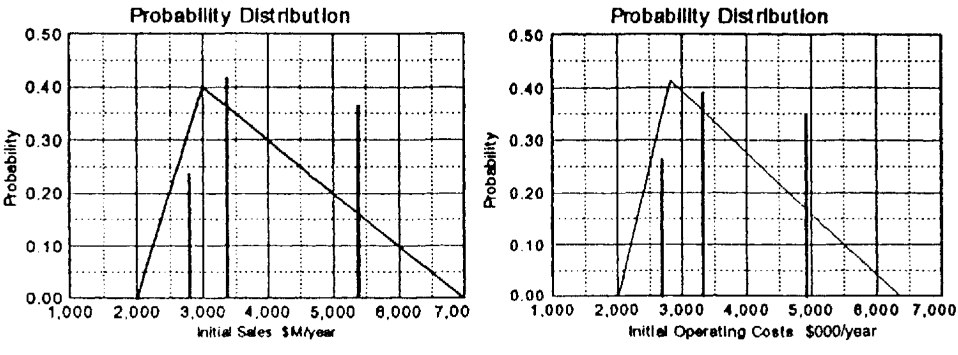

Figure 15 Continuous and discrete distributions for initial sales and initial operating costs.

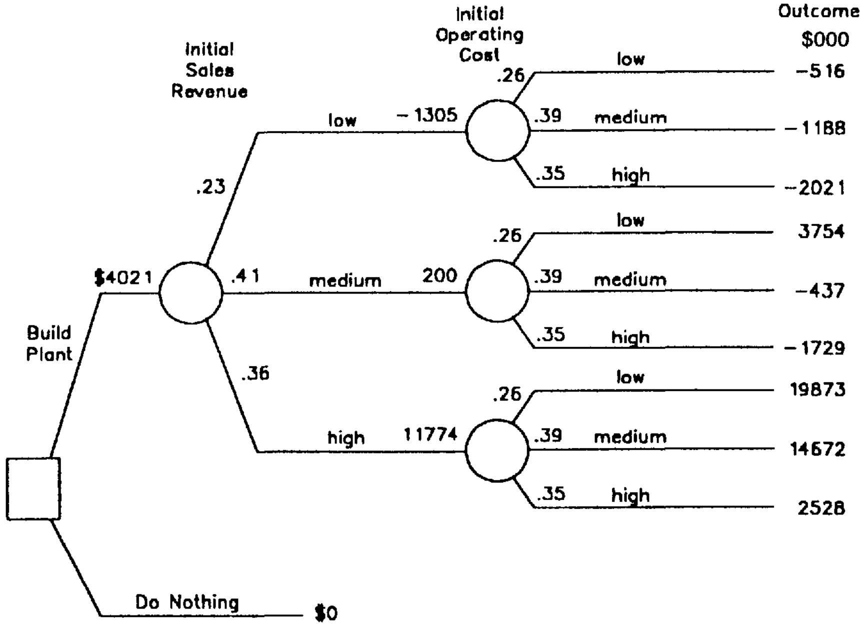

Figure 16 Decision tree analysis of the plant decision. Only the two most important uncertainties are recognized here.

lowing is a brief description of the process. Decision trees are constructed of nodes and branches. The decision and chance events are chronological from left to right. Squares represent decisions, and the branches from a decision node represent alternatives. Circles represent chance events, and the branches from the nodes represent possible outcomes. Rightmost values on a tree are usually [14] outcome values, measured in PV dollars (or utility units). The tree is back-solved to determine the EMV (or EU) of each alternative. Back-solving the tree is simple and involves only two rules [14]. Start at the right side and work leftwards:

When a chance node is reached, calculate its EMV (or EU). This becomes the value of the node and the branch leading into it.

When a decision node is reached, determine the best alternative using either the EMV or EU decision rule.

The reader is encouraged to verify the calculations. Recognizing only the two most important uncertainties, the EMV is calculated to be $4.021 million, approximately the same as the result obtained from the Monte Carlo simulation. The decision tree value may be less accurate than the Monte Carlo simulation result because fewer uncertainties are being recognized. Note how the decision tree analysis can be a very powerful communications device. All the important decisions and chance events are displayed graphically.

E. Value of Information Problem

Decision trees are the most popular technique for valuing additional information. Many problems have alternatives where more information can be obtained, usually at some additional cost and delay. Examples include prototyping, market survey, testing, and further analysis. "Wait" is sometimes a viable alternative because time often resolves uncertainties.

An alternative way to acquire additional information is evaluated just like other alternatives. The most popular approach is to keep the same outcome scenarios but revise their probabilitiesy [16] based upon the new information. Figure 17 shows the structure of a simple, but typical, value of information

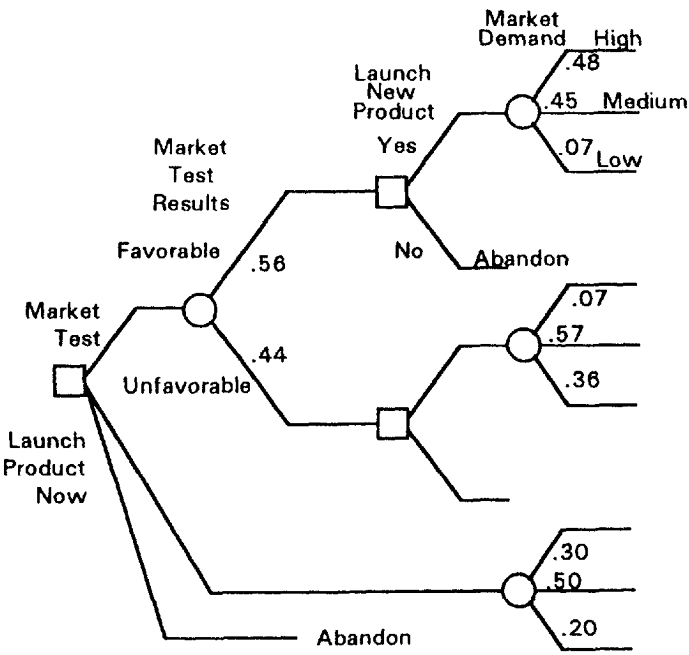

Figure 17 Value of information problem. Notice how the probabilities on the Market Demand outcomes shift depending upon the path taken from the Market Test Results chance node.

problem. If the prototype works, the company could immediately decide whether to launch or abandon the new product idea. Shown also is a third alternative, to first do market testing.

Market testing results are *symptoms* related to what actual Market Demand will result. Value of information problems usually involve acquiring information to learn about or to observe a symptom. A symptom seldom guarantees the outcome of the chance event of interest. However, the new information is useful in revising the probabilities for the various possible outcomes. In this case, Market Testing outcome is correlated to Market Demand. Once the market testing is completed, the results are used to revise the probabilities for the different Market Demand scenarios. The process of revising probabilities based upon new information is accomplished through an elegant but simple formula called *Bayes' theorem.*

VII. SUMMARY

Consistently making good decisions requires crafting and applying a logical decision policy. Investment decisions are straightforward. The financial evaluation process is usually much less sophisticated than the technical expertise involved in a project.

Performing evaluations with an appraisal perspective is a general problem-solving approach. It solves three types of problems: ranking alternative, appraising value, and optimizing. For decisions, appraise each alternative, then choose the best one. In optimizing, chose the combination of controllable variable values that maximizes EMV.

In deterministic analysis, PV is the best monetary value measure. For decision-making under uncertainty, the appropriate measure is EV PV, or EMV. Choosing the alternative having the highest EMV is the optimal decision policy for an objective of maximizing monetary value. This is the EMV decision rule. If primarily costs are involved, minimizing EV cost is equivalent to maximizing EMV.

While *the EMV decision rule is appropriate policy for most corporations*, some people modify it for these cases:

To maximize value under a capital constraint, choose investments in sequence of decreasing.

$$\text{Profitibility index} = \text{PI} = \frac{\text{EMV}}{\text{Investment}}$$

The denominator can be budget dollars or the measure of any other controlling constraint.

For a consistent risk policy, i.e., a consistently *conservative* attitude toward risk, use the expected utility (EU) decision rule instead. This is especially appropriate for important, personal decisions. Note that when the outcomes are small compared to the net worth of the decision maker (or entity), then the EMV and certainty equivalent (CE) are nearly identical.

When there are multiple objectives, first consider whether the nonmonetary objectives can be converted into monetary equivalents. If not, then devise a composite value function of several appropriate decision criteria.

A *good decision* is not the same as a *good outcome*. Decision quality is not defined by outcome quality. However, good outcomes are more likely if good decisions are being made. A *good decision* is defined as one that is logical and consistent with the preferences of the decision maker and all of the information available at the time.

The preceding definition is a liberating idea. We can tell *at the time of a decision* whether the best choice is being made. However, chance events, beyond our control by definition, determine the ultimate outcome. The decision maker should sleep well at night knowing that the choice resulting from a decision analysis is the best under the circumstances.

A good decision can be made with imperfect information. Most are, in fact. Good decisions can often be made with current knowledge. Understanding this frees one to move ahead, recognizing that procrastination is pointless. Delay and further analysis are often viable alternatives to be considered, but they should not be defaults.

The literate engineer understands EV and economic evaluation concepts. He or she routinely applies [17] decision analysis in making cost/benefit/risk assessments in his or her evaluation work. A company employing this engineer can be confident of prudent resource allocations made on the basis of credible analyses.

ENDNOTES

1. Decision analysis is based upon the centuries-old concept of *expected value*. It is foremost among the quantitative management sciences. A classic, and still very relevant, paper is:

   Hertz, David B., 1979, Risk Analysis in Capital Investment, *Harvard Business Review*, v. 57, n. 5, Sept.-Oct., p. 169–181. (an earlier version appeared in the Jan.-Feb., 1964, issue).

2. The author's logic is found in:

   Schuyler, John R., 1995, Rational is Practical: Better Evaluations through the Logic of Shareholder Value, prepared for Petroleum Engineers' Hydrocarbon Economics & Evaluation Symposium, *Proceedings*, March 27–29, Dallas, Texas, SPE no. 030066.

3. Two excellent texts on decision analysis:

Clemen, Robert T., 1966, *Making Hard Decisions: An Introduction to Decision Analysis*, 2nd ed., Duxbury Press, Boston, MA, 664 pp.

and

Goodwin, Paul, and George Wright, 1991, *Decision Analysis for Management Judgment*, John Wiley & Sons, 308 p.

Specific readings on utility, i.e., risk preference theory, are:

Hammond, John S., III, 1967, Better Decisions with Preference Theory, *Harvard Business Review*, Nov.-Dec. 1967, p. 123–145,

and

Swalm, Ralph O., 1966, Utility Theory - Insights into Risk Taking, *Harvard Business Review*, Nov.-Dec. 1966, p. 123–36.

4. An exceptional explanation of the use of PV and a ranking criterion are found in:

Seba, Richard D., 1987, The Only Investment Criterion You Will Ever Need, SPE paper 16310 presented at the 1987 SPE Hydrocarbon Economics and Evaluation Symposium held in Dallas.

Dr. Seba used the term, *discounted profit-to-investment ratio* [= PV/PV(investment)] in the article, instead of the now-favored label *discounted return on investment* (DROI or DCFROI). PV is a *screening criterion*, and those investments that pass are ordered using DROI as the *ranking criterion*.

5. The author's logic is presented in:

Schuyler, John R., 1993, Slaying the Capital Budget Constraint, presented at Society of Petroleum Engineers' Hydrocarbon Economics & Evaluation Symposium, *Proceedings*, March 29–30, Dallas, Texas, SPE no. 25842.

Setting a capital constraint is inconsistent with knowing the cost of capital. There is an important implication, also, that PV discount rates should be lower than commonly used.

6. A great and very readable book on multicriteria decision-making is:

Keeney, Ralph L., 1992, *Value-Focused Thinking: A Path to Creative Decisionmaking*, Harvard University Press, Cambridge, Massachusetts, 416 p.

7. The popular AHP technique is discussed *by its inventor* in:

Saaty, Thomas L., 1994, "How to Make a Decision: The Analytic Hierarchy Process," *Interfaces*, V. 24, n. 6, Nov.-Dec., pp. 19–43,

and somewhat less enthusiastically in:

Zahedi, Fatemeh, 1989, "The Analytic Hierarchy Process—A Survey of the Method and its Applications," *Interfaces*, v. 16, n. 4, July-August, p. 96–108.

Highly recommended: *Interfaces* is the leading journal communicating to managers about operations research (management science) applications. Most articles can be understood by nonmathematicians. *Interfaces* is available in most university libraries or from INFORMS: The Institute For Operations Research and the Management Sciences, 290 Westminster St., Providence, RI 02903.

8. Correlation is a measure of the degree of association between two variables. This ranges from −1 for perfectly anticorrelated to +1 for perfectly positively correlated. Zero correlation means there is no relationship between variables. Crystal Ball (see Endnote 9) uses *rank correlation* (i.e., the correlation between the rank of sorted variable values) to represent these relationships.

9. Monte Carlo sampling is straightforward and can be done with most programmable tools. However, the popular add-in spreadsheet tools provide excellent functionality and convenience. One such tool Crystal Ball®, a product of Decisioneering Corporation, 1526 Spruce Street, Suite 251, Boulder, CO 80302, phone (303) 534-1515, fax: 303-534-4818. The other popular add-in is @RISK (see Note 11).

10. The author expresses calculation result convergence using the *standard error of the mean*,

$$s_{\bar{x}} = \frac{s}{\sqrt{n}} \text{ in the example } s_{\bar{x}} = \frac{12{,}079}{\sqrt{10{,}000}} = 120.79$$

where s is the sample standard deviation and n is the number of data points (e.g., simulation trials).. This measures the uncertainty in the Monte Carlo approximation for the true solution EV. There is a 68% probability that the true solution EMV improvement (i.e., if an infinite number of trials were run) will be within the range \$1,520 ± 121.

11. With the author's appreciation to Mr. Devereux C. Josephs CMC, President, Corporate Consulting, Inc., who originated this deterministic spreadsheet model.
12. @Risk is a product of Palisade Corporation, 31 Decker Road, Newfield, New York 14867, phones: (800) 532-RISK and (607) 277-8000.
13. See Note 10. Here, the standard error is

$$s_{\bar{x}} = \frac{s = \$7.4 \text{ milllion}}{\sqrt{400}\ \textit{trials}} = \$0.37 \text{ million}$$

14. Unless the analyst chooses to place some benefits or cost values along branches inside the tree. This is an optional, and sometimes more appealing, way to construct the tree.
15. A simple explanation of decision trees may be read in:

    Schuyler, John R., 1993, Decision Analysis in Projects: Decision Trees, *PM Network*, v. 7, n. 7, July, pp. 31–34, monthly magazine of Project Management Institute, Webster, NC, installment no. 3 of the invited tutorial series.

16. Decision tree analysis to value an information-gathering alternative (in this case, inspecting a plant) is described in:

    Schuyler, John R., 1994, Decision Analysis in Projects: Value of Information, *PM Network*, October, v. 7, n. 10, pp. 19–23, monthly magazine of Project Management Institute, Webster, NC.

17. Evaluation professionalism and the decision analysis approach is further discussed in:

    Schuyler, John R., 1992, Credible Projections Now Require Decision Analysis, *Cost Engineering*, March, p. 15–19.

GLOSSARY

Analytic hierarchy process (AHP) A system for multicriteria decision-making where the task is to choose the best alternative with respect to a hierarchy of subobjectives or attributes. Subobjectives or attributes are weighted by making pairwise comparisons. Alternatives are also rated along each attribute by making pairwise comparisons.
Bayes' theorem A formula used to revise probabilities based on new information.
Bias A repeated or systematic distortion of a statistic, imbalanced about its mean.

Capital The amount of money or equivalents invested in a business. Tools of production. Capital projects, compared to expenses, are those investements which are *capitalized* (i.e., expensed across time through *depreciation*).
Cash flow Money entering or leaving the company treasury. Net cash flow is receipts net of cash expenses, including taxes paid and capital expenditures.
Certainty equivalent (CE) The amount, known with certainty, a decision maker would be just willing to exchange for an uncertain gamble. The difference between CE and EMV is the *risk premium* or *risk penalty*. This difference is attributed solely to the decision maker's attitude toward risk.
Cumulative frequency (or density or mass) function (c.d.f. or c.m.f.) Graph showing the probability that the parameter will exceed particular values. Computed as the integral of the probability density curve. There are two forms: Greater-than and less-than types, and both present equivalent information.
Decision analysis The discipline that helps decision makers choose wisely under uncertainty. The subject involves concepts borrowed from probability theory, statistics, psychology, finance, and operations research. Also called *decision science*.
Decision tree A graphical representation of expected value calculations, consisting of decision, chance, and terminal nodes connected by branches.
Deterministic Said of a model where all parameters are fixed, or "determinate."
Discount rate The "interest" rate used for present value discounting.
Discounted cash flow analysis Projecting a future cash flow stream and determining its present value.
Evaluation General term for any type of analysis used for asset appraisal, feasibility study, engineering evaluation, project assessment, and all other types of analyses related to decisions.
Expected monetary value (EMV) Expected value of a measurement expressed in monetary terms. Usually refers to the expected value of present value, EV PV.
Expected value (EV) Probability weighted average of all possible outcomes. When the outcomes are measured in monetary units, the term is usually called "expected monetary value" (EMV).
Inflation A rising general level of prices and wages in an economy, expressed as an annual percentage rate.
Mean The arithmetic average of possible outcomes or a set of observations. This is usually the best estimator for a chance event. Synonymous with expected value when referring to the mean of a *probability density function*.
Median The most central value of a population or sample set. Half of the other values lie above, and the other half below.
Mode The particular outcome that is most likely. This is the highest point on a probability density (or frequency) distribution curve. A curve with two localized maxima is called a "bimodal."

Model A simplified representation of a system of interest. Models for decision purposes usually represent a business enterprise or transaction and consist of (account) variables and mathematical formulas.
Monte Carlo simulation See *Simulation, Monte Carlo.*
Multicriteria decision making (MCDM) Using a value function comprised of several criteria reflecting multiple objectives.
Net cash flow (NCF) Cash flow from operations. Capital expenditures are deducted, but overhead, depreciation, interest, and taxes are not.
Objective (noun) The purpose of an organization. A goal.
Objective analysis One which is free from bias, requiring bias-free assessment inputs, objective value measure, and calculation integrity.
Objective or neutral risk attitude Describing a person or policy that is unwilling to pay (or require) a premium for uncertainty. The *certain equivalent* is exactly the *expected monetary value.*
Preference A decision maker's attitude about a particular aspect of the decision process. Preferences in decision policy can be conveniently grouped into three categories: objectives, time value of money, and risk attitude. These preferences are composites of the decision maker's beliefs and values.
Present value (PV) The sum of discounted cash flow values, usually net cash flows. The discount rate represents time preference of money.
Present worth (PW) Same as net present worth and *present value.*
Probability P(x) The likelihood of an event occurring. Synonyms: chance, likelihood, odds. The sum of the probabilities of all possible outcomes equals 1.
Probability density function (p.d.f.) The mathematical or graphical curve which represents a judgment about the likelihood of different outcomes from a chance event. The integral of a p.d.f. equals 1. Also called *probability distribution* and *probability function.*
Random number A number obtained from sampling a uniform distribution across the range of possible values, usually 0–1. A *table of random digits* serves the same purpose, except that the values are integers.
Random variable A symbol or measure of a chance event. Also called a *stochastic variable.*
Real dollars Dollars amounts adjusted, using an inflation index, to a particular point in time; noninflated dollars.
Risk The quality of a system that relates to the possibility of different outcomes. There are unknowns about conditions of nature and about how systems operate. Risk is generally synonymous with *uncertainty*. Informally, "risk" is used when:

The probabilities can be reasonably assessed.

There is a large, unfavorable potential outcome.

and "uncertainty" is used when:

The system giving risk to a probability distribution is poorly understood.
There is a restricted range of possible outcomes.

Risk penalty see *Risk premium*

Risk premium The amount of expected monetary value forsaken by using a value derived from a risk profile curve.

Risk Premium = EMV − Certain Equivalent

Sometimes called *risk penalty*. Risk premium is always positive.

Risk tolerance coefficient The parameter in an exponential utility function that encodes the decision maker's risk attitude.

Sampling (for Monte Carlo simulation) Obtaining a trial value of a probability distribution. With conventional Monte Carlo simulation, a random number between 0 and 1 is equated to the *y*-axis on a cumulative probability function. The corresponding value is extracted and used for the variable's trial value in the simulation run.

Sensitivity analysis An analysis to determine how variations in input values affect the outcome value.

Simulation To represent artificially. In the context of business analysis, to represent the essential features of a system in a model. The model is used to anticipate the behavior and performance of the system under assumed conditions.

Simulation, Monte Carlo A process for modeling the behavior of a probabilistic (stochastic) system. A sampling technique is used to obtain trial values for key uncertain model variables. By repeating the process for many trials, a frequency distribution is built up that approximates the true probability distribution for the system's output. This random sampling process, averaged over many trials, is effectively the same as integrating what is usually a very difficult or impossible equation.

Standard deviation (SD, σ, or s) Square root of the variance. The standard deviation is more meaningful because it has the same units as the quantity measured.

Stochastic An adjective meaning "probabilistic," "statistical," or "random."

Time value of money The concept that a dollar today is worth more than a dollar tomorrow. The relationship is reflected in the time preference of the decision maker. The *present value* concept and formulas are generally accepted to represent time value in the decision model's value function.

Utile (or Util) Arbitrary unit of measurement expressing value on a utility scale. The origin location is also arbitrary.

Utility A scale of value reflecting a *preference* of the decision maker. Represents value versus an *objective* measure, such as money. The *x*-axis (function argument) is in some directly measurable units, such as dollars. The *y*-axis origin and scale (expressed in utility units) are arbitrary.

Utility function A graphic or mathematical function relating value of various outcomes to the intrinsic value to a particular decision maker. Also called utility curve and risk preference curve. Utility value is measured in arbitrary units called "utiles."

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Cost Control Systems

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Cost control is an important part of total cost management. Whatever action we take, whatever we do or fail to do, there are costs involved. Due to the complex interrelationships between the many activities and responsibilities required to carry out project work, a systematic approach to project management is required. One aspect of this approach is cost management.

What is meant by *system*? A system is a series of programmed actions that lead to desired ends. It is the product of intelligence designed to save steps and work and money. A system provides a sense of direction, poise, and preparedness.

> A system is a plan for getting work done, under control, and by using data.

The essence of a *Total System Concept* is that a business exists to serve certain *objectives* and that the overall system (or interrelated factors of people, equipment, materials, and money) can be divided into subsystems having specific functions, which in turn can themselves be subdivided. A clear grasp of this concept gives a task-oriented view of problems and solutions, which is superior to attacking symptoms rather than causes (firefighting).

The earlier part of this chapter (through Section III) was adapted from *Cost Management of Capital Projects* (Heinze, 1996) and the rest from *Computerized Management of Multiple Small Projects* (Westney, 1992), both published by Marcel Dekker, Inc.

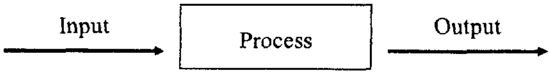


Figure 1 A fundamental open system.

Open systems have a continual input/output exchange with their environment. They may appear static in form, but this is in reality a "dynamic" stability. Open systems behave in an adaptive manner in line with "survival" objectives. Living organisms, social systems, and project environments are characteristically open systems. The fundamental representation of an open system is shown in Figure 1.

Systems thinking has permeated most branches of knowledge. It leads us to the thought that the nature of an entity is discovered not by study of its separate elements alone, but also by observing how these elements interact with each other and with the environment. The property by which open systems can adjust their inputs and processes (operations) while still achieving the same end-result is called equifinality. Equifinality is the essence of cost control. The project objective is achieved through flexibility when managing resources.

When systems are composed of multilevel subsystems and components, that interact in a logical arrangement; this is called a *hierarchy* of systems. The *work breakdown structure* is such a system.

Cost management on capital projects is a dynamic process. During the initial or concept stages of a construction project the expenditures are minimal, but at this time, the commitments for future expenditures are very crucial. Decisions made then have a large influence on cost prevention.

Further on, as we specify in more detail what goes into the plant and after we requisition some of the major equipment, commitments rise sharply. At the same time, the ability of cost management to reduce total cost diminishes. By the time a project task force is established, major design features have already been defined. Even though we are still at the very beginning of the expenditure curve, the cost prevention influence at this time is already reduced drastically in regard to total project cost (Figure 2). However, cost control requires control over our expenditures even beyond the end of the design period. We must, therefore, be acutely aware of cost flows and the means of establishing them.

We must know the portion already expended as well as the timing of future expenditure in relation to the planned program. This encompasses:

Predicting the final capital cost level at any point in time
Knowing the proper expenditure "path" to reach this level
Identifying the magnitude and causes for deviation from the planned cost flow

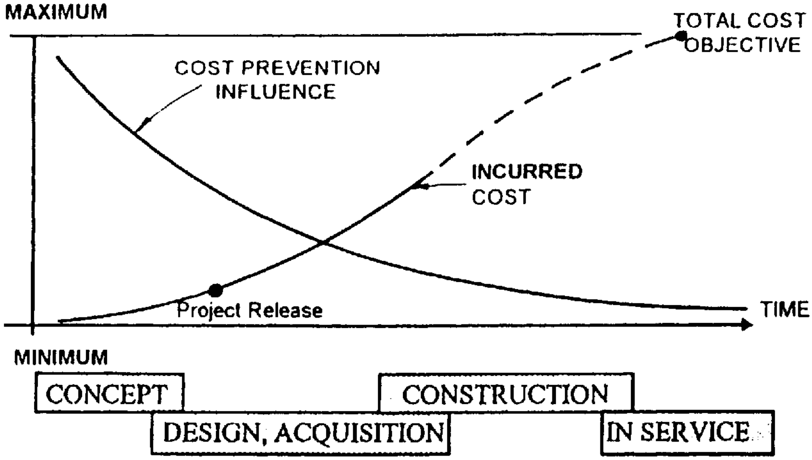


Figure 2 The influence of cost control versus time.

Costs must be known or be foreseen in sufficient time to enable remedial action to be taken if any variation from the target is observed. Controls must be effected *before* a commitment is made.

Many attempts have been made to establish standard action plans and procedures for a successful cost management. The diverse complexity and uniqueness of each type of project makes standard applications very difficult. There are, however, tools available that can greatly reduce project failures.

I. COST CONTROL PROCESSES

The elements of cost control follow a fairly simple sequence. Those elements, when applied to capital cost control become the Cost Control Cycle (Figure 3). Projects are under control only if four basic elements are under control:

Schedules are time scaled plans for the execution of a project.
Progress is the measure of headway made when carrying out these plans.
Budgets are a quantity of funds allocated for the performance of a specified amount of work.
Incurred cost deals with the measurement of the consumption of these funds.

Figure 4 compares the actual timing of activities with the predictions made in the approved schedule. It also compares the dollars spent with the budgeted amount if a cost flow is available. In some cases, progress is measured as percentage completion. The remaining work is then estimated and a new

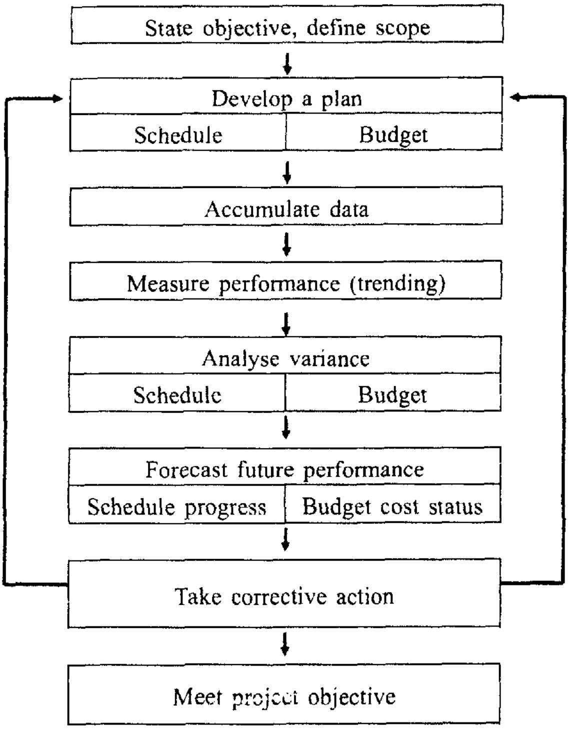


Figure 3 A multiple input control system with feed-back.

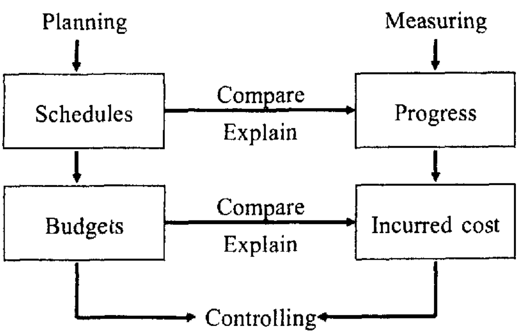


Figure 4 The four basic elements of cost control.

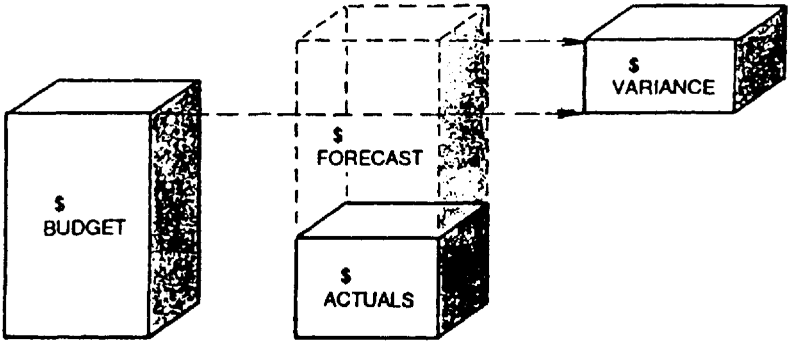


Figure 5 The variance is the difference between the original budget and the revised forecast.

forecast produced. The difference between the budget and the new forecast is the variance (Figure 5).

There can be two different variances:

Variance between actual cost and estimated cost at a specific point in time,
Variance between the approved total cost estimate or budget and the new forecast.

This is often referred to as *Conventional Cost Control.*

When costs run below the estimate, we have a favorable variance. This may be good news to the manager who has to explain budget variances to the owner. He should be advised, however, to check the physical progress on the job. The project may be behind schedule and expenditures are delayed.

If the project is run in a functional manner, the scheduling and costing functions are organizationally separated. It is therefore difficult to relate progress in time with the consumption of funds. This is a disadvantage of the conventional cost control.

A. Cost/Schedule Integration

It would be an ideal world if we could estimate cost on exactly the same basis as we produce schedules. This may be possible on smaller building projects or in the manufacturing industry where detailed networks are available before the work starts and where costs have been estimated by activities or pay items. However, the larger the project becomes, the more difficult it is to match expenditures with scheduled activities. During the earlier phases of a project the costs are estimated and monitored mainly by functional

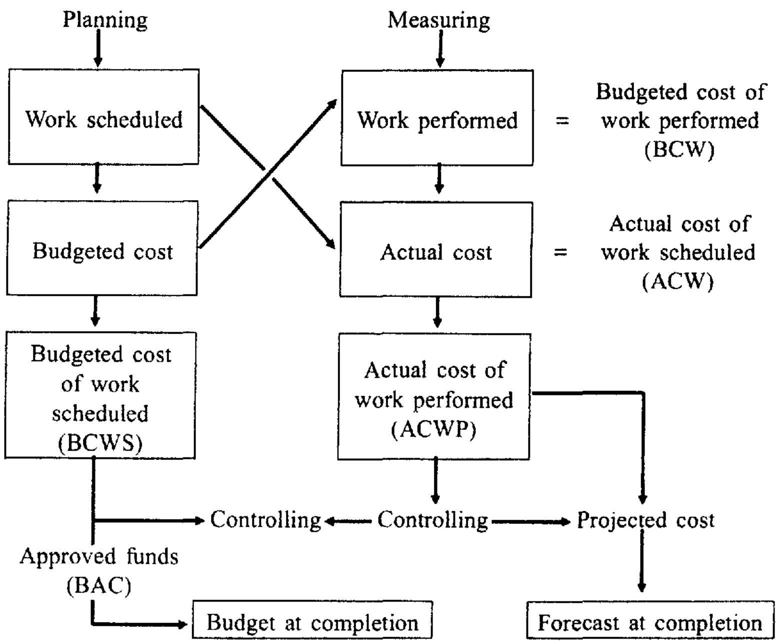


Figure 6 The earned value model; calculation of cost performance.

elements. The budget estimate is compared with the latest forecast. Under conventional cost control, budgets and schedules are not integrated.

A combination of optimistic forecasting and improper accounting usually produces an overly favorable view of final cost. Relating "planned" cost only to actual expenditures does not indicate how well a project is performing.

Progress measures physical quantities or workhours against the Project Schedule. If we measure this progress in relation to the dollar budget, we obtain the Budgeted Cost of Work Performed (BCWP). If we measure the consumption of funds (cost incurred) in relation to the schedule, we obtain the Actual Cost of Work Scheduled (ACWS). Both BCWP and ACWS can be calculated at any point in time (Figure 6).

The *earned value* concept integrates cost and schedule for measuring *overall* project performance. This system is somewhat more complicated than the systems used for a conventional budget process. Computerization, however, helps to deal with the additional data elements that are required.

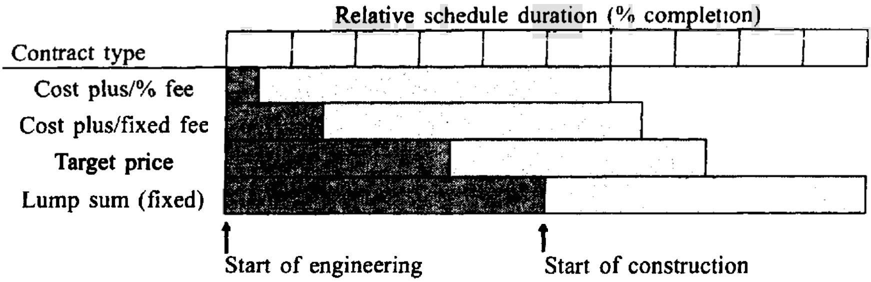


Figure 7 Affect of contract type on schedule duration.

■ = Engineering effort required before start of construction
□ = Duration of the construction phase

Those who are exposed to the earned value concept for the first time must not be intimidated by the many new expressions and acronyms. The basic fundamentals are relatively simple.

Major system acquisitions by governments and large corporations have resulted in the need for very detailed and formal instructions and documentation that are difficult to understand by the uninitiated. For example, cost/ schedule control systems criteria (C/SCSC) are working well for incentive-type government contracts with a high risk factor. But for most project managers a simple, broad-based application of the earned value concept; thus, comparing the *planned* value of the work against the *earned* value of the physical work accomplished and the *actual* cost incurred summarizes project cost performance.

B. Controlling Contract Cost

When an owner decides to contract he or she will already have identified the type of facility, required operational date, project life, reliability, and supporting facilities. The scope and sequence of work then forms the base for the preparation of the bid package.

The type of contract affects schedule duration for the start of construction and completion of the project. This is crucial in understanding the control of total project progress and cost (Figure 7).

What is the cost impact of controllable risks to the owner for two major contract types, the fixed price and the cost reimbursable?

Controllable risks	Fixed price	Reimbursable
Labor productivity	Low	High
Scope	High	Low
Indirect cost	Low	High
Construction quality	Medium	Medium
Safety	Medium	Medium
Schedule	High	High
Labor relations	Low	Low
Project management	Low	Low

Contractural arrangements can have a significant impact on cost. Owners can achieve cost savings through improved contracting techniques. The owner should match his objectives and resources with those of the contractor. Some owners use incentive clauses in an effort to achieve better contractor performance. Owners must be aware that most successful contracts have one fundamental characteristic in common: Thoughtful and meticulous preparation by the owner *before* the contract is let. Both parties should recognize each other's goals and capabilities. Good communication and mutual trust benefit both owner and contractor.

To reduce risk, an owner should only select contractors who can demonstrate that their procedures, systems, and personnel capabilities are adequate to control schedules, costs, and materials, and that they have a good quality assurance program.

The owner's concern about cost control is quite different from that of a contractor. It depends entirely on the type of contract what each ones involvement is. To satisfy the objectives of both owner and contractor, compromise is sometimes necessary.

The Fixed Price Contract

This contract (also called Stipulated Price and Lump Sum) is considered to be the best incentive for the contractor to control costs and thereby enhance productivity. However, the owner must accept the responsibility for providing a complete contract (scope, schedule, quality, site conditions). Because the contractor wants to cut cost and maximize profit, quality of work may not be his priority. It is in the owner's best interest to maintain some degree of influence through contract administration, inspection, and monitoring contract performance. Even though the owner wants to place as much cost responsibility on the contractor, there is a danger that an owner may also place inordinate liabilities on the contractor for certain risks over which the contractor has little control. Also, this type of contract often encourage claims for extras by the contractor.

Cost Plus Contract

Owners run the largest economic risk with a cost plus (cost-reimbursable) contract because they pay all of the contractor's allowable costs including tools, temporary facilities, home-office expenses, and profit or fee. Where the contractor is charged with engineering and materials management responsibilities, these can also be fully reimbursed by the owner, depending on the type of contract.

The contractor has more freedom to act, but the owner must make certain that the contractor adheres to his commitments. Performance measures and reporting procedures must be effectively implemented. This type of contract can offer a negative encouragement to contractors to be wasteful and inefficient if tight cost control is not maintained.

II. COST COLLECTING

To control cost, we must be able to make a valid comparison between the elements of the plan and corresponding elements of actual performance. *There is a difference between financial control and cost control.*

The financial statements produced by the accountant's bookkeeping procedures will not give a project manager the ability to judge the value of the progress made and thereby is not good enough for controlling purposes. Expenses must be recognized when incurred, whether or not paid in cash. The accounting done to meet that need is called *accrual accounting.*

Accrual accounting is based on recording the effect of transactions on financial condition and income when the transactions take place, not merely when they are settled in cash. Furthermore, from the standpoint of the purchaser buying services, the cost and liability should be recorded in step with performance (i.e. as the work progresses), as should the delivery of goods. There are a few exceptional types of costs, however, that are considered to relate to time periods and are accrued in the accounts according to the passage of time rather than in accordance with a performance test.

It is never an easy task to fully implement a system where accrual accounting is completely integrated with the cost control requirement of collecting incurred cost. Capital cost control requires that we are able to measure progress made and the related incurred cost at any point in time.

Financial statements deal with cash disbursements. Periodic statements of cash disbursements are called *cash flows.* They are essential for a corporation to plan project funding and regulate each month's cash drawdown. Interest charges to the project are based on cash flows, not cost flows.

The estimate is based on the schedule, which indicates when the work has to be performed and the timing of materials supplied and equipment delivered and installed.

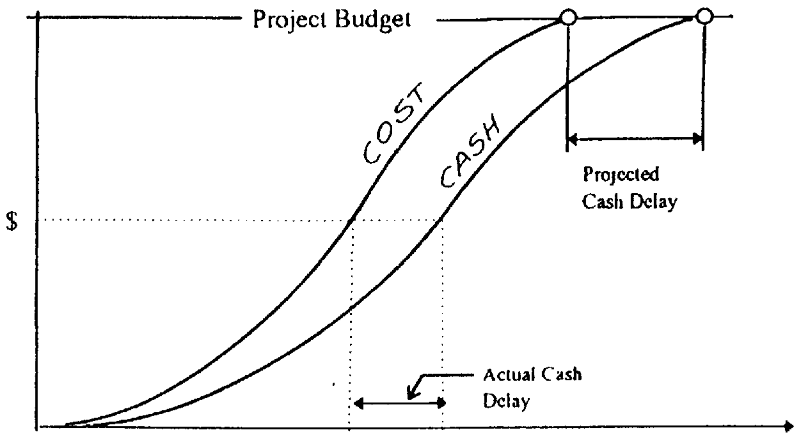


Figure 8 Project expenditure flows.

Project management monitors engineering and construction efforts as they relate to the plan. We must therefore devise a system that recognizes as much as possible the cost related to schedule dates and durations. In other words, we want to express in dollars the value of work done and equipment on site.

In summary, there are three basic types of project expenditures (Figure 8).

Cash flow needed to plan project funding, to set fiscal budgets, to calculate interest during the construction period are to evaluate tenders.

Cost flow identifies incurred cost, measures contract performance against the approved time phased plan, and is used for cost control.

Installed cost is the value of work constructed and is used to calculate insurance premiums.

The three expenditure flows are somewhat out of phase. The rate at which costs are incurred and ultimately funds are disbursed depends on the nature of expenditure. Cash flow delays such as late invoicing, payment approvals, escalation, and holdback recognition leave gaps between cost flows and cash flows.

III. DEFINITION OF PROJECT-CONTROL TERMINOLOGY

Before proceeding further with the techniques of project control, it is important to define our terms. Like most other aspects of project management and cost engineering, the terminology is often ill defined, and used inconsistently. The definitions shown below are those that the authors have found to work well in practice.

Physical progress A measure of the amount of work done to date, based solely on physical accomplishments, expressed as a percentage of the current total approved scope of work.

Work-hours spent The total direct work-hours that have been spent.

Productivity The ratio of planned work-hours to accomplish a given scope of work to the actual work-hours spent.

Learning curve The measurable tendency of the time required to perform a given task to decrease as the number of times the task is performed increases, until a maximum efficiency is reached.

Direct work-hours Work-hours that result in measurable physical progress.

Indirect work-hours Work-hours that are required to support the project activities, but that do not contribute to physical progress.

All-in hourly rate An "all-inclusive" cost per work-hour that includes some overhead and/or indirect as well as direct costs.

Committed cost The amount of money that should be set aside to cover the forecast final cost of all current purchase orders, contracts, and subcontracts associated with the project.

Cancellation cost The amount of cost that would be incurred if the project were cancelled and a fair settlement made on all current contracts.

Expenditure The amount of money that has actually been spent on the project, i.e., the total of all company outlays to cover project charges received to date.

Value of work done The total cost that would be incurred if all the work done to date were to be paid for according to contract.

Design change A change, initiated by the design function, which alters the specific way the design is executed. Design changes are experienced on virtually all projects, and provisions should be made for them in the plan and estimate.

Scope change A change to the basic specification of the project. A scope change adds facilities or capabilities that were not previously part of the project. Scope changes are generally not provided for in the plan and estimate nor covered by contingency. Note that a scope change to a contractor, increasing his assigned scope of work, may not be a scope change to the project.

Field change A change made in the field to facilitate construction. All projects experience field and startup changes, and these should be allowed for in the plan and budget.

Startup change A change made in the field to facilitate the startup or operation of the facilities.

Punch-list A list of small jobs that must be done before the unit is considered complete and ready for startup (also known as a "but-list").

Contingency rundown A systematic reduction of the contingency included in the cost forecast, to reflect the addition of changes and the reduction of uncertainties.

Cost and schedule forecast A prediction of the final cost and completion date of the project if present trends continue.

Trend curve A curve that plots project variables, such as progress and time, and, by using extrapolation and/or a standard curve shape (such as an S curve) can predict the final result.

"S" curve A standard curve describing project variables over the project's life.

IV. TRACKING CURVES: A USEFUL TOOL

A. Tracking Curves: A Good Shortcut Approach

A tracking curve is the means by which we can show:

The variations between planned and actual performance
The forecasted final result, if nothing is done to correct current variations

Tracking curves have the additional advantages of being easy to prepare and graphical in their presentation, so that a great deal of useful information is conveyed quickly. They are, therefore, a very useful tool for multiple small projects in which simplicity and time are of utmost importance.

B. What Is a Tracking Curve?

The purpose of a tracking curve is to represent, graphically, the variation in performance to date from the planned performance. By "tracking" performance to date, the curve also permits extrapolation to forecast the final results if present trends continue. The basic elements of a tracking curve are shown in Figure 9, and are described as follows.

The Dependent Variable

The dependent variable, drawn on the y-axis, is the project-control variable whose performance and trends we wish to monitor, forecast, and control. Typical project-control parameters include:

Physical progress (i.e., % complete)
Work-hours expended
Cost of work done
Productivity
Unit costs
Hourly costs

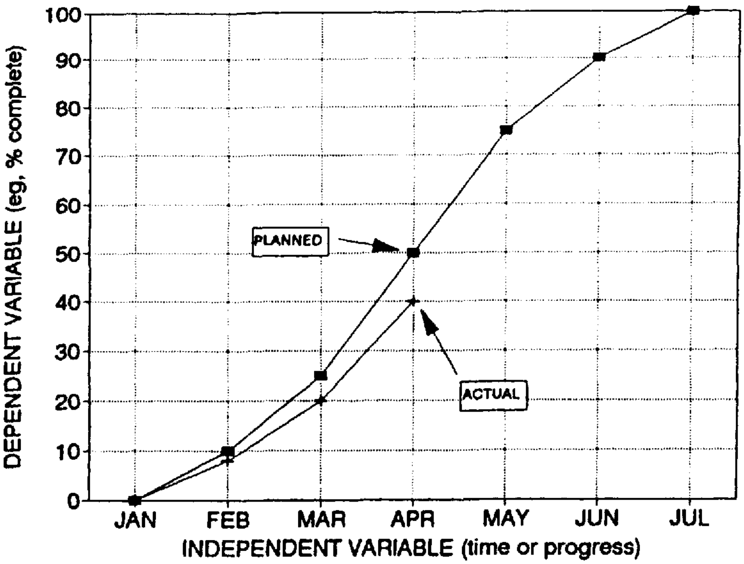


Figure 9 Elements of a tracking curve.

Number and cost of changes

The Independent Variable

The independent variable, drawn on the x-axis, describes that projectcontrol parameter that we wish to use as a measure of "where the project is." The two most common independent variables are:

Time (i.e., days, weeks, months, or dates)
Progress (i.e., physical % complete)

The Reference Curve

The reference curve, often referred to as the S curve, describes the relationship between the dependent and independent variables that has been anticipated by our project model. It might show:

The rate at which we expect to make progress (i.e., the % complete per month)
The rate at which we expect to expend work-hours or costs

The reference curve often takes the form of an "S" on large projects because large projects often experience first a period of accelerating progress, then a steady-state rate of progress, and finally a decelerated rate of progress.

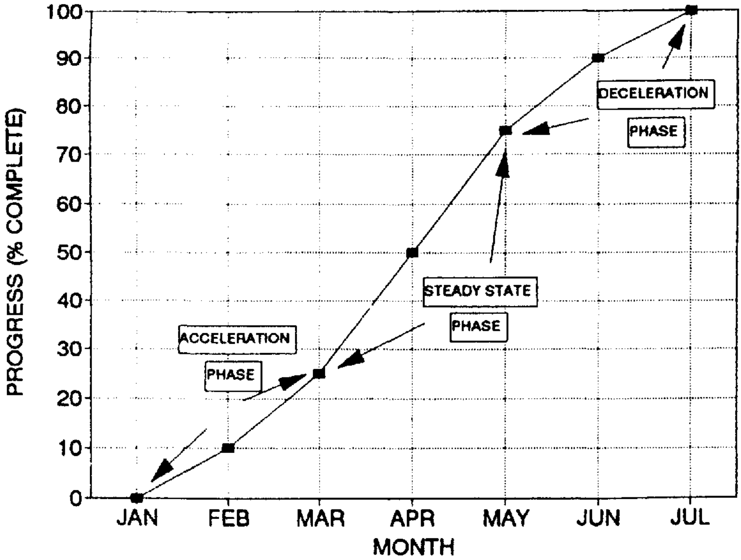


Figure 10 S curve for a large project.

This is illustrated by Figure 10, which shows the stages of construction on a large project, and is described as follows.

1. In the *acceleration stage*, civil work predominates. Site clearance, excavation for foundations and underground lines, installation of temporary construction facilities, and construction of foundations all occur during this phase. The rate of progress is often limited, because the other craft operations (mechanical and electrical work, ironwork, etc.) cannot begin until the preliminary civilwork is almost complete, and there is a limit on just how quickly that work can be progressed. The number of people on the job usually builds up during this stage.
2. In the *steady-state stage*, all crafts are able to work on the job. The number of people reaches a peak during this stage, and remains relatively constant. The rate of progress also reaches a peak and remains relatively constant as well.
3. In the *deceleration stage*, the work of the major crafts is essentially complete, and the number of people is reduced accordingly. The rate at which progress is made also, of course, decreases. The type of work done during this stage (painting, insulation, startup changes, "punch list" items, etc.) also does not appear to contribute much to measurable physical progress.

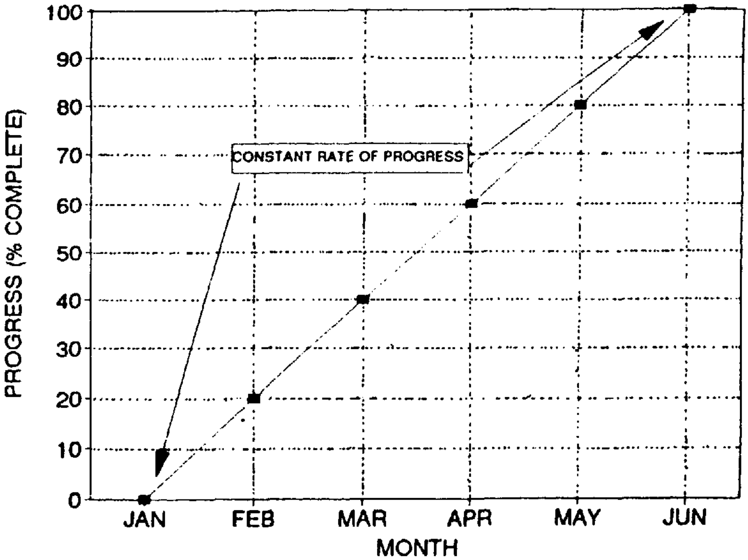


Figure 11 S curve for a small project.

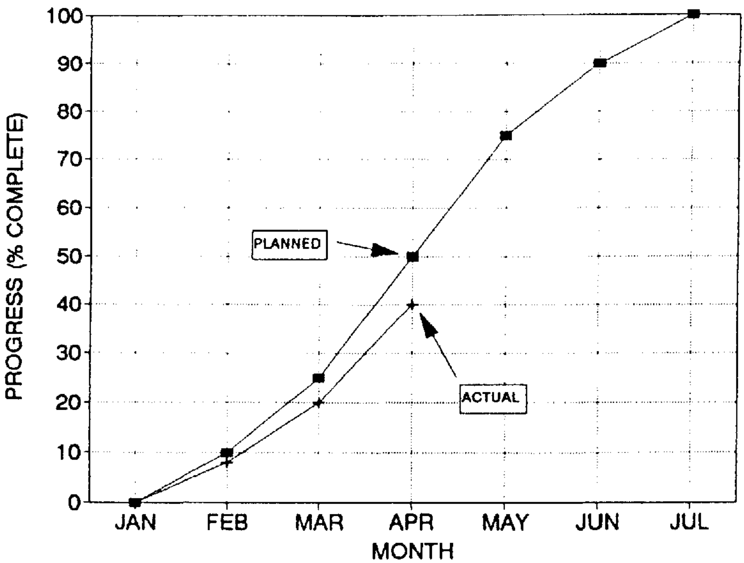
But what of the small project? What shape does its reference curve take? For a small project, it is important to recognize that *the reference curve will not necessarily be an S curve.* The small project may not require all the various crafts or have a period of manpower buildup or rundown. In fact, many small projects, such as turnarounds or other maintenance operations, have a constant number of people from start to finish (see Figure 11).

Tracking-Curve Format

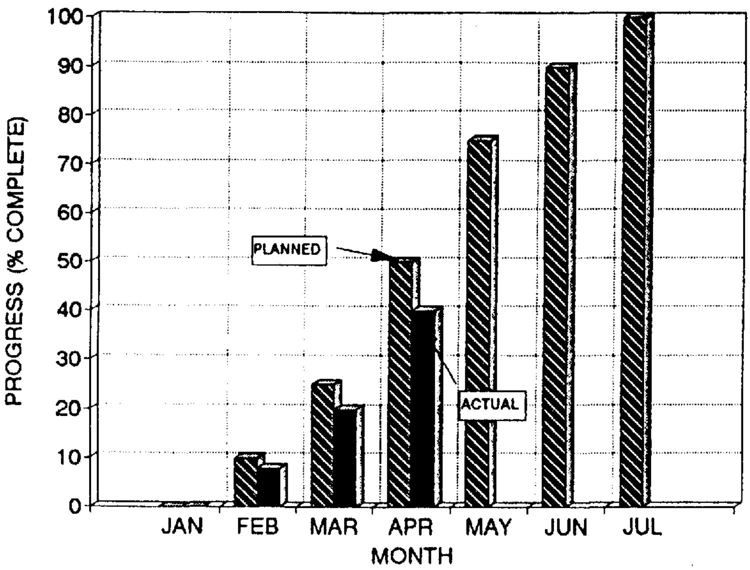
There are several different formats available for tracking curves, the selection of which depends on the type of variables being used, the preference of the user, and any computer hardware or software limitations that might apply. The different configurations are illustrated in Figure 6, and are described as follows.

Cumulative This illustrates the cumulative (i.e., up to-date) value of the dependent variable (see Figure 12). For example, the dependent variable might be "percent complete earned to-date." This type of curve is usually continuous.

Incremental This illustrates the incremental (i.e., for-the-period) value of the dependent variable. For example, the dependent variable might be "percent complete earned this week." This type of format is usually shown as a histogram.



(a)



(b)

Figure 12 (a) Cumulative progress curve for a small project. (b) Progress curve in histogram format.

Combined This kind of tracking curve combines both the cumulative and incremental types on one curve. For those who are used to seeing such curves, this format can be quite useful. However, most other people find it somewhat confusing.

Differential This tracks the deviation of the dependent variable from a reference value (see Figure 8b). The deviation is usually considered to be acceptable if it is within predetermined limits. Trends that indicate that the final value will be outside the limits are a signal that a problem is developing.

C. Setting Up Tracking Curves

Step 1: Select the Dependent Variables to be Controlled

Each company, and often each project, has certain project-control variables that are particularly important. Typical variables are shown in "The Dependent Variable," earlier in this chapter.

Step 2: Select the Independent Variables

Typical variables are shown in "The Independent Variable," earlier in this chapter.

Step 3: Select the Format to Be Used

See "What is a Tracking Curve?" earlier in this chapter.

Step 4: Draw the Reference Curve

It is evident that the successful use of a tracking curve depends on the reference curve's being well thought-out and realistic. If it is not, the variations between planned and actual values will be useless as a tool for forecasting or control. Many users of tracking curves draw the reference curve by using judgements or standard curve shapes (such as the "S"). For small projects, this is unsatisfactory.

The project model provides the basis of the reference curve. Because it defines the work to be done, the resources required, and the direct workhours to be expended in each segment of time, it can be used to derive the reference curves for direct work-hours vs. time, physical progress vs. time, total work-hours vs. time, expenditures vs. time, etc. The progress vs. time curve can then be used to plot other variables against progress.

In deriving the reference curve of progress vs. time from the project model, we can assume that the productivity is constant with time, or that it varies in a predetermined way. Many companies involved in large projects use a productivity trend curve that assumes lower-than-average productivity during

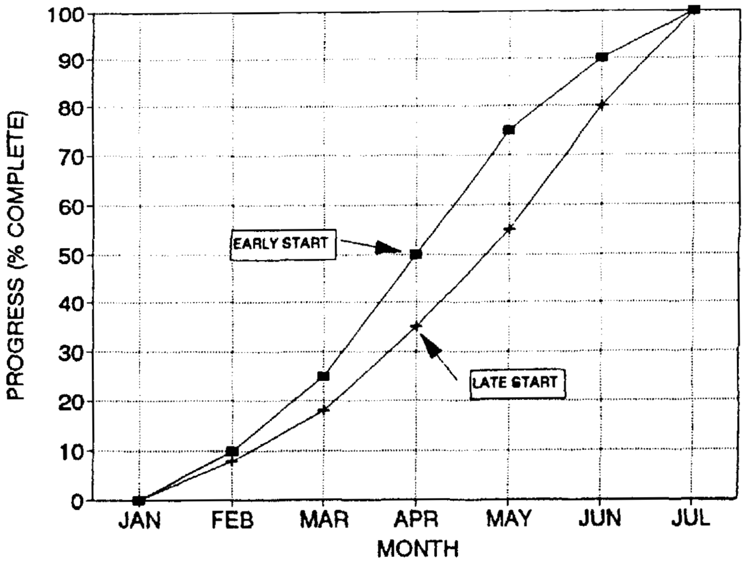


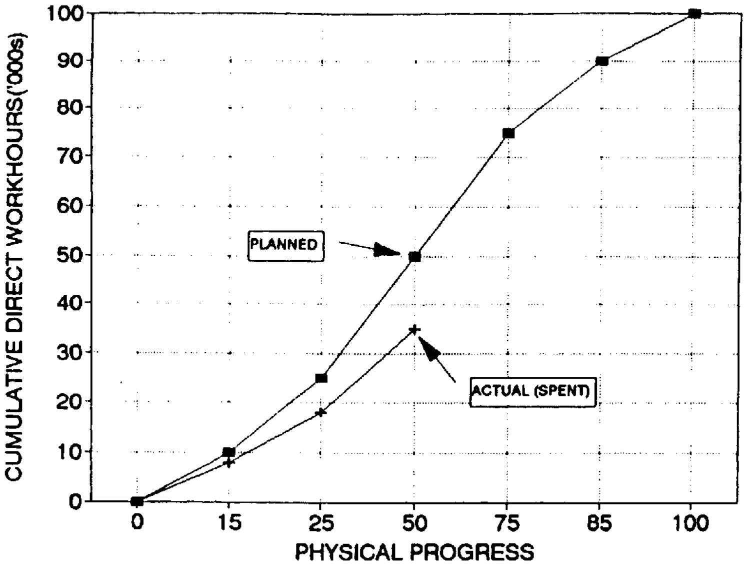
Figure 13 Cumulative progress curve showing start-date variations.

the acceleration and deceleration stages, due to "learning curve" and other effects. However, since small projects, in general, do not have a significant acceleration or deceleration stage, the planned productivity can generally be assumed to be constant. Physical progress will then be achieved over time at the same rate at which the direct work-hours are expended.

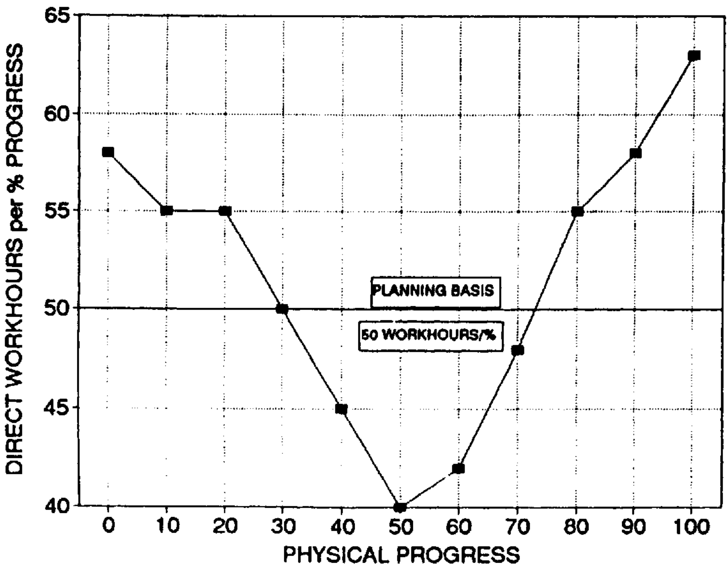
Noncritical activities in the project can be scheduled as if they will start on their earlystart date, their late-start date, or at some time in between. Whatever assumption is made will, of course, affect the planned progress curve: if all activities start on their early-start date, progress will be made more quickly than if they start later. Interestingly, although it is rare for all activities on a project to start on the early-start date, many projects are scheduled as if they will. As a result, progress then seems to lag behind schedule. It is very useful, therefore, to construct progress curves in which the progress for both early-start and late-start assumptions are shown. The actual progress will, hopefully, fall between these two extremes. An example of such a curve is provided in Figure 13 which shows both an early-start and late-start schedule.

Sample Tracking Curves

Figure 14 shows some sample tracking curves of the cumulative, incremented, and differential type.



(a)



(b)

Figure 14 (a) Cumulative work-hours as a function of physical progress. (b) Direct work-hours spent per % of physical progress.

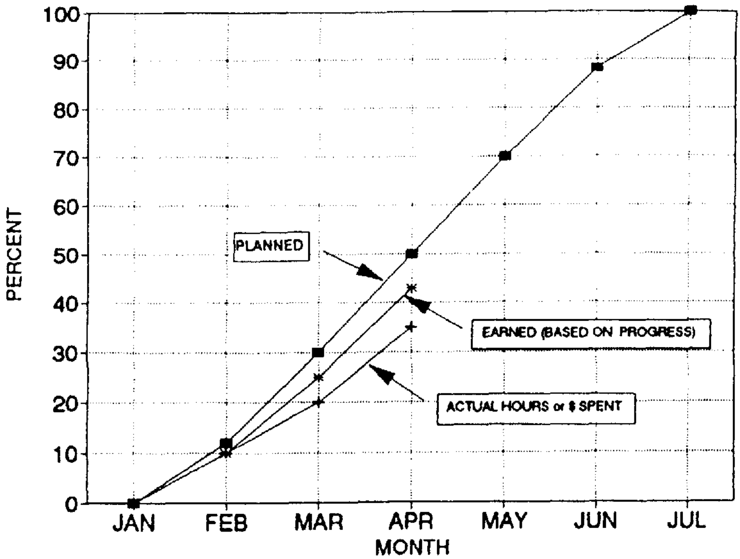


Figure 14 (c) Direct work-hours vs. planned work-hours vs. earned work-hours.

D. Using the Tracking Curve for Forecasting and Control

Identifying Variances in Work to Date

The key to effective control lies, to a great extent, in the process of data analysis. Given that we have captured data that represents what is actually happening on the project, we must now use that data to figure out:

What has happened up to now
What is going to happen if things continue as they are now
What problems might be causing things to go wrong
What corrective action might be taken to avoid or correct those problems

This information is then presented in management reports, with the intention that management (that is, whoever has the appropriate authority) take the necessary action.

To answer these questions using tracking curves, it is often helpful to look al two or more tracking curves together. For example:

If: Progress is below planned progress to date
  Work-hours are below planned work-hours to date

Control variable	Ahead	On target	Behind
Physical progress			
Direct hours spent			
Scope of work			
Productivity			
Availability of resources			
Material			
Labor			
Equipment			
Facilities			
Drawings			
Milestones achieved			
External factor impact			

Figure 15 Project-control checklist.

We might conclude that inadequate manpower resulted in lack of progress

If: Progress is below planned progress to date
  Work-hours are per plan

We might conclude that productivity is below expectations

In fact, there are many combinations of project-control variations, and each one can tell a very different story. In analyzing project data, the project engineer often has to be a detective, using the data as "clues" that when taken together, form a picture of what is really going on.

Checklists are a good way to find our way through the maze of project data. We can begin by using a checklist such as that shown on Figure 15. The checklist shows that we should generally look at the project-control variables, in the sequence shown, ask whether each control parameter is the same as, greater than, or less than planned. The parameters are as follows:

Progress (i.e., physical % complete): Is progress ahead of schedule, on schedule, or behind schedule?

Work-hours (i.e., work-hours spent to date to achieve the given progress): Are the work-hours spent above, equal to, or below the planned work-hours?

Scope of work (i.e., quantities done to date and left to do): Is the quantity of work done to date greater-than, equal to, or less than the planned scope of work? Is the total quantity of work in the project greater than, equal to, or less than that which was planned?

Productivity (i.e., ratio of planned to actual work-hours): Is productivity greater than, equal to, or less than planned?
Resource availability (e.g., materials, labor, equipment): Has labor been supplied to the job in the quantities and disciplines as planned? Has material been provided on schedule? Have approved drawings been provided on schedule? Has the necessary equipment been provided as planned? Have overhead staff and facilities been provided as planned?
Schedule milestones Have major schedule milestones to date been met?
External factors (e.g., weather, strikes): Have external factors had any influence on the project to date? Are external factors expected to influence the work left to do?

To determine the current status of our project, then, we need to look at the answer to each question individually, and also all the questions together. The tracking curves should be designed to help a project leader complete that process quickly, by helping to identify patterns of information.

Forecasting Future Performance

Cost and schedule forecasting is one area of project control in which the philosophy and judgement of the individuals and organizations involved can have a major impact. Some companies and individuals prefer to forecast that the final cost and schedule will be identical to the budget plan, in the hope that any delays or overruns that are currently foreseen will be offset by future lucky breaks. This tendency to cover-up potential overruns or delays has the effect of reducing project-control effectiveness since problems requiring corrective action are not highlighted.

There is also a natural tendency to avoid criticism and punishment. The dilemma of project leaders is often that if they forecast a delay or overrun, there is sure to be trouble right away, but if they report that the project is on schedule and budget, they might (or might not) get into trouble later, if and when the overrun or delay actually occurs.

If a cost or schedule forecast is to be effective as a project control device, it should be defined as follows:

> This cost (or schedule) forecast represents the final actual cost (or schedule) that will be experienced *if no action is taken to correct the problems or adverse trends identified to date.*

In other words, the forecast is not what we think will actually happen, it is what we think will actually happen if no corrections are made. Therefore, a tracking curve can be used to extrapolate data trends to forecast what the curve of actual data will look like. The extrapolation is usually based on:

1. The variations defined by the plot of actual data to date (e.g., progress per month is 75% of the planned progress rate)
2. The shape of the reference curve (e.g., an S curve)
3. The slope of the trend curve through the actual data (e.g., a "flatter" slope)

Tracking curves are a useful way to assure that the possibility of delays and/or cost overruns cannot be easily hidden. The data points reflecting actual performance will generally follow one of several patterns, as described in the following:

No Significant Deviation from the Plan. In this case, we have good grounds for forecasting that the dependent variable will follow the reference curve and that the project will finish on time and within the budget.

Clear Adverse Trend. When actual data points show a clear adverse trend, such as progress being consistently below expectations, it is a clear signal that a delay and/or overrun can be expected if nothing is done. We can expect that the actual values of the dependent variable will follow the shape of the reference curve, but that the slope will reflect the trend established to date. So, for example, if we are a week behind schedule because we are making less progress than planned each week, the cumulative effect is that we will be much more than a week late at the end of the job.

Clear Favorable Trend. If the actual data indicates a clear positive trend, it may indicate that a cost underrun or schedule improvement is possible. However, such favorable results should be reported only at such time as the reason for the favorable results to date can be identified, and it can be expected that the favorable trend will continue.

Scattered Data with no Clear Trend. Tracking-curve data often shows a degree of scatter that is clearly beyond the expected variation. Not only does such data make it impossible to predict trends and make forecasts, but it indicates a lack of credibility in the project-control methods and data. If such data is experienced, it almost certainly indicates that something is wrong with the data collection and analysis method. One frequent problem area is in the definition of terms. For example, it may be that indirect work-hours are being reported as direct, or the progress-measurement system may contain some anomalies. In any case, the problem should be identified and rectified.

It should be noted that some project-control variables, such as productivity, may well experience a scatter pattern, and not exhibit a clear trend.

V. THE IMPORTANCE OF PROGRESS MEASUREMENT

Project control depends, to a very great extent, on the effectiveness of the methods used to measure and report progress and performance. Even on small projects, a progress-measurement method is essential as it defines "where we are" such that we can compare that with "where we planned to be," and thereby identify areas needing attention.

Small projects, because of their size and other aspects of the smallproject environment, often experience ineffective project control because of the lack of progress measurement. Proper progress measurement is often thought to be simply too much time and effort for the small project, but this need not be the case. A progress-measurement method can be defined once, and then implemented uniformly on all small projects. In this chapter we explore the basic principles of the Earned Value method of progress measurement, and then discuss various shortcut techniques that can be applied.

VI. PRINCIPLES OF PROGRESS MEASUREMENT

A. Elements of an Effective Progress-Measurement Method

An effective progress-measurement method should do or be the following:

Provide a measure of the physical quantities of work done
Provide a measure of the current total scope of work of the project
Express the work done as a percentage of the total current scope of work
Be unbiased (i.e., it should not be significantly affected by optimism or pessimism)
Be realistic (i.e., it should reflect the many hard-to-measure items of work that, individually, may be small but which, collectively, contribute significantly to the scope of work)
Be agreed upon (by those whose performance is being measured and by those who are doing the measuring)
Be fair (to those who are doing the work and to those who are paying for it)
Be efficient (i.e., it should not require excessive time to collect, analyze, and present data)
Be well documented (to assure consistency)
Be independent of actual work-hours and costs (i.e., it should measure actual physical work done without regard to the number of workhours spent)

B. Basic Steps in Progress Measurement

The basic steps that are required to set up and implement a progress-measurement method are described below. Each step will be illustrated in "The Earned Value Method of Progress Measurement," later in this chapter.

Step 1: Divide Scope of Work into Packages for Control

Most project-management techniques are based on breaking a project down into components or packages of work, the idea being that each package of work be well-defined and appropriately sized to the level of the person or company handling it. Often a "work package" is assigned to a specific individual, organization, function, or contractor. Examples of work packages are:

An activity on a network plan
A work package in a "work breakdown structure"
A contract or subcontract
A "work order," "task-sheet," or "job-card"
A variation to a contract
The work of one craft or discipline
A specified quantity of work
The work in a given geographical area
The work covered by a certain code in the code of accounts

For progress measurement, it doesn't really matter what form the work packages take, so long as *the total amount of work in all packages equals the total scope of work of the project.* Naturally, it is preferable that progress be measured against network activities so that the progress to date can be used as the basis for a schedule forecast, but this is not essential. Note that activities should be "definable, assignable and significant" in order to facilitate effective progress measurement.

The scope of work may actually be divided several times until sufficient detail is reached. The work packages should also be compatible with the way work-hours are collected, to facilitate productivity measurements.

Step 2: Establish the Standard Work Unit

If progress in diverse activities is to be measured and then aggregated, it is helpful to have a unit of measure that can be applied to any activity, regardless of the type of work being done. For example, we could not add progress in the form of cubic yards of concrete poured to progress in the form of linear feet of electrical cable installed, yet we would like to be able to calculate the net progress for both civil and electrical work. To do so, we define a standard work unit with which all progress can be expressed. The most frequently used standard work unit is the "planned work-hour." This is the basis of the "earned-value" system of progress measurement that will be described later in this chapter. The advantage of the planned work-hour approach is that earned work-hours (based on physical progress) can be easily compared with actual work-hours to give an indication of productivity. In many cases, costs are used instead of work-hours.

Step 3: Define the "Yardstick" for Measuring Progress

This step consists of defining, *in advance*, what amount of work or achievement of milestones constitutes what % complete. This can be done by judgement, experience, or by an allocation of estimated work-hours. It consists of identifying the physical results of the direct labor in the project, as well as the milestones or steps required to complete the work on each item. The yardstick is the key to the "earned value" method.

Step 4: Define the Method for Aggregating Progress

This step consists of defining the means by which progress in one category will be added to progress in other categories to arrive at the overall % complete.

Step 5: Define Who Will Measure Progress, and How Often

The individuals or functions who will actually do the progress measurement should be defined as part of the procedure. It should be clearly understood who will do the measuring, what data will be required, how often it will be required, who will collect and analyze the data, to whom it will be presented, etc.

Step 6: Agree on the Progress-Measurement Method Prior to the Start of Work

Progress measurement is a combination of numerical analysis and judgement. Because the individual or organization whose performance is being measured must, in general, provide much of the information necessary to measure performance, it is evident that good cooperation and communication is essential if the system is to work. For this reason, it is important that the method for measuring progress be agreed upon prior to the start of work. Both those being measured and those doing the measuring must agree that the method for measuring progress is fair.

VII. COST FORECASTING AND CONTROL

What is "cost control"? To some it is the recording and analysis of cost data such as timesheets, purchase orders, and invoices. Such data is historical, and, as such, it makes an essential contribution to cost control. However, no one can control anything solely by concentrating on what has already happened. We will refer to cost control in the context of the things we do to affect the current and future activities of the project, and, hence, the final outcome.

We cannot control costs, but we can control the things that happen on a project to determine its cost. We can assure that the cost impact of the various decisions that are made is recognized as part of the decisionmaking process. We can assure that unnecessary costs are not incurred due to poor productivity, schedule slippage, inefficient allocation of labor resources, unnecessary design or field changes, and so forth. We can, finally, assure that we have a well thought out and documented planning and cost basis for use in tracking and controlling the project, as well as the appropriate methods, systems, and procedures. In fact, all the material presented so far has to do with cost control.

Cost control, then, consists primarily of assuring that the project is managed with full recognition of the cost impact of everything that is done, and everything that happens. In this section we will review some basic principles and aspects of cost control.

A. Analyzing Variations to the Estimate Basis

The estimate basis can be thought of as a "tripod," the three "legs" of which are the design basis, the planning basis, and the cost basis. The basis, therefore, describes what is to be built, how it is to be built, and the pricing levels that are anticipated. All variations between the actual costs and the estimate can be explained in terms of variations to this estimate basis. Reconciliations are used as control devices in which the variations to the estimate basis are identified and costs attached to them to explain the differences between actual, estimated, and forecast costs.

One aspect of cost control, then, consists of periodic reviews of the project as it progresses, and the comparison of these reviews with the estimate basis. We might use a checklist for such reviews (Table 1). As we review each item we should ask: "How does the way the project is actually progressing differ from the assumptions made in the estimate basis? If there is a difference, what is the cost effect likely to be?"

Tracking curves (discussed previously) are a useful way to monitor trends and identify variances. Some additional sample tracking curves are shown in Figure 16. These computer-generated curves show information presented in cumulative and histogram formats. Extrapolations from the tracking curves can be used for cost forecasting.

Table 1 Cost Control Review Checklist

The design basis
Specification of overall performance (e.g., capacity, performance characteristics)
Overall scope of work
Type and extent of design changes
Type and extent of field and startup changes
How late in the project design changes are made
Work-hours spent in design work
Extraordinary technical problems identified
Timeliness and effectiveness of design reviews
The planning basis
Schedule duration
Milestone dates
Contracting plan
Purchasing plan
Activity constraints
Use of shift work and overtime
Manpower density
Progress relative to reference schedule
Labor productivity
Engineering productivity
Availability of materials
Availability of labor
Availability of construction equipment
Availability of drawings
The cost basis
Prevailing escalation rates
Average hourly costs for engineering
Average hourly costs for labor
Average unit costs for materials (e.g., dollars per ton of piping)
Quantities of materials
Number and cost of changes
Contingency required
Indirect costs as a percentage of direct costs
Bulk materials as a percentage of equipment costs
Cost to achieve 1% physical progress

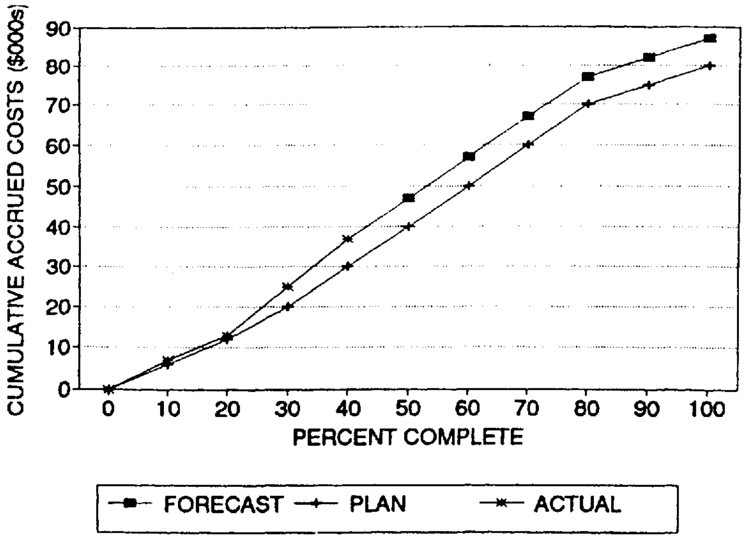


Figure 16 Cost tracking and forecasting. Cumulative cost vs. percent complete.

B. Cost Forecasting

The same rules of forecasting that were described in "Basic Principles of Forecasting and Control" earlier in this chapter also apply to costs. A cost forecast should reflect the expected final cost if things continue as they have been, and nothing is done to correct negative trends. If we are using an integrated cost-schedule-resources project model, the "current model" represents design changes approved to date, the "forecast model" represents what is expected to happen, while the "static model" represents the budget plan and the estimate basis.

In cost forecasting, it is important to distinguish between factors affecting the project that are controllable and those that cannot be controlled or corrected. These might be called "external" or "internal" factors, depending on whether they impact the project from an external cause (and therefore are not subject to the control of the project leader), or whether they are internal to the project. For example, escalation rates cannot be controlled, although it may be possible to take some steps to minimize their impact. Design changes, on the other hand, can be controlled. Labor productivity may or may not be controllable, depending on whether it is determined primarily by market conditions (and is therefore external), multiple-project resource allocation problems (internal), site conditions (internal) or contractor performance (internal).

The net cost impact of the external, uncontrollable factors establishes a minimum level for the cost forecast.

In general, cost forecasts are made by using the project model to calculate the value of work done, and forecast the cost of the work remaining. A forecast can also be made by updating the estimate basis for productivity, wage rates, etc., and recalculating the entire estimate. A key point about cost forecasts is that they are a matter of judgement, and the forecaster should feel free to make the forecast according to his best analysis and judgement.

C. Control of Changes

One of the most frequent causes of cost overruns is changes. This is most unfortunate because changes are generally an internal, controllable factor. Therefore, one of the most important things that can be done to effect cost control is to establish proper control over changes.

Definition of a "Change"

What is a "change?" Many spirited discussions have taken place over just that question, particularly when contract terms cause large sums of money to ride on the answer. We can define a change as follows:

A "change" is a specific work assignment which would not ordinarily be assumed to be required to complete the original scope of work. A change may also be an instruction to perform a specific work assignment in a different way from the way which was previously defined.

Changes are normally made to improve the performance, operability, maintainability, safety, or cost of the facilities.

Note that this definition excludes "design development" work from the category of changes. As design work progresses and the design is defined in increasing detail, alternative approaches to various design problems are studied, and a number of revisions to the work already done normally occur. This is a normal process, and these minor revisions are not generally considered changes, even if they are initiated by the client in the course of normal reviews. If, however, an instruction is given to do the work in a different way than might normally be assumed, or to do an item of work not normally required to complete the original scope of work, then that instruction requires a change to be approved.

Now that we have defined the basic concept of a change, we can define the different types of change (see also "Definition of Project-Control Terminology").

Design change A change made during the phase of the project which modifies work already done or adds work not normally assumed to be required to complete the original scope of work. A design change is initiated by the design function.

Scope change An increase or decrease to the original scope of work. This generally means a change to the overall specification or objectives of the project (e.g., capacity, facilities installed, acres of land, etc.) or to a contractually-defined scope.

Field change A change initiated in the field to facilitate construction

Startup change A change made to facilitate or simplify the startup of the facilities. Also, a change made during the startup phase of the project.

Control of Changes

Most engineers have a tendency to change things; always, of course, to make them better. Changes are inevitable on a project and they are often initiated faster than we can keep track of them. Unfortunately, once changes get out of control, our cost-control work becomes ineffective because we can no longer analyze variances since we cannot distinguish those variances caused by changes from those caused by other factors.

Changes are often difficult to estimate as their cost impact tends to have a "ripple effect." A change that seems to affect one department may have a larger effect than anticipated. For example, suppose the horsepower rating of a pump is increased. In addition to the pump costing more, its driver will cost more too. The pump and driver will weigh more, possibly resulting in increased weight and cost of structural steel and foundation. The piping from the higher-power pump will likely be of a higher flange rating, resulting again in more weight and cost for the piping and its supporting steel and foundations. Similarly, the electrical cables to the pump will be larger and heavier, as will the switchgear and other electrical equipment. Additional work-hours will be required in the field to install this heavier equipment and materials, and additional work-hours required to revise the design. As a result, the engineer who suggested a change to the higher-tap pump, which might cost $5000 more, is often shocked to find that the net cost impact is $50,000 when all the costs are accounted for.

The timing of a change also has an effect on its cost. As seen in Figure 17, a change made early in the design phase, when everything is on paper and is still preliminary, will have the minimum cost. As the design progresses, more drawings in more departments must be changed to accommodate the same design change. Finally, after construction has begun, the change might involve removal or modification of construction work already done, and that involves the highest cost.

The essential elements of a change control system are:

The ability to identify changes as they occur

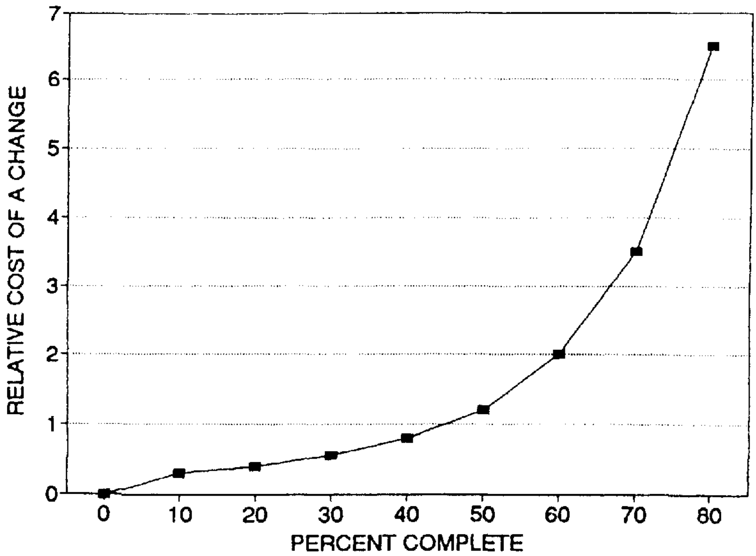


Figure 17 Cost of a change vs. time.

The ability to prepare quick estimates of the cost impact of each change
The requirement that a manager or project engineer with responsibility for the budget approve changes only when the cost impact is known.

To create such a system, we need formal procedures and a quick estimating method. It is also helpful to define the various stages *of* a change, so that they can be tracked through each stage.

Potential change A change that is still in the idea stage, but which is likely to be initiated.
Pending change A change for which approval is sought but has not yet been obtained. A change is pending during the time that the design details are worked out and the estimate prepared.
Approved change A change for which the design and estimate have been approved. Approved changes are usually included in the "current control estimate," and are offset by reductions in contingency.

Cost Reporting

In general, cost reports should have the basic elements provided in the example shown in Figure 18:

Cost category	Budget ($ 000)	Approved changes ($ 000)	Current estimate ($ 000)	Forecast final cost ($ 000)	Variance $	Variance %
Direct costs						
Design	100	5	105	110	5	4.8
Materials	175	7	182	190	8	4.4
Labor	200	17	217	245	28	12.9
Total directs	475	29	504	545	41	8.1
Indirect costs						
Temporary facilitles	50	2	52	55	31	5.8
Supervision	150	3	153	145	–8	–5.2
Home office	75	4	79	85	6	7.6
Equipment	90	6	96	99	3	3.1
Subtotal indirects	365	15	380	384	4	1.1
Total base estimate	840	44	684	929	45	5.1
Pending changes						
Contingency	130	–35	95	90	–5	–5.3
Total	970	9	979	1019	40	4.1

Figure 18 Typical cost report format.

Cost category This groups costs into categories for control.
Budget estimate The budget for the project (the "static" model).
Approved changes Shows the total approved changes to date.
Current control estimate This is the budget estimate plus approved changes, and is the "current model."
Current cost forecast This is the value of work done plus cost of work to go, and is the "forecast model."
Variance This is the current forecast—current control estimate.

Note that the current cost forecast includes provision for pending changes as well as for contingency to cover the uncertainties surrounding the remaining work. Attached to the cost report might be a list of approved, pending, and potential changes, tracking curves as appropriate, a written analysis of cost trends, and a reconciliation to the previous forecast as well as to the budget.

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16

Controlling Engineering Costs

Sylvester C. Myers S. C. Myers & Associates, Inc., Washington, DC

Engineering costs are an important part of budget control, since engineering is a significant percentage of project cost, and it is usually the cost category that is expended first. Control of engineering costs requires a control estimate against which actual costs can be tracked, compared, and forecast.

I. PREPARING THE BUDGET ESTIMATE

Controlling engineering costs should be the first element developed in the planning stage of any major project. This is the time when the engineers will be working very closely with the planning team and all the players that offer input at this stage of the project. When the planners develop the preliminary plans for the project, they may conduct a site survey, to determine how the logistics are going to be implemented. It is important to determine what type of raw materials are needed and available in the area of the project. In doing so, the cost survey can be conducted and a report developed on raw or other materials that will be used in the project. That information should be filed with the team plan for the project.

You can impact the costs at the beginning of the planning stage if you know exactly where you are going, what is in the vicinity of the project location, what can be purchased locally, and types of plants in the area (concrete, block, batch, carpentry shops, steel, rebars, structural steel, other types of suppliers) etc. The budget costs will simply be the costs that the client/owner will appropriate for this project. It's very important to have a budget that one can live with, and one that is controllable by the type of report that has been established. The report can become a vehicle for getting the budget estimate off to a positive start and serve as a guideline in establishing the client's position for the costs. The budget estimate is one that will include every element of cost that should be included in the project. This estimate will include the design costs, construction costs, and all of the consultants whose services will be contributed to this project. The budget cost estimate will take into account any contingencies, and the unknowns of the project.

It is a good idea at this stage to meet with the owner and have an in-depth planning meeting, to give a report of the cost survey and to determine the availability of materials and certain plants in the vicinity of the project. In addition, there should be an in-depth labor study conducted for this project. The budget should be as realistic and carefully thought out as other estimates that may be prepared at this time. By providing a basis for cost control from the very start of a project, a good budget estimate can help assure smooth-sailing pricing out of the project from design/concept to bidding the job, awarding the contract to a contractor, and estimating any change orders to the contract.

II. PREPARING THE DESIGN CONCEPT ESTIMATE

The design concept estimate is the first step of implementing formal engineering cost control for a project. The design concept can be expressed in many different ways. It can be: (1) a written scope, (2) an oral scope, or (3) sketches of an architect's or engineer's idea of the design of the project. It is an early stage of getting a basic floor plan, or geographical map showing the location of the project. It would not consist of more than a half dozen drawings and at the least one or two. It can be very rough, and can reveal to the engineers what the scope will be. At this stage, the engineer may extract information from the budget estimate and include it in the design concept of the estimate. At this stage you have already completed the preliminary survey of costs, labor and other factors for the project. It does not take into consideration what is coming into the next stage of the design.

III. PREPARING THE SCHEMATIC ESTIMATE

Schematic estimates are based on schematics that will be in the form of a floor plan, or geographical plan showing site location. Information is still preliminary, with a bare minimum of project description, such as the footprint of the building area/site, along with schematics of major elements. If it is a site plan, it may show the contours and the geographical location of the project, the egress and ingress of roads, and utility and power lines from which the project may benefit. The schematic estimate, in all probability, will be controlled by square footage, or lump sum costs.

As the design is being developed, engineers will continue to control costs by comparing actual and forecast values of engineering workhours and costs against the current estimate.

IV. 35% OF THE DESIGN COMPLETED

At thirty-five percent completion of the design work, there will be more detailed information from the designer and the support team. At this stage, engineers may start utilizing information that was determined in the cost survey. They will know, exactly, what the wage rates should be for a given area. If they are going to use unit costing, or unit pricing in the estimate, they can start building this into controlling the costs. They may start using subcontractors, such as mechanical and electrical—often the largest subcontracts. The engineers may also go out to vendors for cost information, such as for special equipment. The 35% estimate is going to develop into a volume document with more information based on the design to date.

Based on this information—the status of the design, hours and costs expended and forecast, and more refined planning information—the control estimate for engineering can be updated.

V. 65% OF THE DESIGN COMPLETED

A majority of the plans and specifications are available at this stage. Engineers will have extensive design volumes and quantities, making detailed cost control practical. Everything should be controlled. The use of historical data to compare with actual and forecast performance is recommended.

VI. 90% OF THE DESIGN COMPLETED

At this stage, every element of cost should be well-defined, and the effectiveness and efficiency of the cost estimate should be apparent. The cost control efforts will flow down from what the engineers started during the planning stage in gathering the reports from cost surveys, labor market studies, planning budget, design/concept, to schematics at 35%, 65%, and 90% estimate levels. The 90% estimate should reflect what was in the original budget, and fall within 2–5% of the bidder's estimate, with minor adjustments. If all the preparations were made in the proper format during the planning stage, engineers should be looking at very few changes at the 90% level.

VII. FINAL BID DOCUMENT

At this stage, the design is finalized. The estimate is going to be prepared to establish the owner's position for the bidding of the project. This cost estimate which has been controlled continuously during the planning stage is going to be a vehicle from which the contractor will bid the job. The final bid is used as a guideline to analyze the contractor's bids. It incorporates all the performance and other bond costs to reflect the budget estimate. If it is a government job, the cost engineers want to make sure that the owner's cost position is governed by the FAR (Federal Acquisition Requisition). This will measure the bid, give the owner some idea of what he is going to get for his money, and reconfirm that the approved contractor is thinking on the same level as the cost engineer who prepared the owner's final bid document for the project.

There are some elements that should be included in the bid document and the final design. There are special costs in the specifications of the contract that are in the general provisions; namely, the CPM Network Analysis System. This is a very important factor, as far as schedule and cost control are concerned, because these documents will be loaded with time and cost elements. This is the cost control that will be utilized throughout the contract to determine the contractor's performance of the project. Engineers should ensure that all of the elements in the general provision of the contract, which impact the cost of the project, are included in the contract. An evaluation of all of these elements, the plans and specifications in all of these provisions, will be analyzed for selecting the contractor.

Engineers started controlling engineering costs at the very beginning of the planning stage of a project. They conducted cost surveys with the planning team. They visited the site where the project would be constructed. They conducted studies of the availability of laborers in the area. They studied the skilled and unskilled labor factors. They looked at the logistics of how this project would be handled, and utilized all of this information through budget costs, design concept costs, schematic costs, 35–65–90% costs of the design, and the final design costs for the bid document. In doing so, they started the project management life cycle at the planning stage.

Now the designers have successfully completed the final design. The client has issued solicitations to bid the project. Reviews have been conducted and the selection of the contractor is underway by using the construction estimated cost developed for the owner by the engineer. The client is going to award the contract based on the bidder's fair and reasonable cost. In awarding the contract, the cost engineer and the contractor included all of the elements that were cost-impacted by plans, specifications, and the provisions (special, general and others) of the contract. Engineers have had a handle on all the costs for a typical project from the beginning to the actual award of the contract. Now the client is getting ready to take another step by awarding the contract and keeping the cost controlled, transitioning from the design stage, and monitoring the contract costs throughout the duration of the contract. Engineers will need to have a good relationship with the contractor so they know exactly what the costs will be, if any, for change orders, and to ensure that the owner is going to get his/her money's worth from the contractor's bid. They will monitor the costs of the contract once the contractor initiates work on the contract, monitor any change orders, and use the project manager's life cycle costing. It is important to have the contractor submit a preliminary CPM as-planned schedule loaded with time and costs.

VIII. CONTROLLING DIRECT COSTS

In order for a project to succeed, one must have good planning and cost control. This includes costs, risks, changes, client desires, politics, style, performance, and duration. However, good planning and cost control will not assure the success of a project. The basic element of controlling engineering costs will be direct, indirect, and overhead costs. Direct costs are labor, materials, equipment, services, and fees directly chargeable to accomplishing project objectives.

Direct costs will range between 60–80% of project costs. These costs are 90% historical and factual, and 10% unknown. The 10% unknown costs may be tracked by research and studies of similar type projects. For example, labor costs may be established by records from published union and nonunion wage standards, including all fringe benefits that are compiled for hourly wage costs. Productivity is another factor which is derived to make up total labor costs from (1) time and motion studies conducted by the cost engineers, and (2) records of similar type projects used by contractors and government agencies. Material costs are those that are comprised of tangible products supplied by vendors, contractors, and dealers. These costs include escalation factors that are priced at the midway point of the actual construction. This is done in order to incorporate all of the costs for materials during the construction period of any given project. Equipment is made up of ownership and operating costs. The ownership cost is that which is appropriated for the life of the equipment on a project. For example, if the life of a D9 Dozer is ten years, and it would be used on a project for three years, and the original cost is $100,000, the ownership cost allotted for the three years would be $30,000 for the project.

The operating cost would be computed on an hourly rate as the Dozer would actually be used on the project. The operating cost would include filters, oil and gas (fog), and insurance. The productivity of the equipment can be based on historical data or time and motion studies conducted by cost engineers.

IX. INDIRECT COSTS

Indirect costs consist of direct salary and other fully assigned costs (benefits, paid absences, supervision, and nonproductive time) for professionals, technicians, coordinators, project managers, clerical, training, and other personnel needed for a project. Profit is also an indirect cost. The indirect costs are tracked from previous projects by the cost engineer and derived from the project organization's structure. The project manager and the comptroller are valuable resources for determining indirect costs for any project.

X. OVERHEAD COSTS

Overhead costs are derived from audit reports, contractors, and expenses; namely, office space, leased property and equipment, insurance, supplies, utilities, including telephone, travel, etc. Home office costs are considered part of the overhead and consist of personnel that are directly involved in any project in which the home office is engaged for any project.

For example, if there is a $1 million cost for five projects, the home office cost would be one-fifth, or $200,000 each. If the home office cost is 15% of the $200,000, the home office cost would be $30,000 appropriated for the duration of the project.

XI. WORKING TIME VS. ELAPSED TIME

Working time takes into account holidays, weekends, lunch breaks, and the like. For most American organizations, the work week is comprised of five 8-hour billable work days (resulting in a 40-hour work week). Elapsed time refers to actual time, and ignores such things as lunch breaks and weekends. For example, paint will dry regardless of whether it is a weekday or weekend. In calculating the time it will take to complete a task, it will make a big difference whether you look at working or elapsed time.

XII. STRATEGY FOR CONTROLLING ENGINEERING COSTS

Focus on Controllable Costs: Expenditures that can be directly tracked and managed.
Obtain Timely Information: Assure that cost information will be regularly available, and produced in time to gauge financial status before cost, schedule, and performance objectives of projects are impacted.
Control Implementation Expense: Use budgets as the principal tool for controlling implementation expenses—budgets are aimed at keeping projects efficient.

XIII. THE PROJECT BUDGET "LIFE CYCLE"

"Top-down" estimates of the project focus on thorough analysis by project managers.

Estimates may be submitted to customers with proposals.
Estimates may also be prepared after contract is signed.

Detailed "bottom-up" estimates are subsequently prepared, and converted for a time-phased project budget, which is used to control project implementation. This project budget is:

Used as the baseline for tracking and reporting project progress
Reviewed when considering modifications to the project plan
Updated when the project plan is modified—"upscoped" or "downscoped"
The basis for the Final Budget Report, which compares final budgeted costs with actual costs

XIV. KEY CONCEPTS

Budget A plan of expenditures of hours and units of material, expressed in financial terms.
Project budget A project financial plan that is related to a calendar scale to enable expenditures to be made on a time-phased basis.
Costs Expenses for materials, personnel, and services utilized to implement a project according to its proposed and/or contracted specifications.
Cost variance The budgeted cost of work minus the actual cost of work performed.

XV. SOME IMPORTANT CONSIDERATIONS

1. Budgets are only estimates, based upon a set of assumptions and collected data.
2. Budgets must be based only on the current approved scope and specifications of the project.
3. Budgets must be changed when the scope of the project changes significantly (rule of thumb ±5%).
4. Budgets need to be changed when the schedule changes to reflect latest costs or changes in resources, materials or services availability.

XVI. REASONS FOR BUDGETING

To evaluate a project's estimated costs before authorizing its implementation
To provide a basis for tracking and managing project expenditures
To establish a managerial baseline against which to measure actual expenditures
To provide the project manager with a tool for evaluating routine project decisions

XVII. COSTING DEFINITIONS

Incremental cost Related directly to each specific project based on decisions on staffing, contracting, scope, and site of each project.
Average cost A mathematically constructed value that "represents" the total cost for a large population of projects, divided by the number of projects (used for planning and estimating, not for managing a specific scope of work).
Direct costs Labor, materials, equipment, services, and fees directly chargeable to accomplishing project objectives.
Variable cost A level and type of cost that changes according to the amount and nature of work performed.
Expense A charge incurred when a bill or invoice is processed or work time is reported against the project's authorized job codes.
Contingency A reserve established by the project manager to pay for unplanned costs or less than optimal performance due to unforeseen circumstances.

XVIII. INCREMENTAL COST ELEMENTS

Direct labor expense Direct salary and other fully assigned costs (benefits, paid absences, supervision, and nonproductive time) for professionals, technicians, coordinators, project managers, clerical, training, and other personnel needed for a project. A separate budget needs to be set up for each functional organization represented in the project.

Contract labor expense Direct salary and other costs and fees charged by outside contractors hired to perform services relating to implementing projects, including site preparation, wiring and cabling, professional services, etc.
Material Any materials associated with the organization's projects, including wiring, cabling, conduit, software, documents, etc.
Equipment Any equipment used as a part of system or services, furnished by customers or acquired by purchase or lease.
Extraordinary services expense For supplementary special equipment, tools, test equipment, storage charges, special handling, and transportation charges or project-related incidental expenses.
Fees for permits and licenses These include building permits and special licenses to conduct business activities.
Overtime Premium charges for employee or contractor labor efforts beyond regularly scheduled working hours or days
Travel Any transportation costs, rentals, common carrier charges, and related per diem and subsistence expenses
Special training requirements Unique training for gaining skills on third-party equipment, facilities, or software
Project management incidental expenses Costs associated with running a project office and supporting a project team, including copiers, data, telecommunications, tolls, parking charges, meeting/meal expenses, team recognition activities/awards, etc.

XIX. BUDGET DEVELOPMENT METHODS AND CRITERIA

The preceding sections described in general terms the various types of engineering cost control estimates and their use. We will now explore the process by which these control estimates are prepared.

A. Two Phases

1. Preliminary Budget: This is the top-down cost estimate prepared by the project manager at the start of a project or included in a proposal.
2. Finalized Project Budget: This is the detailed, bottom-up estimate that has the "buy-in" commitment of functional organizations involved in its implementation.

B. Criteria for an Effective Engineering Control Estimate

1. It is related to the project's work breakdown structure.

2. It provides separate budgeting of work categories, e.g., wire, terminals, etc., are separately budgeted.
3. It provides budgeting by site—each physical project site location has a separate budget, e.g., Building A, Building B, North Campus, West Campus.
4. It provides budgeting by phase—work category, by location, by due date, or by milestone; e.g., site preparation, Building A budget, 4th floor gray wire installation.
5. Rule of thumb—for effective control, budget time units should not exceed 2 weeks.

XX. PURPOSES

A. Preliminary Budget

1. Helps the project manager understand contract requirements and the project's scope and magnitude in terms of costs, before funds are actually expended.
2. Serves as a reference point for evaluating and measuring the credibility of the finalized project budget.

B. Finalized Project Budget

1. Determines the total cost of the project in terms of resource hours and dollars for each work package (by functional task level—work done by functional units identified by WBS task).
2. Establishes a reference point to evaluate and measure performance of the overall project and various functional units working on the project.

XXI. PRELIMINARY BUDGET (COST ESTIMATE) DEVELOPMENT PROCESS

1. Review the RFP, prime contract, and all related contract terms and conditions.
2. Define project scope and identify functional work categories.
3. Determine standard work times for all products and services, if available, and convert these to work hours and dollars for this specific work scope.
4. Estimate systems integration work hours, and convert to dollars.
5. Estimate user training requirements; convert to expense dollars.
6. Review subcontracting requirements; estimate costs.
7. Estimate managerial, clerical, and extraordinary expenses.
8. Estimate building construction costs for site preparation activities.
9. Total all estimated expenses.

XXII. FINALIZED BUDGET DEVELOPMENT PROCESS

1. Develop the project work breakdown structure (WBS).
2. Estimate the work hours of effort needed to complete each functional work item (work package task), generated by the WBS.
3. Discuss/negotiate realistic work-hour estimates (resource requirements, hourly rates, task durations) with functional unit managers.
4. Calculate the total cost of each functional work item/activity using the formula:

Work package cost =

$$\frac{\text{Functional work hours by category} \times \text{Loaded labor rate}}{\text{Productivity}}$$

5. Analyze managerial, clerical, and extraordinary expense estimates for accuracy, including training, contract services, overtime, software support, etc.
6. Assign managerial, clerical, and extraordinary expense estimates to each WBS work item (task/activity) by direct allocation or by pro-ration (if the expense is common).
7. Prepare a time-phased distribution of the finalized project budget estimate based on work-item schedules, start, finish, resource work hours, productivity, and expense allocations.

XXIII. TIME-PHASED DISTRIBUTION OF THE BUDGET

1. Distribute planned expenses by time period, once overall hours, dollars, and resources are agreed on by the project manager and functional managers.
2. Basis: When work actually will be done and billed or charged; when labor hours are reported.
3. Know when the functional activity is due to start.
4. Know when the activity is scheduled to be completed.
5. Estimate the work hours to be applied each, day, week, or month, by:
   Number and type of resource
   Productivity factor
6. Determine managerial, clerical, and extraordinary expenses to be attributed to each functional activity.
7. Assess which common managerial, clerical, and extraordinary expenses need to be pro-rated across functional activities as overhead, and when the expenses will begin and end.

XXIV. USING THE BUDGET FOR COST CONTROL

Engineering costs are dirven by just a few factors:

The quantity of deliverables required (e.g., number of drawings)
The type and complexity of the deliverables
The normal work hours required to produce each type of deliverable (e.g., man-hours per drawing of a certain type)
The productivity (e.g., is the work being perfomed using more of fewer manhours than expected for this type of drawing?)
The all-inclusive hourly rate (e.g., $/man-hour for this discipline)
The hours and costs for "level-of-effort" activities (These are activities, such as technical supervision or clerical, that do not produce a deliverable)
The associated costs of engineering (e.g., reproduction, computer use, travel)

Control of engineering costs requires that a control budget be established, and both actual and forecast costs be tracked against it. Each of the above variables can be tracked for use in analysis and forecasting. Engineering activities represent not only a significant portion of total project cost, but also the greatest opportunity to minimize and control total cost.

REFERENCE

1. *Project Management Scheduling & Cost Control Educational Service Institute,* The George Washington University, Washington, D.C. 1992, pp. 8–13.

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Controlling the Cost of Engineered Equipment

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I. INTRODUCTION

This chapter combines techniques from previous chapters, and explains how to apply them to control costs associated with engineered equipment. This chapter is intended to build upon Chapter 15, the cost control process and methodology, and Chapter 4, estimating engineered equipment costs. It is assumed that you already have a cost control model in mind, and that you have an idea of how engineered equipment costs have been established.

The project life cycle for engineered equipment includes eight distinct phases as well as three overarching methodologies that should be applied to the project throughout its life cycle. The phases and methodologies are shown in the following list:

Phases

- Feasibility/preliminary planning
- Conceptual design
- Materials management
- Detailed design

- Preinstallation
- Execution
- Debug, startup, and acceptance
- Life cycle costs

Methodologies

- Material management/supplier interface
- Value engineering
- Change management

There are control techniques that work best in each phase. The combination of control techniques throughout the equipment life cycle will provide you with a thorough and well-documented approach to optimizing costs. You can be assured that if you follow the approach outlined in this chapter, you will be well on the way to successful cost control.

A. Definition of Engineered Equipment

For purposes of this chapter, engineered equipment is any piece of equipment that must be either manufactured or developed, or customized either by you as a customer, or by a vendor or supplier for a particular application at your firm. Engineered equipment can be found in any industry including process, manufacturing, pharmaceutical, chemical, nuclear, environmental, transportation, power, health care, and others. This chapter is intentionally generic so that the ideas presented can be applied to engineered equipment in any industry.

Engineered equipment includes components in all disciplines including piping, mechanical, electrical, civil, and chemical. It can also be of any type including computers, industrial machines, pumps, robots, conveyors, etc. Generally, engineered equipment must be designed to meet specific customer requirements. Engineered equipment excludes off-the-shelf, commercially available equipment that might meet customer requirements without the additional phases described above.

For this chapter we assume that engineered equipment is costly, has long-lead times, is technically complex, has stringent tolerances, includes technological development (i.e., is an upgrade from the existing way the customer performs some function), is being provided by an outside supplier, and is required within a tight schedule. These assumptions form a kind of worst-case scenario in order that as many topics as possible may be covered. In fact, you may not need to use all the ideas presented here.

A "fitness-for-use" strategy dictates that you should use only what you need to use to get the job done. In short, do not apply so many of these ideas that your control efforts become counterproductive, or cost more than they are worth. The cost of cost control is an issue that should be addressed early during the project life cycle. Your project team should set limits for the amount of time, level-of-detail, and cost you feel is reasonable for controlling costs of engineered equipment. There are standards for reasonable cost ranges for the administration of engineered equipment and additional information is available in the references cited as additional reading and the bibliography. In general, project management and cost management should cost somewhere around 5–10% of the total capital cost of the engineered equipment. There are many factors that influence the absolute value of this administration cost. Factors include fitness-for-use, your project organization, and supplier location.

B. Definition of Life Cycle

"Project life cycle" refers to the entire range of activities required to complete the engineered equipment mission. The life cycle begins with very early activities such as the customer's vision and preliminary decisions such as how much to spend and when the work should be done. The life cycle includes all the intermediate phases of engineering and design. It also includes installation, debug, and start up, but it does not end there. A proper life cycle includes work after what we have traditionally thought of as project completion. This includes engineering follow-up, long-term maintenance, replacement, salvage value, future upgrades, performance warranties, and other activities that affect cost of the equipment over its useful life. This life-cycle approach allows you to compare engineering alternatives on a comparable basis so you can be sure that you are making the right decisions from a cost point-of-view. Life-cycle costing also gives you a more accurate picture of the real cost of your asset so your management can be in a better position to decide about how many to buy, which alternative to select, how much of the cost to fund, whether to purchase or lease, and more.

II. FEASIBILITY AND PRELIMINARY PREPLANNING STAGE

Preplanning activities are completed by a project team at the onset of a project. They are extremely important because they become the basis for many of the policies and practices that are in place throughout the project team's life. Preplanning activities also may have the greatest impact on final project cost. Preplanning activities are best carried out by a team through partnering.

A. Partnering

In 1990, a group of researchers from The Pennsylvania State University studied 16 medium-sized high-tech projects to determine why some projects are more successful than others. The first "critical project success factor" they derived was a "well-organized, cohesive team to manage, plan, design, construct and operate . . ." the equipment. The value of a strong and knowledgeable project team cannot be overemphasized. Further, it is incumbent upon the project manager to be enough of a leader to remove people from the team who are weak contributors, indecisive, or who create personality conflicts. The researchers found that projects that do not correct for these problems suffered adverse cost consequences.

Partnering is basically just making sure that you include all those people who have anything to do with the equipment involved in decisions about the equipment during all phases of its life cycle. In other words, form a team very early on, as soon as the idea for a new piece of equipment looks as though it is going to become a reality. The team should include representatives from all groups who may be able to positively impact the equipment. Normally, people will be glad to have the opportunity to be involved early, when they have the greatest opportunity to have a real impact. Team members and their respective responsibilities vary depending on the size of an organization and the capabilities of its people. The following is a suggested team matrix that has been shown to be effective. Project team representatives may include people with the following responsibilities:

Customer Sponsor

A customer representative or sponsor is responsible for insuring that the needs of the customer or user are being met. The sponsor needs to collect data from the current process, develop specifications, write requirements, retain ownership over project scope, and manage the interface with customer management. The sponsor should also collect performance data to benchmark current equipment performance, providing a way to calculate the improvement from the new equipment. The team needs to use the performance data to characterize current performance and then use that information to establish new equipment requirements.

Engineering Manager

The engineering manager should coordinate all the engineering disciplines, such as electrical, HVAC, mechanical, coatings, civil, structural, piping, and others. This manager is also responsible for developing the engineering conceptual design proposal—essentially the engineering recommendation that is the response to the customer's requirement. The engineering manager maintains the responsibility for insuring that the equipment continues to meet customer expectations even as requirements and equipment capabilities change over time.

Project Control Engineer

The Project Control Engineer will set up the control system (i.e., establish a project breakdown structure), manage a cost tracking and reporting system, analyze and interpret costs, recommend cost and schedule-based project changes, track and report schedule progress, manage change, maintain project documentation, manage the project budget and cost forecast, and additional activities as required. The Project Control Engineer should set up a work breakdown structure to track engineering costs at a level that facilitates effective control, and a cost reporting system that allows multiple sorts (discipline, area, process, organizational, etc.)

The Project Control engineer should also set up and maintain a change management process to control project scope and cost. An effective change management process includes documenting a baseline cost estimate, managing a process to document changes and get them authorized, and updating cost forecasts (versus budgets). Change management is a basis for control because control is based on comparing actual costs to forecasted costs. Forecasted costs are authorized budgeted costs plus approved changes. A change management process that is maintained on a weekly basis helps control "scope creep."

Lastly, a Project Control Engineer should keep track of cost savings to document cost performance. Management will never know how bad the job could have been unless you list the proactive steps taken to control costs and their resultant savings.

Construction Manager

The Construction Manager forecasts installation resources, plans pre-installation work, coordinates with facility representatives, raises constructability and installability issues, and helps determine the installation schedule among other activities.

Materials Manager

The Materials Manager has responsibility for contract terms, material unit pricing, purchase order and commitment management, invoicing, supplier interface, shipping and storage, tracking the progress of the equipment as it is being manufactured or fabricated, and may be a primary focal point for supplier communication with the project team. The Material Manager has responsibility to recommend the contract type, whether it be cost reimbursable, firm bid, or some combination of cost types. Contracts where suppliers share in cost savings and cost penalties have become increasingly popular, and should be considered so that the supplier becomes a partner with the project team.

Project Manager

The Project Manager retains overall responsibility for successful project completion. He or she has ultimate responsibility to insure that the project is completed within the budget, is on time, meets all customer requirements, and performs according to customer expectations. The project manager has a significant communication, leadership, coordination, and control job. This person builds and leads the team, and manages interfaces with external groups who support the project.

Operations & Maintenance

Equipment operators need to be involved in project planning at early phases in order to provide input about equipment operations that is unavailable anywhere else. Operators need to help develop equipment requirements since they are the ultimate users. Their input will help insure that operability issues are addressed, and that operator error is not a contributing factor to any future problems. Maintenance people have invaluable input on issues that can help to reduce long-term costs of the equipment.

Supplier

Suppliers frequently have more technical expertise than the customer, and can offer valuable assistance in specifying customer requirements. Supplier input during early design stages can be crucial in helping to control costs. A good supplier with long-term business interests will help a customer specify equipment that is most producable by the supplier. The supplier can help a customer avoid specifying equipment that is so "custom" that it will be very expensive to produce. A supplier can focus attention on design parameters that may be "wants" as opposed to "needs," and can thereby insure that the customer gets high value.

B. Project Management

In addition to partnering, it is also critical to implement project management. Project Management is essential for cost control to be effective. Project Management is the application of knowledge, skills, tools, and techniques to project activities in order to meet or exceed stakeholder needs and expectations.

There are distinct advantages to using Project Management (PM) over functional management of engineered equipment projects. Project Management:

- Places overall accountability with one person, a project manager.
- Assures that decisions are made for the good of the overall project rather than for any single contributing functional department.
- Places decision making at the appropriate level. The project manager has the broad perspective that leads to the right decisions.
- Coordinates the efforts of functional contributors.
- Provides a focal point to facilitate communication.

- Facilitates setting up a project-wide cost tracking and reporting system. It provides a Project Control Engineer with the authority and access to cost data from multiple sources.
- Assigns accountability for each cost account.
- Invests planning time up-front to avoid "putting out fires."
- Forces a project team to consider time, money, human resources, and quality issues in addition to product and process engineering.
- Allows time for investigation and documentation of each phase. Documentation is extremely important as a way to prevent claims for extras, and to avoid schedule delay and acceleration claims.
- Makes it less likely that important tasks will be omitted, as the use of a project breakdown structure insures that all activities are included, and that no cost is included more than once.
- Makes it more likely that potential problems will be spotted in time for corrective action to have a positive impact.
- Allows the project team and customers to decide jointly on funding, manpower, time and specification issues and trade-offs.
- Keeps customers informed of progress.
- Has built-in quality control through stipulated review points and go/no-go junctures.
- Encourages customer involvement because they know the status of the work.
- Provides for accumulation of cost data that can be used as a basis for estimating subsequent projects of this type;
- Provides economies of scale savings in mobilization and learning curve.
- Centralizes asset control.
- Centralizes records management.

C. Equipment Justification and Benefits

The equipment project team should establish detailed project justification and a benefits matrix as a basis for cost control. This business case should spell out those specific benefits that are expected to be achieved as a result of the completion of the equipment project. This is important during early phases from a cost point-of-view because the team will need to collect costs to substantiate the benefits throughout the project life cycle. For example, if the equipment is being purchased and installed to reduce waste, then the cost of waste should be not only baselined so that preproject costs are known, but also tracked through the project life cycle and beyond to show that the equipment has delivered as intended.

This activity supports the concept of cost control as not just cost reduction during execution, but as a more global control of life cycle costs for the process operation. It is more meaningful and significant to be able to report that as a result of the equipment project, the XYZ division has seen a 10% waste reduction and a 25% productivity improvement that contributed to a $1 million increase in net corporate profit, than it is to report that the team saved $25,000 by implementing cost saving measures during equipment installation.

D. Documentation

Document everything. You will be glad you remembered these two words if you take them to heart. Complete and thorough documentation is extremely important as a cost control tool. Here's why. Unless there is a very progressive level of cooperation and agreement among all project participants, it is likely that there will be disagreement at some point over project scope, cost, schedule, or functionality. The purpose of documentation is to provide written evidence of administrative decisions, incurred costs, submittals, quality control, and all activities associated with meeting contractual responsibilities and enforcing contractual rights.

You can provide the evidence if you maintain a complete record of all transactions. Additionally, you will forestall continuing disagreements and claims for extras once the other parties to the contracts learn that you maintain a detailed record keeping system. Other reasons to document include documenting progress, recording potential constructive changes, keeping cost baselines against which changes will be tracked, and documenting assumptions for significant decisions so you can change courses of action as you gather additional information;

The following is a partial list of documentation that you should maintain to support cost control:

- Detailed, daily log of current activities
- Conversations with suppliers
- Proposed schedules and sequences
- Estimates and backup worksheets
- Meeting notes
- Site visit notes, photographs, and videotapes
- Bidding documents including addenda

Basically, who is entitled to damages and how much they get is decided by applying a few basic principles to the facts. It is the assembly and proof of facts in the form of documentation that is so critical. Documentation is a detailed biography of a project. It is an integrated procedure of recording and authenticating events for selective retrieval at a later time. Documentation is made up of two parts. The first is knowing what is wanted, and recognizing the facts that will be of most value. The second is obtaining this information and having it available in its most usable form.

III. CONCEPTUAL DESIGN PHASE

A. Customer Requirements

It is very important to prepare a detailed requirements document that specifies expected equipment performance. This is a preliminary engineering document that describes what the customer needs, and what the equipment must do. The requirements document is the basis for development of engineering alternatives that respond to the customer's needs. This is an important cost control document because it establishes preliminary project scope, and is the basis for an initial budget estimate. Scope and cost changes may be tracked against this as a baseline. The requirements document also sets down initial performance specifications that can be the basis for acceptance criteria that will determine the success of equipment functionality.

B. Conceptual Design Proposal

A conceptual design proposal documents the team's answer to the customer's requirements document. It includes analyses of different engineering alternatives, recommends a solution, and describes how the requirements will be met by the solution. This proposal is important for cost control because it contains additional detail that helps finalize project scope, and therefore increases cost certainty. The proposal outlines much of the strategic direction that the project will take that in turn determines most of the costs that will be incurred. Costly scope changes are less likely to occur if the equipment is well defined at this point.

A conceptual design document includes a list of design issues that need to be resolved, an assessment of the evaluation of alternatives that explains why the recommended solution was selected, intermediate cost and schedule information, performance specifications, acceptance criteria, and a preliminary list of all equipment components. Unclear project scope and ambiguous specifications are two primary causes of capital cost overruns. It makes sense to spend time at this relatively early stage to develop these aspects. Time and money spent adding definition during conceptual engineering pays off later in the project process. Be sure to adequately budget for a thorough conceptual engineering effort.

C. Economic Analysis

A standard way to choose between engineering alternatives is to use a cost method called present value. Present value is the value today of a stream of costs, discounted at an appropriate discount rate. It is basic compounding in reverse. Present value converts various cash flows occurring over time to equivalent amounts at a common point in time, considering the time value of money, so that a valid comparison between engineering alternatives can be made. The present value formula is shown below:

$$P = V(1 + i)^{-t}$$

where

P = present value
V = future value
i = interest rate
t = number of periods

A simple example may serve to illustrate how to use the present value formula. Assume that you have an existing manual accounting method, and that you are considering replacing it with a computer purchase. Costs are as follows:

	Manual	Computer
Initial purchase cost		$100,000
Annual salaries	$85,000	35,000
Salvage value	0	25,000

Should we buy the computer or stay with the manual method? The present value calculation will help us choose.

The computer is depreciable on a double declining balance basis at the rate of 20% per year, and is expected to be obsolete in three years. Assume a minimum rate of return of 10% after taxes. The present value method of discounted cash-flow analysis gives the following set of calculations:

Annual cash savings is		$85,000 – $35,000	= $50,000
Depreciation	1st year	= $100,000(0.20)	= $20,000
	2nd year	= $80,000 (0.20)	= $16,000
	3rd year	= $64,000 (0.20)	= $12,800

	Year 1		Year 2		Year 3	
	NI	CF	NI	CF	NI	CF
Cash savings	$50K	$50K	$50K	$50K	$50K	$50K
Depreciation	–20K	0	–16K	0	–12.8K	0
Income before tax	$30K	50K	$34K	50K	$37.2K	50K
Tax @50%	–15K	–15K	–17K	–17K	–18.6K	–18.6K
Income after tax	$15K	35K	17K	$33K	$18.6K	$31.4K

NI = Net income, CF = Cash flow

Now use the Present Value formula for each year:

$$P = (\$35{,}000)(1 + 0.1)^{-1} = (\$35{,}000)(0.909) = \$31{,}815$$

Year		
0		–$100,000
1	($35,000)(0.909) =	$31,815
2	($33,000)(0.826) =	$27,258
3	($31,400)(0.751) =	$23,581
3	($25,000)(0.751) =	$18,775
		$1,429

So it is more economical to purchase the computer because the present value is positive.

D. Drawings

An often overlooked activity at this stage is checking the quality of existing engineering drawings. It is imperative that engineers and designers understand drawing status before using the drawings as a basis for preliminary design modifications and cost estimates. The quality of existing drawings should be checked for accuracy. Every measurement should be field-checked so that you don't end up specifying incorrect dimensions on supporting work and process hookups.

E. Value Engineering

Value engineering is a method to reduce costs while maintaining equipment quality, without compromising functionality. It is not redesign per se, although it may result in some redesign. Value engineering involves an evaluation of planned materials and methods, and challenges each aspect of design. Value engineering virtually always results in cost reduction, and provides documentation to prove that the recommended engineering solution is the right one for a particular application.

Value improvement is a result of a systematic use of recognized techniques that identify the basic performance functions of a product, and ensure that they are provided at the lowest total cost. This provides engineered equipment cost control. Extensive analysis is involved because value is a function of what a piece of equipment does, and how well it does it. Value analysis concentrates on a detailed examination of function and cost.

It is beyond the scope of this chapter to fully address Value engineering or value management, but a brief overview may serve to introduce the reader to this important cost control technique. Value studies use interdisciplinary teams to:

Analyze equipment components and their functions
Gather and interpret cost data
Measure value in terms of functions that fulfill customer needs
Develop and evaluate alternatives to improve value or eliminate low value
Develop ways to implement the best alternatives;

Value studies use a job plan as a structured approach. A job plan includes six phases that address what the equipment is, what it does, what it costs, what it is worth, and what else will do the job. The phases are shown below:

Phase	Description
Origination	Form team, organize study
Information	Analyze components, determine performance needs
Analysis	Analyze functions, determine function costs
Innovation	Generate alternatives
Evaluation	Screen alternatives, determine feasibility
Implementation	Make recommendation

Value engineering is highly recommended for controlling and minimizing engineered equipment costs. It is presented in more detail in Chapter 19.

F. Conceptual Cost Estimate

It is imortant to take the time to develop detailed bases for equipment cost estimates. Improving conceptual estimate accuracy will payoff as actual costs are compared to your budget baseline, and as equipment is further defined and project scope developed.

A proper and professional conceptual cost estimate includes shipping costs, holiday and overtime costs, and any electrical power required as a result of the addition of the equipment in addition to the direct costs of engineering, material purchases, and installation.

It is important at this early estimating stage to establish individual accountability for equipment costs. A cost estimator should help to assign cognizant individuals who will be responsible for not only establishing this initial estimate value for detailed cost accounts, but also for tracking those actual costs, and addressing any variances from the budget. It is this individual ownership of detailed cost accounts that makes cost control a real event and not just a buzzword in a project management plan.

The conceptual cost estimate can never be exact. The project has insufficient equipment design and project scope definition for the estimate to be very accurate at this point. Accordingly, there should be a plan to revise and update the cost estimate at key milestone points throughout project life. The quality of the estimate can be substantially improved at conceptual design completion, detailed design completion, when purchase orders are in place, when manpower resources have been forecasted, and at other milestones. The estimate plan should include provision for these updates so that estimate uncertainty decreases as design progress increases. A more detailed explanation of conceptual estimating appears in Chapters 1–6.

G. Cost Risk

The conceptual cost estimate should include adequate contingency. Contingency is included to accommodate unforeseeable additional cost activities that are likely to occur. Contingency is included to reduce cost risk and increase the likelihood that the project will be completed at or under the budget.

Contingency is an allowance for costs that may result from incomplete design, changes due to unforeseen conditions and market variations. The amount of contingency depends on the status of the design, procurement, and construction as well as the complexity and uncertainties of the project's component parts. Contingency excludes changes in scope.

Contingency is alternately viewed as belonging to either the project team, or to management. From management's point of view, contingency is that amount, that when added to the estimate of most likely cost, balances management's risk of overrunning costs against the probability of winning a contract (or of committing funds that will ultimately remain unused). From a project team's point of view, contingency is the amount that, when added to the estimate of most likely cost, reduces the team's risk to an acceptable level of overrunning a budget.

Contingency can be developed on a line-by-line basis if appropriate knowledge and skills are available. Once levels of uncertainty are assessed, they can be expressed as a percentage of total cost. Application in this way facilitates the task of updating contingency during cost estimate reviews. Lastly, cost estimates ought to contain statements of assumptions underlying the contingency allowance. For example, the estimate ought to state that the allowance for contingency is a strong function of technical risk, but a weak function of installation risk for example.

Contingency is best calculated through a technique known as cost risk analysis (see Chapters 12–14). One way to do cost risk analysis can be accomplished by using one of the PC-based software programs available that conduct Monte Carlo simulations. Cost risk analysis is a statistical evaluation of the cost risks associated with the equipment project. It is a probabilistic approach that defines the contingency that should be added to your point estimate so that you have a total cost estimate that accounts for risks. Risk analysis begins with an appraisal by project experts (you and the rest of the project team) of uncertainty around the cost of each capital activity. The project team assigns high and low cost ranges to each activity. Then a simulation program is used to simulate completion of the project as many as a thousand times. Each time, the cost for a particular activity is assigned, according to some distribution (presumably a beta) within the estimated cost range. The result is a cost distribution associated with a range of probabilities. Management can use the resultant table to select a level of cost risk they are willing to accept in order to be assured that the project will not underrun a budget.

The team should identify and communicate risks before proceeding with a project that includes significant technical risk. This will reduce the likelihood that you will see scope creep and the hidden costs associated with components just being developed and elements of equipment that have not yet been fully tested. The project team has an obligation to make management aware of the potential for cost increases associated with technological risk.

H. Project Definition

One of the basic tenets of project management is that it is cost-effective to spend more time up-front in capital engineering-procurement-construction projects to define the project, clarify work scope, plan the details of procurement and execution strategies, and investigate alternatives to be sure that you are doing the right things. In accordance with this concept, it is prudent to be well into detailed engineering before you establish your budget estimate for engineered equipment costs.

If engineering and design is around 50% complete, you should have enough information that your cost estimate accuracy range can be significantly narrower than during the conceptual phase. A typical cost estimate accuracy range is –5 to +15% at this point in the project life cycle. Improving project definition prior to project funding approval greatly improves the likelihood that you will be able to control your costs such that the final completion cost will be at or under the budget at authorization.

I. Benchmark

The process of evaluating engineering alternatives and selecting and recommending a "best" solution calls for contacting other customers who have purchased and installed the same equipment being considered for your project. This benchmarking will help you see whether the equipment under consideration is appropriate for your application. Benchmarking provides insight into problems others may have that you would otherwise be unaware of. You can react to that and take advantage of lessons-learned by others by including engineering modifications in your scope-of-work and conceptual estimate to reduce cost risk, and by expanding your performance specifications to insure that you will end up with the performance your customer expects. Benchmarking may also give you a database of performance data so you will have a better idea of the level of improvement your customer can reasonably expect to see once the equipment is installed.

J. Long-Lead Equipment

As conceptual design proceeds, and as materials managers become more involved, it may be apparent that some equipment or equipment components have lengthy time requirements between order placement, and equipment delivery. These will become critical-path items on a project schedule, and should be managed separately. The team should place emphasis on completing requirements for this equipment so that it can be ordered in a timely manner. Managing long-lead items helps prevent additional costs associated with schedule delays.

IV. MATERIALS MANAGEMENT PHASES

A. Contract Negotiation

The contract type can heavily influence costs. The equipment project team should carefully evaluate the advantages and disadvantages of each contract type, and select the one that best suits their needs. There are many different types of contracts that may be negotiated between suppliers and customers for equipment purchase. This is not intended to be a complete discussion of all the types. Two types are listed as examples of the influence contract type has on cost performance.

Cost-Plus

A cost-plus contract reimburses the supplier for all costs, plus a fee. Two advantages of a cost-plus contract are that the project can start before the availability of a complete set of drawings and specifications, and changes are easy to incorporate as the project progresses. Cost-plus contracts typically present very little risk to a supplier.

The cost estimate by the supplier for a cost-plus contract usually has a fairly low degree of accuracy. In a cost-plus incentive fee contract, a negotiated set of fees is tied to actual costs. If the actual cost is higher than the target cost, the supplier gets a lower fee, and if the actual cost is lower, a higher fee. Cost reduction methods include close monitoring and assessment by the customer of supplier labor productivity.

Lump-Sum

Lump-sum is a fixed price contract where a supplier must provide the customer with a single price for the total project. Advantages of a lump-sum contract for a customer include knowing what a large portion of a project will cost before it starts. There may also be a presumption that, due to competition between suppliers, the project will be completed for a minimum cost. The advantage for a supplier is that they know the scope of work early in the project life cycle, and there is a strong incentive to work more efficiently (i.e., cut their own costs) to increase supplier profits. For the supplier, a lump-sum contract represents high financial risk. The supplier must prepare a detailed cost estimate to reduce his cost risk.

One of the most effective ways to reduce costs on lump-sum contracts is to prevent a proliferation of change orders to the contract. This prevention is best accomplished during the conceptual design phase by having project team people with extensive experience review the plans and specifications to minimize the possibility of changes once the contract is executed.

Rapid action on problems that arise during execution will also reduce additional costs. Delay in providing the design modifications and in providing instructions to the lump-sum supplier always increases total project cost, and the completion date. Project teams should insure that procedures are in place to resolve disputes when changes or problems occur during execution/installation.

Value engineering incentive programs are a third cost reduction tool that can be applied to control costs on lump-sum contracts (see the pprevious section on Conceptual Design Phase: Value Engineering and Chapter 21).

There are a number of contract types that may provide equipment cost and schedule benefits. The following is a list of ten different contract types and a brief description of their applications:

Fixed-price escalation: Used when purchasing equipment that will be delivered over several years. An escalation clause protects suppliers and customers from the effects of inflation.

Fixed-price incentive Used for purchasing equipment that is poorly defined or is a first-of-a kind. Protects a supplier from uncertainty.

Fixed-price redetermination Used when the initial purchase can be priced, but subsequent components cannot be, due to material and labor fluctuations.

Cost-sharing Appropriate when new equipment will be developed that the supplier may be able to market elsewhere. Allows a supplier to have a portion of the development costs paid by the customer.

Cost-plus incentive Used when equipment is so poorly defined that even a maximum price cannot be determined.

Cost-plus award-fee Allows a customer to reimburse actual supplier costs plus an additional amount of money awarded for accomplishing cost and/or schedule goals.
Cost-plus fixed-fee Reimburses the supplier for all agreed upon costs. Used when the supplier has some idea of what costs will be, but is unwilling to take a fixed-price risk due to the existence of some contingencies.
Time and materials Used most often for repairs.
Letter subcontracts Used when large contracts must be started before final supplier negotiations are complete. This lets the supplier start work so that delivery can be made according to a previously agreed-upon schedule.
Indefinite delivery Provides the least contractual protection and is employed when the buyer is not sure of the production schedule or the quantity of material needed.

Contracts is an area of equipment cost control that requires input from a qualified expert. Attorneys experienced in contract law, and experienced materials managers should provide guidance on selection of the contract type that will provide the best value for your equipment project.

B. Equipment Description

It is absolutely critical that accurate and fully developed equipment definition be provided to the supplier. Having the equipment adequately defined helps to minimize supplier changes, modifications, and rework, and the resultant costs. Any changes to the equipment requested may also adversely impact project schedule and result in additional schedule delay costs. Any changes from the baseline scope of work, from a suppliers perspective, will probably result in a claim for extras that will increase actual costs.

On the other hand, suppliers may develop equipment improvements during the course of their manufacturing. Improvements that result in cost savings can take the form of productivity improvements, assembly efficiencies, recommendations for material substitutions resulting from materials testing, materials savings resulting from redesign (or value engineering) efforts, improvements resulting from technological development, and improved design from design reviews.

Supplier equipment improvements may be especially likely if improvement goals are specified in advance, and if there are contractual incentives for a supplier to control and/or reduce costs.

C. Supplier Evaluation and Selection

Cost control includes the steps taken to insure that your choice of suppliers minimizes cost risk. Supplier selection includes more than just bid evaluation. Steps may include the following:

Prequalify the supplier by verifying that they have specific experience with the type of equipment being purchased.

Evaluate the supplier's financial stability to reduce the potential that they will be trying to obtain an inordinate amount of progress payments up-front in order to finance the cost of producing your equipment.

Assess the supplier's workload. Too little work may indicate unfavorable reviews by other customers, and too much work may be an indicator that the supplier may have difficulty meeting your delivery schedule or may bring in new, inexperienced resources to work on your equipment.

Look at the expertise of the supplier's engineering and manufacturing staff. Be sure that they provide the level of competence that will insure that the equipment will meet quality goals. Make sure that the contract specifies installation support, and that the supplier has experience in startup and debug.

Become aware of the potential longevity of the relationship between the supplier and your firm. Cost control is more likely when the supplier has reason to safeguard its reputation because there may be additional contracts forthcoming. A supplier may be more willing to emphasize goodwill and customer relations issues if they stand to gain from additional contracts. Further, a supplier may absorb minor cost increases on your project so as not to jeopardize negotiating positions for larger, long-term contracts.

Make sure that the supplier is able to provide long-term support for the equipment if the customer does not have the expertise to maintain all aspects of it. A supplier may provide periodic and routine maintenance like cleaning, lubrication, and replacement of frequently worn components. A supplier may also provide upgrades as materials, software, etc. become obsolete or superseded. Finally, the expertise of a supplier may be required for major overhaul should there be a problem that is beyond the capabilities of customer technicians. The availability of supplier engineers is an issue, as is their level of expertise. These issues should be discussed and resolved before selection so that both parties understand mutual expectations, and so that long-term equipment performance is enhanced.

D. Payment Authorizations

Cost control includes your ability to verify that you have received the value of goods and services for which you authorize payment. Project management procedures should include provision for you to be able to evaluate in detail whether you have received what you asked for at the quality level you specified, when you scheduled that it should be received. Contractually, there is little practical recourse once a payment is made. Spend the time to carefully review requests for payment, and conduct tests as necessary to verify that the equipment meets specifications.

E. Scope of Supply

Establish rapport with the supplier as soon as possible, and list each and every activity as a responsibility of either the supplier or the customer. This is to insure that all work scope is part of the completion plan, and that no required function is overlooked or assumed to be completed by the other party. Clarifying work scope in this way helps to insure that the cost control estimate is all-inclusive.

Supplier versus customer responsibilities should be clearly delineated so that their respective detailed activities are included in cost and schedule plans. Any oversight at this point will increase cost. Responsibility matrices are useful for this purpose.

F. Detailed Acceptance Criteria

One key component of cost control in vendor operations is being able to manage costs during the time from delivery through start up and acceptance. Customers need to know in advance if the equipment has been manufactured in accordance with their specifications. Detailed acceptance criteria should be negotiated well in advance. These criteria will be the basis for approving payments, and for accepting the equipment.

If equipment acceptance criteria have been properly prepared, then the equipment will achieve expected performance levels, and help the customer achieve the benefits outlined in the justification and business case. To insure that this is the case, a customer may reasonably expect that a supplier will correct or revise any aspect of the equipment that does not perform to the contract. A mechanism for enabling this correction is an equipment performance warranty. The performance warranty says that the supplier guarantees that the equipment will perform to the acceptance criteria. If it does not, the supplier will take those steps necessary (including redesign, replacement, repair, upgrades, etc.) to make sure that it does. The additional steps are at the supplier's expense so that this is a cost risk minimization procedure for the customer.

G. Change Management

Change management during equipment manufacture is important for maintaining actual costs at estimated levels. Change management says that whenever the supplier has reason to believe that they will vary from the specified design, scope of work, estimated cost, or schedule, they will notify the customer via a change notice. Ideally the change notices will be timely so that corrective action can be influential in altering final costs. Changes must be approved by the customer since these costs are expected to be borne by the customer. The customer must have the opportunity to review equipment progress, and evaluate proposed changes and their respective cost and schedule impacts. Awareness and timely notification gives the customer the opportunity to decide whether or not to accept the change proposals. Acceptance may mean that the change will be funded from project contingency.

H. Communication

Engineering should maintain excellent communication with suppliers including discussions of ongoing vendor development during detailed design that could lead to customer rework.

For good communicatiojn, establish a single point-of-contact at both the supplier and customer.

Watch constructive changes. Informal verbal communications between customer and supplier engineering staff can be construed as constructive changes to the original and agreed-upon scope of work. This is another reason to centralize communication.

V. DETAILED DESIGN

A. Design Changes

It is assumed that the baseline design was fixed at the point of conceptual design approval. However, it is also a certainty that design changes will arise throughout the detailed design phase. This is the place to put your change management process into action. Document every proposed design change on an "engineering change notice" form, and route it for approvals. This request for approval should include the reason for the change, and the cost and schedule impacts of the change. The collection of these change documents helps explain budget and forecast changes from the cost baseline. You will probably be required to produce a periodic report that lists the design changes to-date, and their cumulative cost. Of course, design changes are minimized by the thorough up-front engineering we talked about in the section Conceptual Design Phase.

At some point the project team should consider recommending that a design be frozen. That is, a design that meets customer expectations should not be allowed to be changed any further. There is a real risk of making so many design changes that cost and schedule performance will be adversely affected. Also, the project team needs to address the issue of customer enhancements. It is fairly common for a customer, once they see how well the engineering solution responds to their requirements, and once they become aware of the detailed capabilities of the new equipment, to request additional enhancements. Enhancements are customer directed scope increases above and beyond what was specified in the original requirements document. In some cases, enhancements can be justified where they allow for future expansion, eliminate waste, decrease labor costs, or otherwise contribute to the original justifications upon which the project was approved. But often, enhancements are not justified. The value engineering technique discussed in the section Conceptual Design Phase is a good tool for questioning enhancements, and for disallowing changes that do not add value to the final equipment.

B. Quality Control

An appropriate definition of quality is providing customers with exactly what they have asked for. In turn, customers should ask for exactly what they need. The elements presented in the section Conceptual Design Phase are designed to help customers do just that. Quality may include cost performance as well as schedule performance and equipment functionality. Quality cost performance may be described in several ways. It may include any of the following:

- Reaching more inexpensive design alternatives through Value Engineering
- Working with a supplier to develop cost savings in equipment manufacturing
- The final cost is at or below budgeted cost;
- Working with a supplier to maintain current material prices in spite of schedule delays
- Brainstorming to develop ways to cut labor costs;
- Accelerating a schedule at least-additional-cost
- Reducing costs associated with rework by verifying all drawing dimensions

Most often, quality assurance refers to equipment functionality. It is imperative that the equipment works exactly as it is expected to, when it is expected to, and gives the customer the benefits upon which the project was justified. Several techniques for increasing the likelihood that this will happen are included in this Chapter under different Sections. They include the following steps:

Make sure the customer knows what they are asking for by insuring that they have measured their current process and have prepared a complete requirements document.

Make sure that you have adequately investigated alternatives including the use of the Value Engineering process, and benchmarking.

Don't over-specify. For example, check to see whether commercial tolerances are sufficient as opposed to the customer's more stringent tolerances.

C. Quantitative Methods for Decision Making

There are several decision-making and problem-solving systems in use today that can be applied to equipment engineering-procurement-construction (EPC) projects in order to analyze and improve cost control. These systems include mathematical modeling as a base for building operations research models. When the equipment is complex, costly, or involves significant risk, such models may be useful.

Controlling equipment projects involves rational decision-making as a means to alleviate burdensome scheduling, planning, and cost problems. Rational decision making is a part of the project planning process. As you have seen, project planning establishes those policies and procedures that determine equipment cost.

Quality planning is typified by objective approaches that eliminate bias, insure consistency, establish standards, economize time, and facilitate understanding of the decisions by others. Equipment EPC projects are characterized by complexity. For this reason, analog models for representing actual situations are inappropriate. More abstract models using mathematical symbols and relationships give a truer picture. Abstract models are a crucial part of a good quantitative approach to decision making.

A second characteristic of equipment EPC projects is that model parameters are frequently uncertain. They are subject to variation with each succeeding observation. To account for this portion of the nature of equipment uncertainty, stochastic models are used. Stochastic modeling is especially useful in optimizing a quantity with consideration given to existing constraints. Development of mathematical models is perhaps the most critical step in the overall procedure of quantitative decision-making. The models should directly address what you are trying to accomplish. They must include all independent variables for each particular situation.

Model formulation is mostly a function of the user's ability to analyze and understand the problem, and of the ability to translate verbal descriptions of the problem into mathematical symbols and relationships. It should be emphasized that no single model is necessarily correct. Several analysts can develop different models that may all yield relatively accurate decision-making results. The models are said to be equivalent, and indicate that modeling is an art.

Model building then, requires identification of the objective function and definition of the variables that affect decisions. The objective function is the measure of effectiveness represented in terms of control variables.

Solutions to models take several forms. Among them are graphical, algebraic, and those using differential calculus. Given an appropriate model, an efficient way to solve for the "best" answer is to use alternatives to trial-and-error approaches. Use of these alternatives, called algorithms, is usually most appropriate for electronic data processing. It is simply impractical to attempt the volume of calculations required by other than high-speed electronic means.

It is beyond the scope of this chapter to provide adequate explanations of all the various types of quantitative decision-making methods; however, more information is provided in Chapters 12–14. We can say there are two types of models, deterministic and probabilistic. Deterministic refers to decision making under certainty, while probabilistic refers to decision making under risk. It is fairly easy to assign most equipment EPC projects to probabilistic models. Decision making under risk requires use of expected values, knowledge of probability distributions, and calculation of areas under curves.

Deterministic models include linear programming, dynamic programming, and inventory theory. Probabilistic models include expected value criteria, decision trees, simulation, forecasting, and sampling techniques. Types of models can be further categorized into techniques that can be used during detailed design to insure that the right decisions affecting cost are made. Utility theory is a decision strategy. Linear programming, integer programming, transportation and assignment problems, PERT/CPM, inventory models, and replacement analyses are all optimization models. Risk analysis, queuing theory, and simulation are all analysis models. Models using regression analysis, correlation, and cluster analysis are statistical tools. Most of the types of problems that cause the greatest cost control problems lend themselves to being fit into one or more of the aforementioned models.

Through the use of quantitative methods involving use of techniques that allow for peculiarities of equipment projects, accurate and timely information for decision-making can be available. Quantitative methods can make the decisions required during design less costly, more easily communicated, and can result in greater life-cycle cost control. The benefits of quantitative approaches result in improved planning, schedule, quality, and cost, and allow redirection of limited engineering resources to resolution of other pressing issues.

D. Design and Engineering Cost Control

A standard model for a cost control plan includes 6 elements. They are shown in the following list:

Establish cost baseline
Track actual costs
Compare actual costs to budgeted costs
Analyze the variance
Recommend and implement corrective action
Report cost management

Establishing a cost baseline was discussed in the section on Conceptual Cost Estimating. At this point, you should have a system in place for tracking the actual labor costs incurred by engineers and designers on your team. The Project Control Engineer should be monitoring costs on a weekly basis, and highlighting any activities that appear to be nearing their budgets. Significant effort may be required for the Project Control Engineer to contact team members to find out why there are potential cost overruns on individual line items. Explanations include those that require action (like increasing cost forecasts, adjusting budgets, or cost transfers due to mischarges), and those that require no action (like activities whose actual costs are nearing budgets but that are not expected to overrun them).

A Project Control Engineer may increase a forecast via a cost transfer from contingency (see the section Conceptual Design Phase: Conceptual Cost Estimate), for underestimation, oversight, additional design progress, and a host of other reasons.

A budget can be increased for an approved scope change. Correcting mischarges indicates to others that you have an adequate cost tracking system, that you review actual charges, and that you have a plan in place to take corrective action to control costs.

Cost control also includes a number of additional techniques. One is trend analysis. Trend analysis is merely tracking cost trends for select levels-of-detail to detect trends that may be useful in forecasting future costs. Trending is useful as a way to forecast expenditures in order to predict variances from estimates at-completion.

Another tool is earned value. Earned value is a method for measuring project cost performance. It compares the amount of work that was planned with what was achieved to determine if actual progress is as-planned. Earned value is an effective cost control technique because it 1) helps determine whether there are cost performance problems, 2) pinpoints where cost problems may be occurring, and c) helps to identify cost concerns that may otherwise not be apparent. The following is a very simple example just to illustrate the concept of earned value, and its relevance to cost control:

Baseline estimate (i.e., budgeted cost of work scheduled)	
Quantity:	100 drawings
Labor:	600 man-hours
Unit rate:	6 man-hours/drawing
Labor rate:	$75/hour

Actual in-progress performance (i.e., actual cost of work performed)	
Quantity	35 drawings complete
Labor	182 man-hours expended
Unit rate	5.2 man-hours/drawing
Labor cost:	$13,650

Assume that the original drawing quantity is found to be underestimated, and that the revised quantity-at-completion is 125 drawings.

Earned value (i.e., budgeted cost of work performed)	
Progress measurement	35 drawings/125 drawings = 28% complete
Labor earned	28% (600 man-hours) = 168 man-hours
Cost variance	$ 13,650 = (182 man-hours)($75/hr)
	$–12,600 = (28%)(600 man-hours)($75/hr)
	$ 1,050
Cost performance factor	168/182 = 0.92 (where > 1 is better)

A conclusion of the earned value calculation then is that even though the actual unit rate is better than estimated, the increase in quantity more than offsets that labor savings. In this example, we have expended 182 man-hours, and earned only 168 man-hours. So overall cost performance is poorer than it should be at this point. The earned value process has also highlighted a quantity increase as a result of the progress measurement requirement. Unless there is a more formal progress reporting mechanism on your equipment project, this may be the only place that this kind of information is brought to the attention of cost managers.

Costs in this situation could be controlled by any of the following measures:

Forecast a new completion cost, and transfer funding from contingency to cover this oversight. A new forecast, assuming a straight-line projection of the to-date unit rate is as follows:

	90	drawings to-complete
×	5.2	man-hours per drawing/drawing is the to-date rate
	468	man-hours to-complete
+	182	man-hours expended
	650	man-hours estimated at completion

- Implement corrective measures to reduce the unit rate to 4.6 man-hours/drawing so that there are 418 man-hours to-complete, and the labor estimate at-completion is still 600 man-hours.
- Review engineering scope to determine whether the number of drawings can be reduced without any equipment project compromises.

E. Detailed Drawing Reviews

Designers need to be aware of the need to conduct detailed drawing reviews in the interest of cost control. Multidisciplinary projects usually contain interferences that are not readily apparent during design. Overlays and other techniques are required to uncover interferences that could result in costly redesign or rework during execution. The inclusion of a construction representative on the project team during design is one way to prevent rework and its associated costs. A construction manager should bring attention to potential interferences with existing conditions or newly designed layouts, and work to prevent them from remaining as part of the project design through the execution phase. A construction manager may request "walk-throughs" as a way to visualize locations, routings, and other design parameters that may impact potential interferences.

F. Manufacturability Reviews

If supporting brackets, sole plates, mounting hardware, or other connecting pieces are required, and are the responsibility of the owner, their design must be reviewed by a fabrication representative. The fabrication representative needs to review designs, recommend changes that will facilitate fabrication and reduce cost, and provide feedback to the project team on alternatives. The fabrication representative has specialized knowledge in the areas of machining, materials, and other methods, that may invalidate the designs presented by engineering staff. Engineering, design, and fabrication must act in concert to avoid unnecessary shops costs.

G. Constructability Reviews

Similarly, the construction manager needs to review engineering drawings as they near release dates for constructability. A construction manager's skills in construction methods may be invaluable in suggesting alternate ways of designing equipment and its associated support systems. A construction manager should provide feedback on design changes, materials changes, sizes, clearances, locations, etc., based on knowledge of installation tools and equipment, potential interferences, capabilities of hoisting equipment, adjacent process equipment, and other factors. The construction manager's careful review of plans as-designed should result in a minimum of rework, access problems, interferences, incompatibility problems, and out-of-sequence work.

VI. PREINSTALLATION PHASE

A. Training

Training is a factor in life-cycle cost. Proper operator training and involvement throughout the project life-cycle will increase the likelihood that the equipment will be properly utilized. Proper operation reduces start-up risk and helps to insure that production will occur with a minimum of waste, lost time, and other increased costs.

B. Staging

Advanced staging of the equipment at its ultimate location, or at least as much of the total equipment package as possible, may be a real cost reducing technique if it is a viable option. The benefits of staging include on-site training on actual equipment for operators, on-site installation of software or any other customer-specific applications by customer engineering staff, hands-on measurements by an installation crew to verify size, the opportunity to conduct pre-installation testing, the opportunity to complete electrical, pneumatic, hydraulic and other hookups in advance, and the possibility that you may be able to capitalize equipment asset value earlier than planned. These advantages are especially important if the customer is required to suspend or shutdown operations while the new equipment is being installed and started-up. Staging is an important cost control tool because it reduces shutdown risk, and enables a customer to resume normal operating conditions as early as possible.

VII. EXECUTION PHASE

A. Capitalization

From a financial management perspective, it may be advantageous to capitalize new assets as soon as allowable. Accordingly, cost control can include timely capitalization of new assets, retirement of replaced assets, and any credits for returned or traded-in equipment. Prompt capitalization can result in an improved cash flow for the company.

B. Predelivery Construction

As with early deliveries in the staging method discussed in the section on Preinstallation Phase, it may be advantageous from a cost point of view to complete as much installation work as possible prior to shipment and delivery. Pre-installation execution work may include cable runs, piping, exhaust vents, floor drains, removal of existing equipment, concrete pads, excavation work, structural steel support work, etc. Predelivery construction helps reduce total cost by reducing installation schedule risk, improving manpower resource allocation, and allowing additional time to resolve any installation problems that may arise so that maximum effort can be directed to the equipment when it is time to install it.

C. Potential Problem Analyses

Potential problem analysis (PPA) is a cost control tool used just prior to the start of installation to uncover and resolve problems that have the ability to adversely impact equipment costs. Generally, a PPA is an opportunity for the project team together with independent experts to review the project installation plan, and try to find any pitfalls that may occur. The team as a whole should "play devil's advocate," and imagine worst-case scenarios. As potential problems are raised, it is incumbent upon the team to present plans to address them.

Potential problems are listed in a column during this exercise, and two additional columns are added for each problem. One column is the likelihood that the potential problem will occur, and the second is an assessment of the severity of the problem if it does occur. Ideally, the project team will have adequate plans to address all "high likelihood," and "high severity" potential problems. The review group can then choose to concentrate on the remainder of the problems, and set limits for which problems the team should focus additional efforts on.

D. Establish an Operations Center

Major equipment installations can be extremely complex to manage effectively. And, smooth installation and start up is essential for cost control. A way to manage the myriad of coordination and control issues that present themselves during execution is to establish a technical and administrative operations center. The operations center is temporary in nature, remaining only as long as the installation activities. The center should be located as close as possible to the actual installation site. It should be equipped with communication equipment (telephones and a list of office and home telephone numbers, pagers, electronic mail capabilities, fax machine, and access to a building paging system if applicable), and presentation equipment (overhead projector, chalkboard, flip-charts, and an electronic print board). The center should be open at all times so that it can be used by 2nd and 3rd shift personnel if applicable.

Exemplary communications and control of issues at this point are key to cost control. Lack of communication and control can easily lead to schedule delays. Schedule delays add significant cost. An operations center is used for many purposes including:

- A technical operations center serves as a vehicle for transferring installation information between shifts, and between project team members.
- It is used for coordination between the project team and a newly formed customer-based operations and maintenance group.
- It creates a central focal point for collecting and disseminating information on equipment status and performance.
- It provides a message center so that no time is lost in trying to track down key project people for installation decisions or engineering modifications.
- The center can be used to post charts that show daily progress so that all team members understand current issues and can plan for upcoming activities.
- The center also acts as a focal point where management and other interested parties can come to find out about the equipment installation.

During installation, the project team should develop daily and detailed punchlists of activities that need to be completed before the equipment can be considered "installed." The operations center wall is an ideal location to post these punchlists.

Detailed construction schedules and cost estimates should be prepared so that the execution phase can be properly planned and controlled. These schedules are much more detailed than those used to plan the majority of project work. For example, the time scale for execution activities should be in hours instead of days or weeks as used for the bulk of engineering, administration, and procurement. Detailed execution schedules can be posted at the operations center, and used by all as a planning and control tool.

There are many installation, debug, commissioning, start up, accreditation, testing, and acceptance issues that arise during late stages of equipment projects, and their resolution requires exceptional coordinating, communication, and control efforts. A technical operations center provides an environment in which these measures can be undertaken with optimal effectiveness.

E. Field Directives

One of the last concerns in planning for cost control is to ensure that there is a procedure in place to request and approve engineering changes during execution. Construction trades, installers, subcontractors, and others will invariably find better ways to install the equipment, and perhaps even some interferences (in spite of all the work you have done to prevent them). You should take advantage of this feedback by forwarding the ideas to the responsible design engineer for his or her consideration. This process requires that responses be turned around in a matter of hours so as not to impact the execution schedule. Responses should be in written form so that the installers have a permanent record of why they installed the way they did.

VIII. DEBUG, STARTUP, AND ACCEPTANCE PHASE

A. Startup Costs

Startup costs should be scrutinized more closely than actual costs during earlier phases. Startup is a phase during which large costs are incurred during a relatively short period of time. As such, there is ample opportunity during this phase for mischarging, and overcharging. It will help your cost control efforts if you analyze actual costs on a weekly basis, and apply corrective actions on an ongoing basis. Project participants must be aware that there is a vigilant person who tracks and analyzes costs each day, and who challenges any that seem to be out of line.

B. Installation-to-Operations Transition

At some point the project team will turn over responsibility for the equipment entirely to an operations group representing the customer. The transition of responsibility from the project group to the operating group should be managed as a separate and distinct project. The transition team should be led by a customer operations person who has a long term interest in equipment operations and maintenance. This person will be responsible for insuring that the equipment meets acceptance criteria, that it is accredited for the products being produced, that it responds to the original customer requirements, that it has appropriate levels of both short and long term technical support, that it has been installed according to the manufacturers guidelines, that it includes the most current versions of software (if specified and if applicable), that the right training has been completed, that customer operations and maintenance personnel are fully prepared to take day-to-day responsibility for the equipment, that equipment performance is documented to verify its contributions to long-term benefits, and that there is a plan to address each punchlist item that remains after supplier personnel are gone.

These are very important end-of-project activities that deserve considerable attention to insure that they are adequately addressed.

C. Project Completion

Cost control dictates that the end of the capital project be clearly defined. Someone on the project team needs to be responsible for closing charge accounts, making sure that all equipment that can be is capitalized, monitoring any accounts that need to remain open, updating property asset listings, and other final cost activities. The project control engineer should close account numbers promptly to avoid collecting "lingering" charges.

If engineering drawings have not already been updated, that activity should be emphasized at this point so that quality engineering drawings are available for the next capital project.

Finally, the project control engineer should prepare a completion cost report to document cost performance. The final cost report should present details of budgets, forecasts, and actual costs at levels 1, 2, and 3. The cost report should explain any cost variances, and list details of cost savings.

IX. LIFE CYCLE COSTS

A. Maintenance Costs

In keeping with the concepts of total cost management and life cycle costing, you should include all costs associated with the equipment over its useful life. These costs include long-term maintenance costs. These are important because their inclusion in cost analyses insures that customers make the best decisions from a cost standpoint. Maintenance costs range from 3–10% of initial investment cost/yr depending on the nature of the facility and its conditions.

B. Operating Cost

Operating cost is the cost of keeping a piece of equipment running. It includes costs of raw materials, utilities, labor, and miscellaneous supplies. Operating cost control requires a program that is updated periodically to meet changing conditions for such factors as varying material price and quality, changing product quality, demand and price, increasing maintenance costs, technological obsolescence, and other causes.

Many of the factors that influence operating costs were determined during initial design and construction. For example, good plant layout will minimize operating labor and repair and maintenance costs. Operating cost problems include low yields, high raw-material usage, high waste, rework, low production rates, high maintenance costs, high utility costs, and excessive labor requirements.

Operating cost control follows the same model as capital cost control. Establish a cost baseline, track actual costs, compare actuals to the estimate, analyze variances, and implement corrective action. In operating costs, the baseline is a standard cost. A standard cost is an expected production cost that is based on knowledge of process operations and an understanding of the product.

Modifications to correct operating inefficiencies such as high maintenance costs can be put in place at any time throughout the life of the equipment. However, as for the capital project, they must be justified on the basis of overall savings in operating costs.

C. Equipment Replacement Analyses

Collecting and reporting actual costs during equipment life has an important application in equipment replacement analysis. In addition, costs should be reestimated that consider extreme usage, repair costs, a large amount of idle time, and other unexpected conditions. The estimate should be revised at the time that a replacement decision is being considered. The revised estimate will be current and will also reflect current-year dollars.

Deciding whether to replace a current piece of equipment is a matter of listing current actual costs/hr and expected costs/hr for the new equipment under consideration in a format that compares the two on a comparable basis. The following matrix is an example:

Existing equipment	Actual costs				Est. costs	
Years	1	2	3	4	5	6
Machine value loss						
Investment cost						
Maintenance and repair cost						
Raw material cost						
Operator labor						
Utilities cost						
Downtime						
Productivity differential						
Total	$3	$4	$5	$6	$7	$8

New equipment	Estimated costs					
Years	1	2	3	4	5	6
Machine value loss						
Investment cost						
Maintenance and repair cost						
Raw material cost						
Operator labor						
Utilities cost						
Downtime						
Productivity differential						
Total	$5	$4	$4	$5	$6	$7

The economical time to replace equipment is when the next year's cost of the existing equipment is greater than next year's cost of the new equipment. In the example above, the existing equipment will cost $7/hr next year (year 5), but the new equipment will cost only $5/hr in its first year. So, unless the existing equipment's next year's costs can be reduced somehow by more than $2/hr, it should be replaced.

X. SUMMARY

Engineered equipment costs can be controlled as long as they are managed as part of an overall total cost management plan. Many equipment costs are determined very early in project life during feasibility and preplanning stages. Emphasis should be placed on developing thorough, complete, accurate and professional customer requirements and conceptual design proposal documents so that equipment is fully designed and the project has adequate scope definition before the budget estimate is in place.

Much of the accuracy in equipment cost estimates, and the control during engineering and construction is best managed by project team members. So, in large part, cost success is a function of the knowledge, experience, dedication, and diligence of the project team. Place appropriate emphasis on selecting and retaining the best team members available.

Effective cost control is more likely to occur within an environment that is set up to facilitate cost management. That environment is a project management setting that includes total cost management. Project management and total cost management insure that the right equipment is selected, for the right cost, on time, and that it provides optimal functionality—in short that the equipment cost, quality, schedule and functionality are responsive to the customer.

Maintain complete and detailed documentation to support equipment justification, to prevent and prepare for claims for extras and schedule delays, to record the bases for cost estimates, to provide written evidence of quality, and to document progress.

Use cost management techniques such as present value analysis, value engineering, cost risk analysis, and earned value analysis to insure that cost risk is minimized and cost control is optimized.

Select the right contract type for your equipment job, and establish good rapport with your suppliers to take advantage of the opportunities available during procurement to control equipment purchase costs.

Conduct drawing, manufacturability, constructability, and potential problem reviews to take advantage of the expertise of others. Reviews will help insure that current activities are planned and executed with subsequent activities in mind.

Organize and set up a control center that directly confronts complexity, inadequate communication, and other causes of potential cost overruns during installation—one of the points in the project life cycle with the greatest opportunity for cost overrun.

Engineered equipment costs include those that occur after the equipment is installed. Be sure to consider post-installation costs (i.e., life cycle costing) when reporting equipment cost, comparing alternatives, and considering replacement.

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Controlling the Cost of Materials

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I. INTRODUCTION

One of the keys to a successful project is the ability to define requirements at the beginning. The second key is to then monitor and control the acquisition and use of those requirements as the project moves through its life cycle. Successful projects also exhibit the ability to define, incorporate, monitor, and control changes to those requirements in a timely and cost efficient fashion. Chapters 4 and 5 have already discussed the process of defining the up-front requirements of a project for engineered and installed equipment and bulk materials, and then estimating those requirements in terms of both quantities and costs. Chapter 15 discussed the cost control process and implementation, as well as various cost control methodologies. This chapter will discuss monitoring and controlling material costs and quantities for all types of material, including engineered and installed equipment, for bulk items such as piping, electrical and instrumentation, and for subcontracted services. The chapter will define terms, management strategies, methodologies and techniques for monitoring and controlling material quantities, and costs. Examples of spreadsheets and report formats that may be used to accomplish the above goals are shown in the figures. These examples may be used "as is" or tailored to meet your specific project requirements. They are included to serve as a starting point to effectively monitor and control the material quantities and costs for your project.

II. DEFINITIONS

The following definitions are taken, where possible, from *AACE International's Standard Cost Engineering Terminology, AACE Recommended Practices and Standards.*

Accrual An expense or cost that has been incurred or earned during a particular period, but which has not yet been paid.

Bid conditioning The process of working with suppliers and vendors to fully understand their bid to assure that the bid meets all the required technical specifications and to attempt to arrive at the most advantageous pricing.

Commitment The sum of all financial obligations made, including incurred costs and expenditures, as well as obligations, for goods and services that will not be acquired or performed until a later date.

Consumables Supplies and materials that are used up during construction. Includes utilities, fuel and lubricants, welding supplies, worker's supplies, medical supplies, etc.

Control Management action, either preplanned to achieve the desired result or taken as a corrective measure prompted by the monitoring process.

Cost The amount measured in money, cash expended, or liability incurred, in consideration of goods and/or services received.

Direct cost In construction, the cost of installed equipment, material and labor directly involved in the physical construction of the permanent facility. In manufacturing, service and other nonconstruction industries, the portion of operating costs that is generally assignable to a specific product or process area.

Expense Expenditures of short-term value, including depreciation, as opposed to land and other fixed capital.

Field cost Engineering and construction costs associated with the field site, rather than with the home office.

Field labor overhead The sum of the cost of payroll burden, temporary construction facilities, consumables, field supervision, and construction tools and equipment.

Indirect costs In construction, all costs that do not become a final part of the installation, but which are required for the completion of the project. These may include field administration, capital tools, direct supervision, start-up costs, contractor's fees, and insurance costs. In manufacturing, costs that are not directly assignable to the end product or process.

Local cost In foreign work, the cost of local labor, equipment, construction materials, taxes and insurance, incorporated in a construction project, using local currencies.

Material cost The cost of everything of a substantial nature that is essential to the construction or operation of a facility, both of direct and indirect natures. Generally includes all manufactured equipment as a basic part.

Material requirements planning (MRP) A system that uses bills of material inventory, open order data, and master production schedule data to calculate requirements for materials. It makes recommendations to release replenishment orders for material. Further, since it is time-phased, it makes recommendations to reschedule open orders when due dates and need dates are not in phase.

Monitoring The periodic gathering, validating, and analyzing of data on project status to determine any existing or potential problem areas. Can include on-site inspection and other methods.

Planning bill of material An artificial grouping of items, in bill of material format, used to facilitate master scheduling or material planning.

Price The amount of money asked or given for a product or service (e.g., exchange value).

Procurement The acquisition (and related activities) of equipment, materials, and nonpersonal services, by such means as purchasing, renting, leasing, contracting, or bartering, but not by seizure, condemnation, or donation.

Purchase Material items or nonpersonal services that are acquired through the use of a Purchase Order system.

Qualification submittal Data pertaining to a bidder's qualifications that are submitted as set forth in the bidder's instructions.

Quality assurance All those planned or systematic actions necessary to provide adequate confidence that a product, process, or service will conform to established requirements.

Quality control Inspection, test, evaluation or other necessary action to verify that a product, process, or service conform to established requirements or specifications.

Rental (leased) equipment cost The amount that the owner of the equipment (lessor) charges to the lessee for use of the equipment.

Requirement An established requisite characteristic of a product, process or service. A characteristic is a chemical or physical property, a dimension, a temperature, a pressure, or any other specification used to define the nature of the product, process or service.

Salvage value The cost recovered or that could be recovered from a used property when removed, sold, or scrapped. Also, the market value of a machine or facility at any point in time.

Specification, design A detailed written and/or graphic presentation of the required properties of a product, material, or piece of equipment, including a description of its' fabrication, erection, and installation.

Specification, performance A statement or required results, verifiable as meeting stipulated criteria, generally free of instruction as to the method of accomplishment.

Subcontract Any agreement or arrangement between a contractor and any person in which the parties do not stand in the relationship of an employer and employee and where neither party is the owner.

Subcontractor An individual, partnership, corporation, joint venture, or other combination thereof having a direct contract with the contractor or with any other subcontractor for the performance of a part of the work at the project site.

Sunk cost A cost that has already been incurred and that should not be considered in a new investment decision.

Take off Measuring and listing from drawings the quantities of materials required in order to price their cost of supply and installation in an estimate and to proceed with their procurement.

Termination Actions by the owner, in accordance with the contract clauses, to end, in whole or in part, the services of the contractor. Termination may be for the convenience of the owner or for default by the contractor.

Terms of payment Defines a specific time schedule for payment of goods and services and usually forms the basis for any contract price adjustments that are subject to escalation.

Time extension An increase in the contract time by modification to complete an item of work. Time extension may be granted under the corresponding provisions in the general conditions. An excusable delay generally entitles a contractor to a time extension.

Total cost bidding A method of establishing the purchase price of movable equipment. The buyer is guaranteed that the maintenance will not exceed a set maximum amount for a fixed period of time and that the equipment will be repurchased at a set minimum price when the period ends.

Variation in estimated quantity The difference between the quantity estimated in the bid schedule and the quantity actually required to complete the bid item. Negotiation or adjustment for variance is generally called for when an increase or decrease exceeds 15 percent.

III. "UP-FRONT" PLANNING EFFORTS

The first key to controlling material quantities and costs is to ensure that the scope of work is as fully defined as possible in the design and cost estimating phases of the project. The ideal situation is to have the project fully designed and specified prior to beginning construction or installation. Numerous variables, such as market conditions, owner requirements, and weather restrictions may render it impossible to have the project completely designed and specified before construction or manufacturing begins. The typical project will move through several phases, during each of which the scope will become more and more defined. The cost estimating efforts described in Chapters 4 and 5 will also move through several phases, with the quantities required for the project becoming more and more defined. As the design drawings and specifications become finalized, material take-offs will be performed to determine the quantity of materials, equipment and subcontract services. These quantities are then multiplied by appropriate unit prices to determine the estimated costs for the materials.

It is not unusual for construction or installation on a project to begin when the detailed design definition is only 30–40% complete. When this happens, it is imperative that the scope of the work for the first activities (normally mobilization, construction of temporary facilities, site improvements and purchase of consumable items) be fully defined. The material quantities and estimated costs will then be known for these activities and procurement of the necessary materials, equipment, and services can be accomplished within the scheduled time frame. As more of the project becomes defined, additional information will become available concerning material quantities and costs of subsequent activities. Procurement can then begin for those items. For manufacturing projects, the associated support facilities (such as the equipment required for manufacture of the specified part, offices for personnel, warehousing space, and utilities) may already exist. In this case, the first activities will be procurement of the required direct and expense materials for the manufacturing process.

One management tool that is often overlooked on all types of projects is the development and use of a detailed procurement and production schedule that describes those activities that must take place prior to a procurement action. These activities may include the development of a Request for Proposal (RFP), the evaluation of contractor's bids, and bid conditioning, if required. The schedule should also address those activities that must occur while the procurement process is taking place (on-site inspections, vendor drawing and data transmittals, checkout procedures, and start-up). This procurement schedule is the logical "tie-in" between the design activities and the construction, installation or manufacturing effort, since it defines when items should be procured and when they will be available at the site or facility. The schedule may be part of an overall Material Requirements Planning (MRP) or Materials Management System (MMS). An MRP or MMS uses planning bills of material inventory and open order data to calculate requirements for materials. A systems overview of the field portion of an MMS is

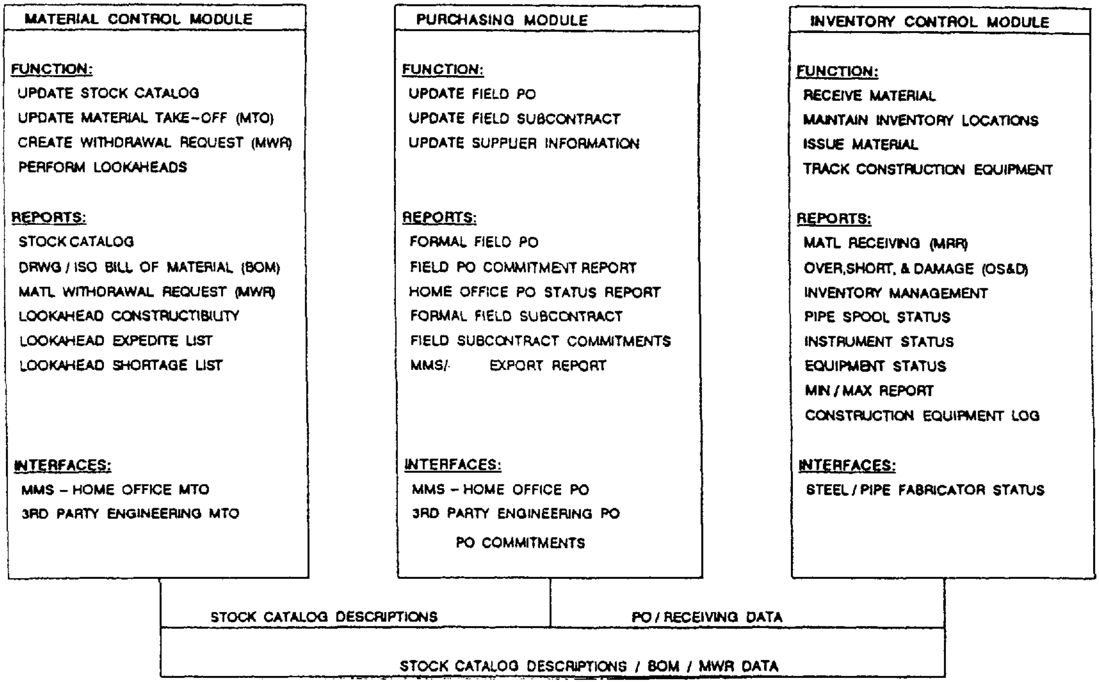

Figure 1 Materials management field procedure—systems overview (MMS).

provided in Figure 1. Very often, the procurement of major or "long-lead" items will determine the critical path of the schedule, and therefore, the finish date of the project. There may also be mismatches in dates between when information such as drawings and specifications is required and when the information can actually be supplied. These problem areas can be identified and resolved early in the planning stages through the use of interactive planning sessions. Interactive planning involves all members of the project team (including owners, contractors, vendors, subcontractors and suppliers) in the development of the project schedule. Conflicts in the scheduled activities are highlighted at an early stage and actions can then be implemented to overcome and resolve the conflicts. The outcome of an interactive planning session will be a realistic schedule that is understood by all and that can be supported by the members of the project team.

IV. COST CONTROL PROCESS AND METHODOLOGY

Chapter 15 discussed and defined the Cost Control Process. The general processes, methodologies, and techniques described in that chapter can be applied to the control and monitoring of material quantities and costs, as well. The following sections of this chapter will discuss control and management techniques that may be applied specifically for material, engineered equipment items and subcontract services.

V. METHODOLOGIES FOR CONTROLLING QUANTITIES AND COSTS

The preceding sections emphasized the importance of having the project as fully specified and defined as possible before the procurement of material, engineered equipment items, and services begins. A well-defined scope of work is the single most important management tool for controlling a project. Once the scope is fully defined, changes to the project must be minimized, in order to control additional costs. In the real world of changing weather conditions, market conditions, and owner's requirements, this is not always possible. Hence, it is imperative that at each stage of the project, the scope of work be as fully defined as possible, that every effort be made to control and monitor changes, and to integrate the cost impact of those changes in a timely manner. In addition, there are several management techniques and methodologies that may be used to support the control process. These techniques and methodologies are discussed in the sections below.

Date:
Revision:

Materials procurement and subcontract plan

Client::
Location:
Unit:
Project:

Acc. code	Item description	Eng specs by	Data shts/ dwgs by	Material take-off by	Inq/ pur req by	Procurement				Expediting		Installation		Inspection			Remarks
						Home off.	Field	Client	Other	Equip	Vend data	Client	Other	Home off.	Field	Client	
01	Pumps and drivers																
05	Agitators, mixers																
11	Heat exchangers																
12	Columns (T-510,520,530,540,550)																
12	Trays																
13	Vessels, pressure (shop) (D-511,512,519,520,530,540,550,560,580,590)																
13	Vessels, pressure (field) (D-570)																
14	Reactors (R-515 A/B)																
22	Filters, strainers (F-513,S-529)																

Legend

Note: Subcontractors are summarized on last page of report

Client:

CL-Client

PR-Project
M-Mechanical
C-Civil
S-Structural
IN-Inspection

PRO-Process
P-Piping
E-Electrical
I-Instrument
MC-Material control
F-Field

Home Office or Field S\C
FAB-Equip Fabricator
FSC-Field subcontract
HSC-Houston office subcontract
PSF-Pipe shop fabricator
SSF-Structural steel fabricator

Figure 2 Materials procurement and subcontract plan.

A. Materials Procurement and Subcontracting Strategy

Prior to the start of the purchasing process, the project strategy must be developed so that all members of the project team have a clear understanding of what types of documents and contracts will be used for what types of materials and services. The use of a Fixed Price (i.e., Lump Sum) contract exposes the purchaser to the least amount of risk at the start. However, the scope of the work must be fully defined to allow the vendors and suppliers to submit a complete quotation. As items change within the scope of work, the subcontractor or supplier will ask for subcontract modifications, changes, or contract time extensions. This can then result in higher costs than if some other procurement approach had been used.

Other types of strategies that projects may use include cost plus award fee (CPAF) contracts, cost plus fixed fee (CPFF) contracts and cost plus incentive fee contracts. Another approach for movable equipment is to use Total Cost Bidding. In addition, it should be decided in advance as to which items will be purchased and which items will be rented. An example of a Materials Procurement and Subcontract Plan form is provided in Figure 2.

Decisions should also be made as to what type of specifications will be used for procurement of materials and services. In most cases, a full set of engineered specifications will be used to define the material or service being procured. In other cases, performance specifications may be used that only generally define the desired outcome of the procurement. The vendor or subcontractor must then decide how best to meet the desired outcome.

B. Subcontractor Bid Conditioning

Bid conditioning is the process of working with vendors and suppliers, up-front in the procurement process, to attempt to achieve the best quality, at the best price, within the best time frame. On private sector projects (those projects that are performed for a private client rather than a government entity), the materials management, procurement, and project personnel will work with the vendors and suppliers from the start of the initial development of the RFP. The vendors may be asked for information concerning specific types of materials, information on lead times to obtain the materials and perhaps information on specialty types of items that may be required or special types of services that may need to be performed. This information will then be incorporated into the RFP that is sent to the suppliers. Working with the vendors and suppliers up-front, in a true team approach, can help to accelerate the schedule, mitigate delays, answer questions both on the part of the purchaser and the vendor, and translate into a smoother procurement process.

Project:	Client: M/R Test-Math	Widgets	Job
Bidder			
Ranking			
Technically acceptable			
Gross price	0.00	0.00	0.00
Discount (percent)			
Net price FOB factory	0.00	0.00	0.00
Progress payments/cost of money			
Special charges			
FOB/FAS point			
Freight charges			
Total evaluated cost to destinatlon	0.00	0.00	0.00
Terms of payment			
Escalatlon (Yes/No)			
Accepts project terms and conditions			
Promised delivery date based on award by			
Shipping weight - lb/cube			
Expiration date of bidder's quotation			
Small, minority or women owned business			
Budget: 0.00 Req. date:			
Reccommended supplier	Selection factors		
	Price:____________		
	Delivery:____________		
	Client pref.:__________		
	Other:____________		

Approvals	Engr	Proj. Engr.	Proc. Mgr.	Proj. Engr.	CO/BL	Client
	Date	Date	Date	Date	Date	Date

Figure 3 Summary of bids form.

This will assist the project in controlling costs for the procurement process, and help to assure that the project receives the best value for the money. For government projects, the above process can take place to some degree. However, care must be taken that all vendors are treated equally, and that there is no indication of favoritism or price fixing. In addition, those procurement actions that consider only one vendor because of the type of material being purchased require extensive justification for "sole-source." Dealing with government regulations in the area of procurement can add both time and cost to the project. These actions must be recognized at the beginning of the process and adequately planned. Every attempt should be made to streamline the process as much as possible.

Once the bids have been received from the vendors, they must be evaluated by the Procurement personnel, the Project Manager or Project Engineer, Discipline or Specialty Lead personnel, and the Project Controls personnel. A bid analysis should be performed that places the bids from all vendors on an equal basis, and can then lead to a logical and justifiable decision as to the "winning" bidder. Again, interaction with the bidders may be necessary during this evaluation process to clarify pricing and delivery requirements, to assure that the materials being quoted meet the required specifications, and to allow the analysis to proceed in an expedited fashion. The bid analysis should add all the evaluation criteria and other factors together to arrive at a weighting system. The evaluation criteria need to be established at the beginning of the process, and should be included as part of the RFP. Examples of evaluation criteria include cost, delivery, management expertise, corporate background, plant capacity, and financial stability. The evaluation criteria will differ if materials versus services are being obtained. The evaluation process should take place for major material items, as well as subcontracts. All members of the evaluation team will be able to evaluate the bids from a different perspective. The Project Manager, Project Engineer, or applicable Discipline Engineer can evaluate the bids from the technical standpoint. Project Controls personnel can evaluate the bids from the cost and schedule perspective, while the Procurement personnel can review the terms and conditions of the quotations. Examples of Bid and Proposal Evaluation forms are shown in Figures 3 and 4 respectively. A Project Controls Financial Analysis for Bids is provided in Figure 5.

The bids need to be "normalized" so that the comparison is valid. This may mean that costs are added to some bids to come to a true bottom line cost or that additional items need to be considered for freight, delivery, and management oversight. A cost/benefit analysis should be performed that addresses what additional benefits (if any) may be derived from going to the higher (or lower) cost bidder. In addition, value engineering may be used to achieve the best quality for the lowest price. For private sector projects, the

Contract No.	______________		
Bidder	______________		
Evaluator	______________		

Section A—Commercial

1. Total estimated cost		$ ______	
2. Total fixed fee		$ ______	
3. Total cost plus fixed fee or lump sum		$ ______	
4. Average salary per hour		$ ______	
5. Payroll burden	$ ______		% ______
6. Labor overhead	$ ______		% ______
7. Reimbursables:			
Travel	$ ______		% ______
Computer	$ ______		% ______
Postage	$ ______		% ______
Telephone	$ ______		% ______
8. Subcontractors MHS	$ ______		% ______
9. Total manhours	______		
10. Fee as a percent of total cost	% ______		
11. Total estimated cost # manhours proposed × average cost/hr	$ ______		

Section B—Responsiveness to Invitation

	Included in + proposal?	
	Yes	No
1. Bid letter	Yes	No
2. Technical approach	Yes	No
3. Schedule	Yes	No
4. Manhour expenditure curve	Yes	No
5. Cash flow curve	Yes	No
6. Subcontractors	Yes	No
7. Experience	Yes	No
8. Organization chart	Yes	No
9. Project personnel resumes	Yes	No
10. Computer programs	Yes	No
11. Completed cost exhibit	Yes	No
12. Acknowledged addendum	Yes	No
13. Attended site visit	Yes	No
14. Submitted bid on time	Yes	No

Section C—Contractual

Comments or exceptions to owner's contract.

Figure 4 Proposal evaluation form.

___

Section D—Technical Approach

1. Quality of technical approach		Max. points ______
Comments:		Initial score ______
______		Final score ______
2. Past experience of bidder		Max. points ______
Comments:		Initial score ______
______		Final score ______
3. Personnel qualifications		Max. points ______
Comments:		Initial score ______
______		Final score ______
4. Management organization		Max. points ______
Comments:		Initial score ______
______		Final score ______
	Grand total	Max. points ______
		Initial score ______
(Point range: 50–200 total points)		Final score ______

Section E—Project Control

1. Quality of schedule		Max. points ______
Comments:		Initial score ______
______		Final score ______
2. Quality of cash-flow curve		Max. points ______
Comments:		Initial score ______
______		Final score ______
3. Quality of manhour expenditure curve		Max. points ______
Comments:		Initial score ______
______		Final score ______
4. Evaluation of proposed project control personnel		Max. points ______
Comments:		Initial score ______
______		Final score ______
5. Evaluation of proposed project control systems and procedures		Max. points ______
		Initial score ______
Comments:		Final score ______
______		
6. Other		Max. points ______
______		Initial score ______
______		Final score ______
	Grand total	Max. points ______
		Initial score ______
(Point range: 50–200 total points)		Final score ______

Section F—Additional Clarification Needed to Evaluate Proposal

______

______

Figure 4 (Continued).

Project Control Financial Analysis

Project:

Contractor	Total costs (incl. fee)	Total man-hours	Duration	Overhead		Burden		Fee		Subcontracts or consultants		Communications		Repro	
					%		%		%		%		%		%

Figure 5 Project control financial analysis form.

Project Control Financial Analysis

Project

Contractor	Reimbursables (% of total)																Overall proposal	General comments
	Travel		Insurance		Computer		Postage		Drafting machines		Word processing							
		%		%		%		%		%		%						

Figure 5 (Continued).

lowest bidder need not be selected if there are other overriding factors, such as better delivery time or if better materials are being proposed. For government projects, the lowest bidder that meets the technical specifications must be selected.

Once the winning vendor has been selected, the procurement personnel should hold a kickoff meeting (by teleconference or in person) for major items, specialty items, or those items that have very long lead times. At this meeting, the bid conditioning process can continue and further refinements to the price and schedule may be achieved. For "normal" bulk items, such as piping, conduit, wire and the like, discussions should be held with the vendor concerning their manufacturing process, how orders are processed through their plant, who to contact with questions and/or problems and how the material will be delivered to the project. Also, at this meeting, it is very important for the project staff to have as much information as possible to give to the vendor. Every requirement, whether it is for vendor drawings, site inspections, delivery or quality assurance/quality control, should be clearly addressed in the procurement documents. Again, this should take place for major items, specialty items, and long-lead items. However, the procurement documents for other bulk items, such as piping, conduit, wiring, clamps, etc., should clearly define the requirements as well. This clear definition of what is required and when it is required, will help to expedite the acquisition of the item, help to keep the project on schedule and assist in controlling the costs.

C. Controlling Changes to Quantities and Costs

Once the scope of the project is fully defined, it then becomes necessary to control and monitor changes to that scope. Changes may be brought on by the owner, the project team, or by a subcontractor or vendor. All projects will experience change. The important thing is to be prepared for that change and to have some method of identifying the change, quantifying the impact of the change on both quantities and costs, and for incorporating the cost impact of the change.

One recommended system is the use of trend, change notice, and change order documents. The trend form is used when the scope of the change is not fully defined. It contains a general description of the change and a Rough Order of Magnitude (ROM) cost for the change. The document is then reviewed with the initiator of the change, the Project Manager and the owner. A change notice is used to identify a change to scope that is (usually) being requested by the owner. Again, it includes a description of the change and a ROM cost. The owner is asked to sign the change notice to acknowledge that the change is valid and to authorize the effort to fully define the scope and costs. Once the change order is completed, it is reviewed with the owner. The owner signs the change order. It is during this stage that the control of the quantities and costs becomes most important. The project team must be sensitive to the fact that no changes can be made to the scope of the work without written authorization. This includes changes to the design by the engineering group, changes to the installation in the field or changes to quantities on procurement documents. It is even more important that, once the change has been approved, it is incorporated into the cost control and reporting system in a timely manner. Any changes to the Estimate at Completion (EAC) or Total Installed Cost (TIC) that are based on changes to the quantities must be fully explained by the Project Manager in the monthly cost report. Any procurement document must be reviewed by Project Controls, and the quantities and costs must be compared to the control estimate to identify discrepancies. If the cost of procuring the item is more than what was estimated, and the Project Manager approves the procurement document at the higher amount, then trending is used to incorporate the difference into the EAC. Examples of Trends/Change Notices, Authorization for Extra Work, and Change Notice Log forms are provided in Figures 6, 7, and 8 respectively.

D. Responsibilities

Below is a generalized statement of responsibilities for the key project team members involved in controlling material quantities and costs. (It should be realized that these can only serve as suggestions, and that the organizational structure of your company will most likely define these responsibilities.)

Project Manager

The Project Manager should review and approve all project requisitions, purchase orders, and subcontracts. In addition, he/she should participate in the bid evaluation process and should insure that the Site Manager or Construction Manager receives all copies of purchasing documents, including purchase orders and subcontracts. The Project Manager should review the costs for procurement of the necessary items on at least a monthly basis, and may want to review them on a more frequent basis.

Project Engineering

It is the responsibility of Project Engineering to design and specify the equipment and materials to meet the customer's requirements and expectations. As changes are made to the design, this information should be given to the Project Controls group to incorporate into the latest Estimate at Completion (EAC). Project Engineering should also review any requested changes for validity prior to incorporating them into the design.

TREND/CHANGE NOTICE: IMMEDIATE ACTION REQUIRED

Trend ☐ Change Notice ☐ CN No: Orig. code:

Client name: Date:

Project title: Project No:

No Work Will Proceed On This Change Except As Directed Below

Description of change: ______________________

☐ Additional information attached ______________________

Justification for change: ______________________

Reference documents: ______________________

Rough order-of-magnitude estimate:	Home office services	$	(Hours:)
	Construction costs	$	
	Total	$	

Schedule impact:

Change originated by: ☐ Client ☐ Firm Name of originator:

Change validated by: Sr. Proj. Engr./Proj. Arch.: ☐ Date:

Design coordinator: ☐ Date:

Firm approval:

☐ Submit for client approval
☐ Rejected; take no further action
☐ Internal change; Proceed with work and prepare detailed estimate
☐ Internal change; prepare detailed estimate but do not proceed with work until authorized

Comments:

Project manager: Date:

Client approval:

Please indicate below how you wish firm to proceed. If you authorize firm to proceed with the work and/or preparation of the change order, then firm will be due all costs associated with the work, including the preparation of the change order.

Please note that the accuracy of the estimates above is rough order-of-magnitude only.

☐ Proceed with work and prepare change order/trend report.
☐ Proceed with change order only; do not proceed with work.
☐ Rejected; take no further action.

Comments:

Authorized representative: Date:

Figure 6 Trend/change notice form.

AUTHORIZATION FOR EXTRA WORK

Client ______________________ Project No. ______

Project ______________________ Change order No. ______

Location ______________________ Date ______

Architect(s) is authorized to proceed with the following work:

Acct#	Item	Material	Subcontract	Labor	Total
	M&L Subtotal				
	Professional services				
	Other direct home office cost				
	_____% Professional services				
	Subtotal				
	Contingency ____% total				
	Subtotal				
	Fee ____% total				
	Time delay charge				
	____ Days @ ____				
	This order—net change				
	Total previous orders—net change				
	Total change to date				
	Original contract total				
	New contract total				

Accepted for client		Engineering firm	
By	______________________	By	______________________
Title	______________________	Title	______________________
Date	______________________	Date	______________________

Figure 7 Authorization for extra work form.

Change Notice Log

Client:		Action codes:	P-Proceed				Page no. of	
Project title:			PCO-Proceed with Change Order Only					
Project No.:			R-Rejected					
Change notice number	Description	ROM estimate amount	Date to PM	Date to client	Client action	Date of action	Change order number	Remarks

Figure 8 Change notice log.

Site/Construction Manager

The Site or Construction Manager is responsible for reviewing and understanding the scopes of work as presented in the purchase orders and subcontracts, for participating in the bid evaluation process, for developing and maintaining a system to record quantities of daily field activities, for reporting the field quantities into the cost reporting and control system on a monthly basis, and for reviewing and approving all field invoices. The Site Manager should also review all requested changes to the construction or installation effort. These field generated changes should be given to the Project Controls group (either in the home office or in the field) for inclusion into the latest estimate at completion (EAC).

Project Controls

Project Controls personnel should participate in the bid evaluations, review and approve all procurement documents from a cost and schedule standpoint, incorporate the field quantities into the cost reporting system, produce a meaningful cost report on a regular basis and analyze cost data, variances and trends. In addition, Project Controls should track the estimated costs of any changes provided by engineering or the field staff as they occur in order to develop the latest EAC for the project.

Procurement

Procurement personnel should develop and generate all purchase orders and subcontracts, provide draft RFPs to the applicable parties prior to their issuance, work closely with vendors and suppliers throughout the procurement process, and participate in the bid evaluation process. In addition, if the project is for a government entity, the procurement personnel must insure that their system meets all applicable codes and regulations for doing business with that entity.

E. Procurement and Cost Tracking Systems

Since every company will differ with respect to the specific systems that are used, this section will describe the general attributes of systems for both procurement and cost tracking. It is imperative that some sort of procurement system be used that will provide the Project Manager, Project Engineer and Project Controls with accurate data concerning procurement actions. The data should be provided on a regular basis (normally monthly, but can be on a more frequent basis if needed). In fact, the best system would allow for continuous, on-line access. The procurement system should provide information about what purchase orders, purchase requisitions or subcontracts have been issued (both cumulative and for the reporting period), what materials

Reported by ____________________ Date ________
Subcontractor ____________________ Driller ________
Drill rig # & type ______________ # Helpers this date ________
Arr. time:_____ Start time:____ Finish time:_____ Dep. time:____

Site #/boring #		Footage drilled	Soil samples (# sent to lab)		Soil—gas samples (# canister dup.)	# Water samples	
1.							
2.							
3.							
4.							

Standby or downtime with explanation and corrective action taken:

Notes, unusual happenings, auger refusal, high contamination, etc.:

Figure 9 Daily field report form.

and services the documents were issued for, what the committed cost of the materials and services will be, what invoices have been received from the vendors and suppliers and which of those invoices have been paid.

A cost tracking and reporting system that can be updated with any changes to the budget (both in terms of quantities and costs), with actual costs as they are committed or expended and with the latest EAC should also be used. Project Controls, in conjunction with the Project Manager and Procurement, should develop the methodology for incorporating the commitment information and changes to quantities and costs into the company or customer cost tracking and reporting system. Methodologies for handling commitments and accruals are discussed below.

F. Handling of Commitments and Accruals

As discussed above, a procurement tracking system must maintain an accurate accounting of committed costs. Project Controls must have access to this system (either on-line or through hard copy reports) to identify the total commitments on an at least monthly basis for comparison to the project budget. For the majority of procurement actions, the committed costs may be identified immediately as incurred cost or actual expenditure. For a relatively few procurement actions, the costs may not be realized for some time after the action. Long-lead equipment and materials, as well as subcontracts fall into this latter category. For these actions, a system must be in place to identify the costs as they are accrued throughout the life of the purchase order or subcontract. These accrued costs will ultimately be identified on an approved vendor or subcontractor invoice, but estimation of the accrued cost is necessary to support timely budget status reporting.

One method of accomplishing the accrual of costs for long-lead items, for fabricated items and for field activities is through the use of a Daily Field Report (Figure 9). This requirement is included in the procurement documents. The vendor or subcontractor must provide a Daily Field Report to the designated project representative (either the Project Engineer or Site Manager). The Daily Field Report outlines the work that has been accomplished for the day, in terms of the quantities established in the procurement documents. For example, if a subcontractor is drilling monitoring wells, the pricing will normally be done on a cost/vertical lineal ft. At the end of the day, the subcontractor would provide a report showing how many feet had been drilled. The report would be signed off by the field representative. At the end of a week, the reports are compiled to determine the total amount of work accomplished for the week. This quantity is then multiplied by the negotiated cost to determine the accrued cost. The accrued cost can then be included in the cost tracking and reporting system, either as an "actual" cost or separately added to the true actual expenditures that have come through the accounting system. If the accrual is included in with the actual costs, reconciliation will be necessary on a monthly basis when the subcontractor's invoice has been paid and ultimately is reflected in the accounting system. This comparison to actual payments to date will provide insight into accrued costs that are not yet reflected in the "official" accounting system. This outstanding accrual amount can then be taken into consideration when developing the EAC for the activity or task.

The Project Manager or Project Engineer, with assistance from Project Controls, defines the criteria to determine which procurement actions will be subject to accruals reporting. As noted above, these items may include long-term fabrication of supplies or materials, any substantial one-time purchases and subcontracts. Certain "open-ended" procurement actions, such as equipment rental, are also included. An objective means of measuring the completion of the fabrication or subcontract should be developed. One approach is to identify major milestones within the overall fabrication or subcontract activity. Examples of these milestones could be Mobilization, Submittal of Vendor Drawings, Site Inspection, or other key activities. The milestones are then proportionally weighted so that a valid percent complete for the activity can be calculated. For instance, the subcontractor may submit a bid that has Mobilization to the Field as 10% of the total costs. Once the subcontractor has mobilized, credit can be taken for that activity and 10% of the total cost can be accrued.

Project Controls should verify the reports from the procurement reporting system for purposes of commitment and accruals tracking. The total commitments for the project are determined by adding the cost of the labor expended to date, plus the committed costs for all procurement actions. This committed cost is then related to the budget cost for the project, either on an activity basis (such as piping, electrical, or concrete) or on a total project basis.

Project Controls should also obtain the status of the procurement actions that have been developed for accrual reporting purposes. The current accruals should be reported on the monthly cost report as a separate item from the "expended" to date costs. This will alleviate the problem of including accruals in with the actual costs, and then having to perform a monthly reconciliation between the accruals and the actuals. The accrued costs and actual expended costs are also compared to the budget and committed costs. This can be done in a tabular or graphical format.

G. Reporting Requirements

The reporting requirements for a project will vary. Since the requirements will be project-specific, the examples provided in the figures show typical formats that may be used for trends, change notices, bid evaluations, and cost reports.

VI. INVENTORY MANAGEMENT

A system to track deliveries, storage, damage, and use of the procured materials and items is also required. The system should include means to handle the acceptance and checking of materials received, to identify shortages, and to identify which materials have been issued for construction or installation. Materials personnel and on-site Engineering personnel must coordinate the materials that have been ordered with the materials that have been received. State of the art systems use bar coding to track the acquisition and use of materials.

VII. SUMMARY

The purpose of this chapter has been to provide practical techniques for controlling material quantities and costs. Forms that may be modified or used "as is" have been provided as a starting point. In addition, it is hoped that the reader has gained a greater appreciation for tools and management techniques that can help create a successful project.

ACKNOWLEDGEMENTS

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Applying the Principles of Value Engineering

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I. PREFACE

Value engineering (VE) is an important management tool that enhances project teamwork. The VE study may be the first time that various agencies, construction managers, designers, specialists, owners, and VE specialists meet face-to-face to discuss the project design. After working together for three to five days, they get to know each other, and the understanding that results may be even more important than the dollar savings.

While initial cost savings are an important result of a VE workshop, many managers are looking for even more. They want improvements in quality, such as enhanced security, aesthetics, healthier environment, or better acoustics. In addition, life-cycle costs are becoming more important. Some look not only at the facility operation costs, but strive to reduce user operating costs, such as tenant salaries or vehicular operation hours. Some of these goals may result in increased initial costs, which other VE savings may finance.

This text is dedicated to fostering teamwork and improving understanding among project team members. In addition, it is dedicated to achieving cost effectiveness concurrent with enhancing quality. Most of the Section titles follow the Value Engineering job plan. Additional sections cover introductory material, the job plan itself, life-cycle costing, and human factors. The appendices contain additional reference material such as current Federal regulations and discount factors.

II. INTRODUCTION

A. Why Value Engineering?

Because there are many possible design solutions for a given project, the chances are very remote that the initial combination produces the best value. Consequently, we need an explicit, formal, and visible technique to search for the best value combinations. In addition, we need proof that value has been delivered.

More boards of directors, shareholders, members of congress, and taxpayers are no longer relying only on the professional competence of design teams, but are also seeking additional evidence that alternatives have been explored and value delivered. Today more than ever we need to challenge and question the way we have done things in the past, instead of solving new problems with old solutions.

There is a need for a competent cost management and cost containment approach to development—an approach that confronts inflation, erosion of profitability, and the need to improve competitiveness.

B. Setting Value/Investment Objectives

Value, like beauty, is very much in the eye of the beholder. Eight concepts of value include esteem, use, cost, exchange, aesthetics, safety, convenience, culture—there are probably more. We are most often concerned with cost value, but some of the other concepts can be equally as important. As part of the process of defining value, it is imperative that an owner defines at the outset of the project his/her value or investment objectives. However, this is often easier said than done. A few objectives are:

Build at lowest possible cost
Build at historical norm, with or without allowance for inflation
Build at optimum life-cycle cost
Build for maximum return on investment
Build for maximum value within a given capital budget

Some of these objectives present conflicts, but it is vital that they are defined clearly for the benefit of everyone involved.

C. Reasons for Poor Value

No employee or design organization deliberately introduces or causes poor value. Here are ten reason why it often occurs:

1. Lack of information
2. Decisions based on wrong beliefs
3. Habitual thinking
4. Negative attitudes
5. Reluctance to seek advice
6. Shortage of time
7. Changing technology
8. Lack of a yardstick for measuring value
9. Old specifications
10. Poor human relations

In 1965, the Department of Defense conducted a study to determine the sources of opportunity for value engineering (also known as value analysis). The aim of the study was to obtain an indication of range and degree of application. From a sample of 415 successful value changes, the study identified seven factors which were responsible for about 95 percent of the actions that resulted in savings. Predominant among these were excessive cost, additional design effort, advances in technology, and the questioning of specifications.

The study revealed that a single factor was rarely the basis for a value engineering (VE) action. It also revealed that very rarely did change result from VE correcting bad designs. Second-guessing designs to find them deficient provides little value opportunity. Most designs are not performance deficient. They will work as the designer intended. However, it is also true that value improvement is possible with most designs.

D. Common Objections to Value Engineering

The most common reactions to value engineering are: "What's new? We are doing this anyway." To a certain extent, that is true. All of us in the industry are dedicated to obtaining the best value for our investment dollar. However, we tend to do it in an implicit, erratic, informal way. What VE does is provide a *disciplined* approach in the search for value.

Designers may initially tend to be hostile, believing that VE compromises their integrity in some way. However, the VE group does not decide which proposal to accept. These decisions are made by the Owner, original designer, or, most often, group consensus. VE simply tries to get people to think that there might be a better way.

We often hear, "If you are going to use VE, then it is bound to delay the project." Experience suggests that, because VE forces decisions to be made earlier in the project than they are usually required, design time can be shortened with properly managed VE. Simplified construction which results from VE recommendations can reduce construction time. VE can be a fast tracking technique!

VE is not simply a cost-cutting exercise; anyone can do that. Once a client's value objectives have been defined, they are respected as the analysis proceeds.

Obviously VE costs money—is it worth it? If done correctly, the cost of a VE task will be repaid many times over by the savings identified. As one project manager said, "Should you not find substantial savings, that means that we've all done a very good job and will sleep a little better tonight thinking about that!"

E. What VE Can Do for You

VE can respond to situations where estimates predict budget overrun, bids are over the budget, cost problems are suspected, the "gilded lily" is suspected, tests of value are needed, or value improvement is required. Experience indicates that the value of any project can be increased by VE. The Environmental Protection Agency's VE program has produced an $18 return on each dollar invested in VE studies. EPA achieved a 5.6% capital savings on $7.5 billion of construction with enhanced reliability, and EPA limited VE services to the 30% design completion point, with follow-up studies at 60% design.

The Navy's program has produced a $25 return on each dollar invested in VE studies. They achieved an 8.2% capital savings on $5.0 billion of construction. This was accomplished with VE studies being conducted only at 35% design completion. The Navy is now expanding their program to get the benefits of concept and working drawing studies.

Other owners which have implemented successful VE programs include the City of New York, the City of Baltimore, the Corps of Engineers, METRO Seattle, The Port Authority of New York and New Jersey, Department of Defense, the City of Los Angeles, the U.S. Coast Guard, and similar organizations overseas.

An effective VE program can result in benefits to the designer. His/her project will have better cost control; there will be better communication with the owner; decision making can be expedited; design profitability may increase; there should be fewer change orders; and he/she should have a more satisfied client.

Savings of 5–10% of construction cost are regularly obtained through VE. Stated in terms of the initial investment made in VE, returns on investment of 50:1 are common with returns rarely below 10:1. Improvements to cost include both initial and operations/maintenance costs. Other benefits to the owner include a better understanding of the project, better function, improved quality, and a second opinion.

F. History of Value Engineering

The value engineering (VE) technique emerged from the industrial community during the years of World War II. During 1938–1945 every industrial facility was scheduled to maximum capacity, with priorities running higher and higher. Steel production of all types was all totally scheduled as well as copper, bronze, tin, nickel, ball bearings, roller bearings, electrical resistors and capacitors, and all vital products and materials.

Mr. Lawrence Miles was a purchasing engineer in the headquarters of the General Electric Company. Miles was assigned the task of "finding, negotiating for, and getting" a number of vital materials, such as materials to expand production of turbo-superchargers from 50/week to 1,000 for B-24s, and armament parts for expanding production of B-29s. In this environment, it was not possible to stop short of achieving the essential results.

Frequently, suppliers, already over-extended, said "No" to an increased schedule of new, necessary products. In this desperate situation, Miles was forced to basics. "If I can't get the product, I've got to get the function. How can you provide the function by using some machine or labor or material that you can't get?" Time and time again there was a way to do it. Engineering tests and approvals were rushed and schedules met. Thus, "function" grew in vitality and was to later mature into the development of the VE techniques.

During these war years, Miles found that many of the substitutes provided equal or better performance at less cost. The functional approach proved to be so effective that he was never to abandon it.

In 1947, Miles requested the opportunity to establish a research activity in GE's Central Purchasing Department to study this new approach. Miles received the support to develop, refine, and utilize what then was first called value analysis (VA). Based upon the success experienced by General Electric, the concept spread throughout private industry because of its ability to yield a large return for a relatively modest investment.

The first Government organization to implement a formal program was the Department of Defense's Bureau of Ships in 1954 (now the Navy Ships System Command). They called the program "value engineering" to reflect the emphasis on their type of organization which was engineering. This name is now the most commonly used and accepted since the chartering of the Society of American Value Engineers in 1959. However, it was not until late 1961 that the program was formally implemented throughout the Department of Defense.

Before 1961, most of the experience relating to VE dealt primarily with manufactured hardware, yet the methodology of VE was applicable to the design process in general. Establishment of a formal program by the Department of Defense, across the board, involved their design and construction agencies in VE. Between 1963 and 1965 the three military services instituted programs by staffing full-time value engineers and by introducing VE incentive clauses into their construction contracts, permitting contractors to propose VE changes and share in resultant savings.

After a lull during the mid '80s, the Executive Branch and the Legislative Branch interests increased. Hearings have recently occurred on Capitol Hill; the General Accounting Office has published many recommendations encouraging the use of VE; and bills requiring the use of VE are periodically before Congress.

G. Timing of a Value Engineering Study

Two of the most important factors influencing the selection of the appropriate time for applying VE are: 1) The magnitude of the potential savings and 2) The degree of receptivity of the environment in which VE is to be applied. Figures 1 and 2 illustrate the typical life cycle phases for any given facility and portray a common situation in which savings potential decreases with

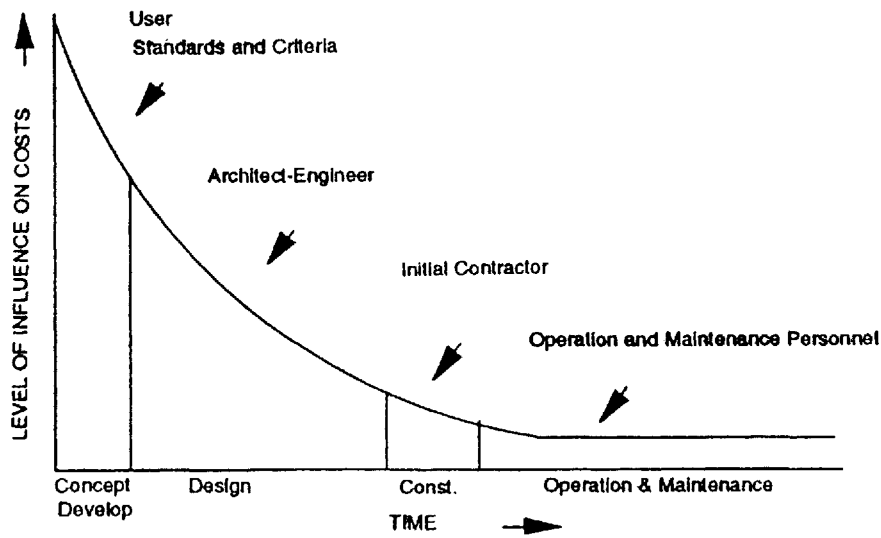

Figure 1 Relative influence of major decision makers on total facility costs.

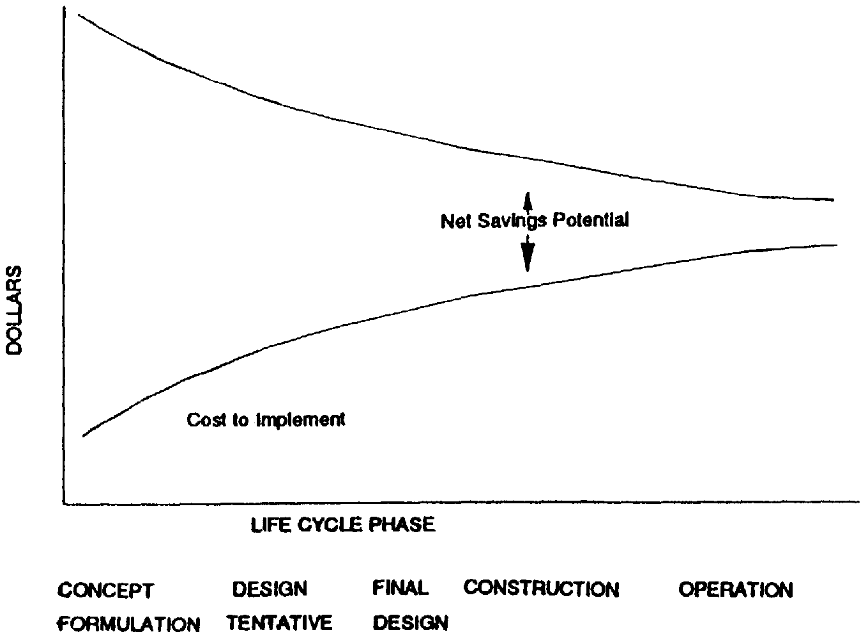

Figure 2 Savings opportunity versus implementation costs.

age. Each phase of a program represents a known baseline that begins broad in content and becomes more and more definitive with time.

The heart of the VE concept is to work against a given baseline in order to change or redirect the baseline and arrive at an end result that will satisfy required functions. For this reason, VE may be applied repeatedly at any point in the life cycle, as new information and details are produced.

However, as illustrated by Figures 1 and 2, the further you are in the life cycle phase, the smaller the cost reduction potential, and the greater the investment required to implement.

III. THE JOB PLAN

A. Introduction

A task accomplished in a planned and systematic manner is likely to be more successful than one which is unplanned and relies upon undisciplined ingenuity. The VE job plan is an expansion of the traditional problem-solving approach.

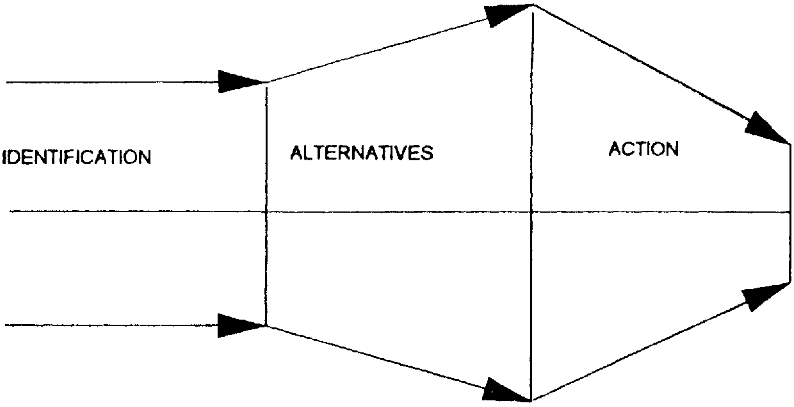

Figure 3 Traditional problem solving method.

The traditional problem-solving method places heavy emphasis on convergent thinking in its three steps: 1) problem identification, 2) generation of alternatives, and 3) decision regarding a course of action. See Figure 3. This traditional method implies there is a distinct problem and a correct answer. Applying this method to a real situation often results in finding an optimum solution to the wrong problem.

The VE job plan produces better results because it stresses an alternating use of divergent and convergent thinking as shown in Figure 4.

B. Why a Definite Plan?

The job plan presents the thought process for accomplishing a study. In addition, it lists tasks required to properly perform a value study. The job plan provides:

A vehicle to carry the study from inception to conclusion
A convenient basis for maintaining a written record of the study as it progresses
A logical separation of the study into units that can be planned, scheduled, budgeted and assessed

C. Phases of the Plan

This text uses the nine-step approach. Actually, there are no sharp lines of distinction between the phases. They tend to overlap in varying degrees and generally studies require some recycling through several phases of the plan.

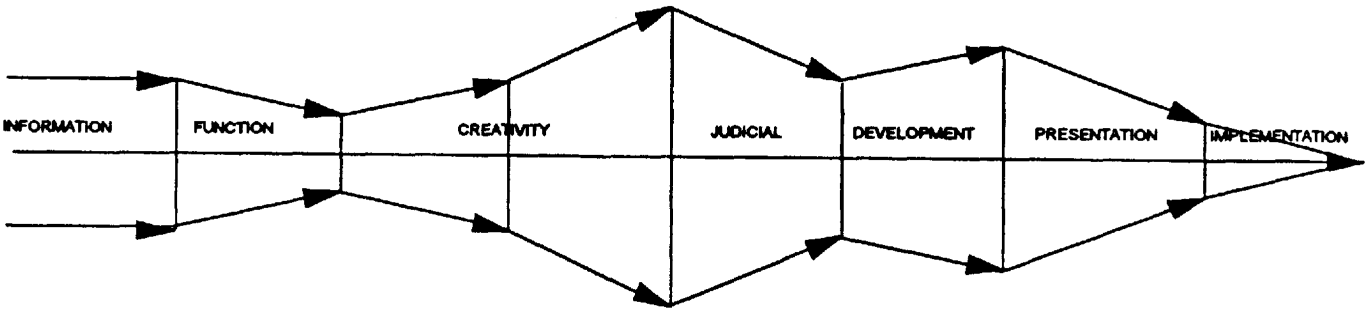

Figure 4 VE job plan rhythm.

An effective VE effort must include all phases of the job plan. However, the proper share of attention given to each phase may differ from one effort to another.

D. The Phases of the Nine Step Model

Phase 1: Selection and Orientation

Objectives. Determine projects and topics that result in the greatest benefit from VE.

Key questions.

1. What are the significant cost elements to the organization?
2. Can these elements be changed?

Phase 2: Information

Objective. Obtain a thorough understanding of the system, operation or item under study by a rigorous review of all the pertinent factual data.

Key questions. During this phase the following key questions must be answered:

1. What is it?
2. What does it cost?

Phase 3: Function

Objective. Identify, define and classify the functions of the study item in order to allocate costs to them and judge their value.

Key questions. During this phase the following key questions must be answered:

1. What does it do?
2. What must it do?
3. What is it worth?

Phase 4: Creative

Objective. Generate, by creative techniques, numerous alternative means for accomplishing the functions selected for cost improvement.

Key question. "What else will do the job (perform the basic functions)?" The completeness and comprehensiveness of the answer to this question determines to a very high degree the effectiveness and caliber of value work and the likelihood of developing an outstanding solution. Additional alternatives which have not been considered will usually exist regardless of the skill and proficiency of the study team.

Phase 5: Judicial

Objective. Now is the time to judge! Select for further analysis and refinement, those most promising ideas from the long "shopping list" of ideas that have been generated.

Key questions.

1. How feasible is each idea?
2. Will each perform the necessary function?

Phase 6 - Development

Objective. Develop selected ideas with the intent of making specific recommendations for change to management. The process involves not only detailed technical development and testing, but also an assessment of the probability of successful implementation.

Key questions.

1. Will it work?
2. Will it meet all necessary requirements?
3. Who has to approve it?
4. What are the implementation problems?
5. What are the costs?
6. What are the savings?

Phase 7 -Presentation

Objective. This phase involves the actual preparation and presentation of the best alternatives to persons having the authority to approve the VE proposals. This phase of the VE job plan includes the following steps:

1. Preparing and presenting the VE proposals.
2. Presenting a plan of action that will ensure implementation of the selected alternatives.
3. Obtaining a decision of positive approval.

Key questions.

1. What is recommended?
2. Who has to approve it?

Phase 8: Implementation

Objective. Ensure that approved recommendations are converted into actions. Until this, savings to offset the cost of the study will not be achieved. Three major objectives of this phase are:

1. Provide assistance, clear up misconceptions, and resolve problems that may develop in the implementation process.
2. Minimize delays encountered by the proposal in the implementation process.
3. Ensure that approved ideas are not modified during the implementation process in such a manner that compromise would cause them to lose their cost effectiveness or basis for original selection.

Phase 9: Follow-up

Objective. This last phase of the job plan has several objectives listed below. They might seem quite diverse but when achieved in total, they will serve to foster and promote the success of subsequent VE efforts.

1. Obtain hard copies of all completed implementation actions.
2. Compare actual results with original expectations.
3. Submit cost savings achievement reports to management.
4. Submit technical cross-feed reports to management.
5. Evaluate conduct of the project to identify problems that arose and recommend corrective action for the next project.
6. Initiate recommendations for potential VE study on ideas evolving from the study just completed.
7. Screen all contributors to the VSP for possible receipt of an award and initiate recommendations for appropriate recognition.

Key questions.

1. Did the idea work?
2. Did the client save money?
3. Would you do it again?
4. Could it benefit others?
5. Have the savings been reported?
6. Has it had proper publicity?
7. Should any awards be made?

E. Summary

The VE job plan can be applied to any subject suitable for a study. In serving as a vehicle to carry the study from inception to conclusion and in observing certain formalities, the job plan: (1) Ensures that consideration is given to all necessary facets of the study. Although the job plan divides the study into a distinct set of work elements, judgment is necessary to determine the depth to which each phase is performed. Each plan must be made in light of the resources available and the results expected. (2) Requires those making the study to clearly define the functions performed by the item under study. (3) Ensures that time is made available for the essential creative work and the necessary analysis of this creative work so that best choices can be made for further development. (4) Leads to the establishment of an effective program aimed at the selection of the best value alternatives. (5) Concludes with specific recommendations, the necessary supporting data, the identification of necessary implementing actions, a proposed implementation schedule and a required follow-up procedure.

The job plan is normally followed in sequence, phase by phase. However, in actual practice it is often necessary to do additional work to a previously completed phase before reaching a decision. Thus, in practice, the phases may overlap broadly, and such early steps as information gathering may continue throughout most of the VE effort. The VE job plan is a planned program that has been tested, is being used, and has proved to be workable.

IV. THE INFORMATION PHASE

A. Phase 2: Collecting Information

Objectives. Obtain thorough understanding of the system, operation, or item under study by a rigorous review of all the pertinent factual data.

Key questions.

1. What is it?
2. What does it cost?

Procedure:

1. Collecting information. All pertinent facts concerning the system, operation, or item must be drawn together. The paramount considerations are getting all the facts and getting them from the best sources. The VE team should gather complete information consistent with the study schedule. All relevant information is important, regardless of how disorganized or unrelated it may seem when gathered. Wait until all facts have been gathered before organizing them. Support data with tangible evidence and copies of all appropriate documents. Document opinions of knowledgeable persons.

Figure 5 provides a checklist of the type of information to seek to assure getting all the facts. Figure 6 is a checklist of sources. In addition to specific

Physical data	Information on physical characteristics such as: shape, dimensions, material, color, density, fire resistance, sound absorption, deflection resistance, components.
Methods data	Information on *how* it is: operated constructed, made, shipped, fabricated, written, developed, installed, packaged, repaired, maintained, organized, managed, controlled, documented.
Performance data	Information on *what* its present performance is, and what its performance requirements should be in areas of accuracy, response time, design, operation, maintenance, utilization.
Restrictive data	Information on required restrictions concerning: tolerances, methods, performance, procedures, operations, time, schedule, cost orders, regulations.
Cost data	Cost of labor, material, equipment, overhead and budgetary data as they relate to: design, development, installation, acquisition, operation, maintenance, and use.
Quantity data	The anticipated volume or repetition of use for the present and future.

Figure 5 Checklist of information types.

People sources	
Government	Users, designers, owners, managers, operators, maintenance forces, specialists.
Commercial	Contractors, fabricators, suppliers, vendors, distributors, consultants, lessors.
Data sources	
Project data	Planning documents, drawings, specifications, sketches, computations, cost estimates, material lists, financial records, schedules, contract forms, scopes of work.
Criteria data	Handbooks, orders, standard specifications, commercial and government standards, published user regulations and requirements, engineering manuals, maintenance manuals.
Experience data	Test reports, maintenance reports, user feedback, technical cross-feed reports.
Commercial data	Catalogs, product literature, technical publications, magazines, trade or professional associations.
Historical data	Libraries, previous studies, data files, management information systems, previous designs and contracts, conference and symposium proceedings.

Figure 6 Checklist of information sources.

knowledge, it is essential to have all available information concerning the technologies involved, and to be aware of the latest technical developments. Knowledge of the various manufacturing, fabrication, or construction processes is essential.

The more information brought to bear on the problem, the more likely the possibility of a substantial cost reduction. Having all the above information would be the ideal situation, but if all of this information is not available, it does not preclude the performance of the VE effort.

2. *Preparing for acceptance.* Gaining acceptance of proposals is of utmost importance to the success of any value study. "People problems" are usually more difficult to resolve than technical problems. The effectiveness of a person's efforts depends upon the amount of cooperation he or she is able to obtain from engineers, designers, estimators, managers, etc. If he or she is adroit in approach, diplomatic when resolving opposing viewpoints, and tactful in questioning a design requirement or specification, he or she will minimize any problems of obtaining cooperation.

B. Cost Models

Introduction

A cost model is a diagrammatic form of a cost estimate. It is one of the most important outputs of the information phase. It is used as a tool in the VE process to provide:

Increased visibility of the cost of the various elements of a system or item.
Aid in identifying subelements most suitable for cost reduction attention.
Cost targets for comparison of alternative approaches.

Work Breakdown Structure

A cost model is an expression of the cost distribution associated with a specific item, product or system. Often it is referred to as a Work Breakdown Structure (WBS). The concept of a WBS is closely related to levels of indenture of functions discussed in Section 5.

1. A cost model is developed by first identifying assembly, subassembly, and major component elements or centers of work. From this the model can be expanded to include a parts breakdown at lower levels of indenture as necessary.
2. Next, the costs are developed (actual, estimated, or budgeted) for each of the component elements. These can be viewed as the unit building blocks of higher levels of indenture.

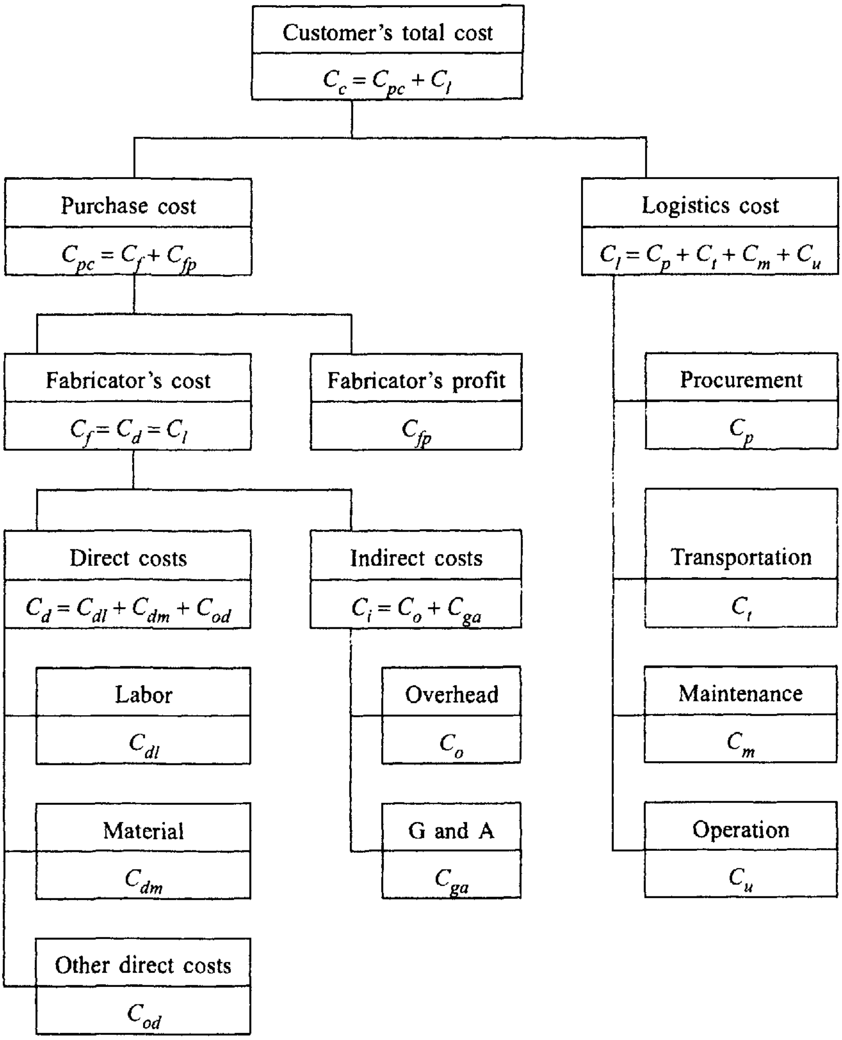

Figure 7 General purpose cost model—paperwork.

General

A general purpose cost model is shown in Figure 7. This model divides the total system cost into two categories, development of the system, and cost for annual system operation/use. The costs at the lower levels of indenture are data collection, transmission, processing, and use. Further breakdown reveals costs for the equipment, personnel, reports, calculations, mailing, routing, analysis, storage, and materials consumed by a specific system. At this level the general purpose model needs adaptation to the specific system being studied.

Program Cost Model

When asking, "What does something cost?" one often wonders if the answer should be given in terms of program cost or item cost. The cost model gives visibility to this issue and helps to ensure there is no misunderstanding when costs are being communicated. Shown in Figure 8 are five common categories of cost for a Government construction program. For a commercial project these would need to be modified by adding cost items for financing charges, building permits, and taxes.

Building Cost Model

The cost model prescribed for use by GSA for construction of buildings is called Uniformat. Construction costs for all facilities are subdivided into 12 basic cost centers or cost elements. These 12 cost centers are progressively subdivided into several more levels of indenture. During the concept stage of design, a VE activity uses primarily cost data at level 2, 3, or 4 of Uniformat. Value work at later stages of design should have more detailed cost data to explore within or below the subsystem level of indenture.

Worth Model

The same form of model used to distribute cost of a system should be used to show the worth of items. The cost model and worth model should be identical in format. The procedures to follow in creating a worth model are:

1. First, the VE team determines the necessary functions to be performed by each element of work at the lowest practical level of indenture.
2. How the worth of each function is determined is explained in Section 5.
3. The worth of each function for a cost element is totaled and becomes the worth for that element.
4. The sum of the worth of all cost elements of the lower level of indenture becomes the worth of the corresponding cost element at the next higher level of indenture.

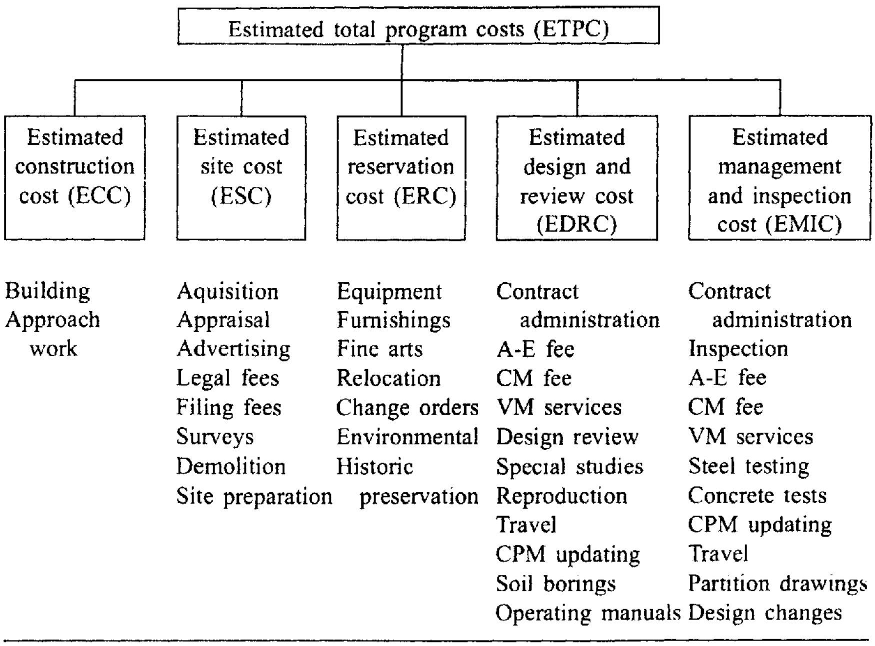

Figure 8 Construction program cost model.

5. Thus, the VE team develops the minimum costs they believe are possible for each block of the cost model. The result is a cost model with minimum costs that become targets to compare with estimated costs. Areas of greatest differences between target and estimated costs are then selected for study.

Example - Government Building Worth

1. From this cost model, the VE team selected the following blocks of cost for further study:

	Estimated	vs. Worth
Superstructure	$9.90	$6.50
Exterior closure	$4.25	$2.95
Electrical, general	$4.00	$2.75
Electrical, special	$2.25	$1.00
Vertical transportation	$2.40	$1.25

2. In this example, the VE team decided that the function of the exterior closure system was to "control elements." The comparator they used as the least cost way to perform this function (commensurate with reasonable performance requirements) was concrete block at $2.95/ft^2. This, then, became their worth target for that system.

Renovation Models

Following the principles of work breakdown structure, one can develop specific models for renovation work to reflect only the scope of a given project. Target costs are based on the simplest most economical way the review team can think of to achieve the function isolated by each cost model block. The blocks used were selected after developing a FAST diagram as explained in Section 6.

Related Ratios

Section 5 discusses the use of parameter costs to judge value. A parameter cost difference can give an indication of cost savings opportunity in the area of methods and materials. It does not, however, help to evaluate system efficiencies, and functional application. There are a number of other important related ratios in building systems which bear scrutiny in judging the value of system quantities and in selecting the most fruitful study areas.

1. The most commonly used related ratios for office buildings are shown in Figure 9. The lowest or "worth" of each factor is the best efficiency achievable in the past for each factor.
2. Other facility types such as hospitals, schools, waste water plants, etc., will have their own unique related ratios. The telephone company, for

Ratios	Abbreviations
GSF/person	GSF - gross square feet
NSF/GSF	NSF - net square feet
BTU/GSF	BTU - British thermal unit
CF/GSF	CF - cubic foot of volume
SFEC/GSF	SFEC - square foot of volume
Roof area/GSF	LF - lineal foot
LF partitions/GSF	SF - square foot
SF/TON	TON - 12,000 BTU/hour
CFM/SF	CFM - cubic feet/minute ventilation
FU/SF	FU - fixture units of plumbing

Figure 9 Related ratios: office buildings.

example, uses the gross ft^2 of building/ linear ft of installed equipment (GSF/LFE) to judge the efficiency of its equipment buildings.

3. The most efficient related ratio multiplied by the lowest parameter cost can also be used as an aid in determining target worth for any given block in the cost model.

Pareto's Law of Maldistribution

Vilfredo Pareto was a 19th century Italian economist and sociologist who believed that economics was essentially a mathematical science. One of his theories maintains that 80% of the wealth in a society is possessed by 20% of the population (Pareto's Law of Maldistribution).

Pareto's theory can be applied to many situations. In project management, for example, 80% of a manager's effort may be spent on 20% of the problems. Pareto's theory of unbalanced percentages can also be applied to the discipline

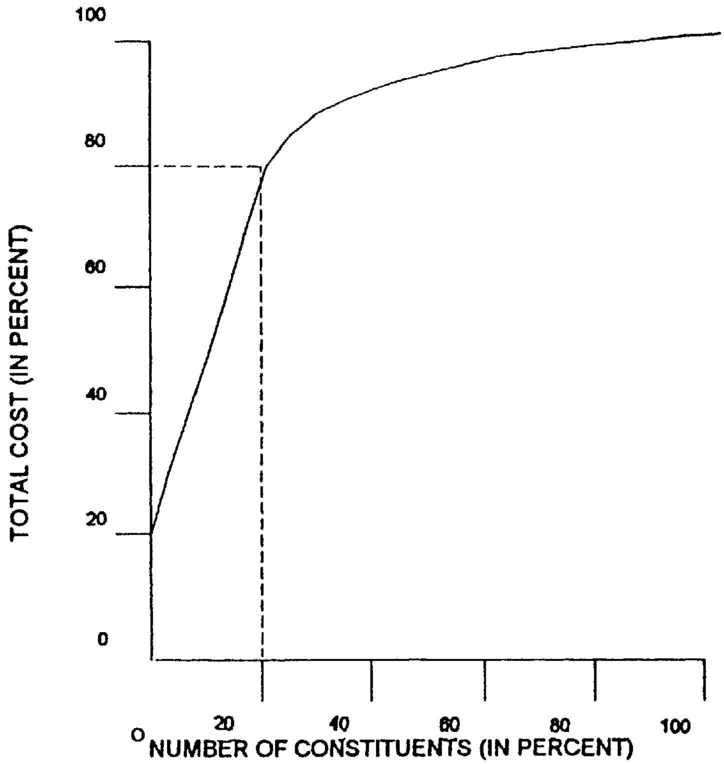

Figure 10 Pareto's law of maldistribution.

of value engineering in that, in most situations, 80% of the cost of a project is derived from 20% of the line items. "VE attempts to identify and isolate the small percentage of the elements in a single system that contribute to the greatest percentage of the cost." (Parker). A good cost model often reveals this principle (see Figure 10).

Summary

A high cost area may or may not have the greatest potential for cost improvement depending on its worth. Calculation of the value indexes for each element of the cost model is an additional screening device to help set study priorities. For each line item, the index is calculated by dividing cost by worth. The cost model is a valuable tool to sift through and organize study effort when faced with a large and complex project or system.

V. THE FUNCTION APPROACH

A. Phase 3: Function Analysis

Objective. The objective of this phase is to identify, define and classify the functions of the study item in order to allocate cost to them and judge their value.

Key questions.

1. What does it do?
2. What does it cost?
3. What must it do?
4. What is it worth?

Introduction

Larry Miles said of functions: "Ah, functions! We buy only functions. What things do. It is the difference between a word and an idea. . . A VA Function must be a better way of doing something. A value analyzed product must be the best possible product for the application. Value does not mean cheap or cheaper but better." (O'Brien).

"To an exceptional degree it focuses on what is important, develops knowledge about it, and then causes great creativity in that area. You select from the creative approaches, answers that may not have come in years with other thinking methods," Miles said. When Miles put his system to work the first time, it resulted in replacing a bronze clip holding a cover on a refrigerator control (that could flex millions of times without breaking) with a lower cost brass clip (that would flex thousands of times). Quality was not sacrificed because the clip would be flexed only about six times in the lifetime of the refrigerator. The $7,000 per year savings may seem like nothing, but when

Miles applied the same technique to everything in the control box, the yearly savings jumped to $1.25 million" (O'Brien).

The designer of an item, service or procedure is one who specifies the materials, writes the instructions and procedures, prescribes the performance requirements, and determines cost. However, it is the *user* of the item, service, or procedure, rather than the designer, who determines value.

A user purchases an item or service because it will perform certain function at a cost he or she willing to pay. If something does not do what it is intended to do, it is of no use to the user and no amount of cost reduction will improve its value. Actions that sacrifice needed utility of an item actually reduce its value to the user.

On the other hand, expenditures to increase the function capability of an item beyond that which is needed also are of little value to the user. Thus, anything less than the necessary function capability is unacceptable; anything more is unnecessary and wasteful. To achieve optimum value, functions must be carefully defined so that their associated costs may be determined and properly assigned.

Determining Function

Miles was particularly good at teaching team members how to determine function:

> On that first morning, this bewildered novice entered a large room filled with the paraphernalia of a typical value workshop. I greeted other equally bewildered attendees as we all waited for the workshop to begin. At 9:00 a.m., the workshop started with the usual administrative announcements and introductions. Exactly one hour later, Mr. Miles was introduced. He walked to the front of the room to begin the training. And what a beginning it was!
>
> He held up a clock. How much is it worth?" he asked. We responded. "Why is it worth $5?" he inquired. We were a very bright group. One of our more outspoken students took it upon himself to educate Mr. Miles in the design and production of electric clocks and discussed in detail how the labor, material, and overhead incurred in the manufacture of the clock determined its value. Larry profusely thanked our self-appointed spokesman.
>
> "How about the rest of you?" he asked, "Do you agree?" We all nodded affirmatively. "Well," he said sagely, "let's test your logic. Suppose I add some additional—very costly—labor to the clock. Would that make it worth more?" We looked at each other. Of course it would. And again, we nodded in unison.
>
> With that, Larry took a perfectly good clock and threw it against a wall as hard as he could. It was smashed to pieces. We were absolutely

horrified: There was not a sound in the room. You could have heard the proverbial pin drop, had someone dared to drop one.

Quietly he asked. "Now what is the clock worth?" We were nonplused. What was the answer?

Quietly Larry said, "Function! The clock does something. Its value is determined by what it does. Its value is not related to its cost of manufacture."

For forty students, that smashed clock represented a new understanding of the concept of value and a new beginning for each of us as we became better acquainted with the precepts of Value Analysis during the next three weeks. Three decades later that smashed clock remains perfectly vivid in my memory and helped to etch indelibly in my mind as in the minds of thousands of others, the meaning of value. . . (O'Brien).

In VE, function is normally expressed using two words—a verb and its noun object:

The verb answers the question, "What does it do?" The verb defines the item's required action (it may generate, control, pump, emit, protect, transmit, etc.). The noun answers the question, "What does it do it to?" The noun tells what is acted upon, (electricity, temperature, liquids, light, surfaces, sound).

The noun should be measurable, since a specific value must be assigned to it during the later evaluation process. For example: The function of a water service line to a building could be defined as "provides service." "Service," not being readily measurable, does not facilitate seeking alternatives. On the other hand, if we define the function of the line as "transport water," the noun in the definition is measurable, and acceptable alternatives, being dependent upon the quantity of water being transported, can be determined.

The system of defining a function in two words, a verb and a noun, is known as two-word abridgment. This abridgment represents a skeletal presentation with retention of relative completeness. Advantages of this system are that it forces conciseness, avoids combining functions, and avoids focusing on specifics.

Figure 11 provides a partial listing of typical verbs and nouns often associated with hardware and software items.

Function Types

Inherent in the definition of value management is the full retention of all necessary usefulness and esteem features of the item being studied. Value work must be done without reducing necessary quality or the features and

Hardware (materials products, building systems)

Verbs			Nouns	
absorb	detect	modulate	air	oxidation
allow	emit	prevent	compression	radiation
alter	enclose	rectify	current sheer	temperature
amplify	filter	reduce	energy	tension
attract	impede	repel	flow	torque
change	increase	resist	force	weight
conduct	induce	shield	light	
contain	insulate	support	load	
control	interrupt	transmit		

Software (systems, procedures, paperwork, contract provisions)

Verbs			Nouns	
accept	control	process	adjustments	material
acknowledge	edit	program	claims	performance
adjust	estimate	record	conditions	personnel
alter	expedite	report	contract	priority
analyze	order	request	control	production
apply	inform	route	customer	receipt
authorize	instruct	schedule	data	records
balance	monitor	transform	delivery	reports
cancel	notify	transmit	details	requests
certify	order	transport	efficiency	requisitions
claim	post	identify	failure	resources
compile	prepare		information	schedule
			information	shipment
			inventory	status
			labor	terms

Figure 11 Partial list of verbs and nouns.

attractiveness the user is willing to purchase. Therefore, VE recognizes two types of functions: work (use) functions and sell (esteem) functions.

Use functions are often referred to as work functions. They relate directly to the utilitarian purpose of the item and to its use value. The verb–noun combinations in Figure 11 are use functions.

Verbs		Nouns	
create	reflect	appearance	form
enjoys	see	balance	prestige
establish	smell	beauty	preparation
feel	taste	color	style
hear	think	convenience	symmetry
improve	texture	tone	feature
			ego

Figure 12 Esteem functions.

Esteem functions are often referred to as sell or aesthetic functions. They relate directly to the desire of a user to acquire an item at a cost in excess of bare utilitarian value. These functions relate to the esteem value or aesthetic value of an item. The verb–noun combinations in Figure 12 are esteem functions.

The Aesthetic Function

Somehow, in recent years, the intense need and desire to redo construction costs has been equated with the act of reducing quality or making sacrifices in requirements down to just above the limit of tolerability. Client, architect, and contractor all have been party to reducing costs by chopping away frills such as the textured coat of paint, or the fountain and pool, or the granite entrance, in an effort to meet the budget. Yet, the ease with which the "frills" get cut has always been amazing. It leads one to believe that the architect too easily compromises his aesthetics, or possibly that they were not too well thought out in the first place. Required aesthetics never should be deleted from construction. That which is required should be provided, or the building shouldn't be built if design performance is to be accomplished in response to human needs.

This point of view on VE should surprise the reader. In his very first text on the subject in 1961, Larry Miles sets forth the following position: "Inherent in the philosophy of value analysis is full retention for the customer of the usefulness and esteem features of the product." He continues on to state that value work must be done "without reducing in the slightest degree quality, safety, life, reliability, dependability and the features and attractiveness that the customer wants."

Miles states, that "all cost is function" and that all a customer wants is a function. He either wants something done or he wants someone pleased. Miles was the first to present both use functions and aesthetic functions in serving the needs of man as part of the value process. Fully understanding this concept will lead one to the conclusion that conditions exist when aesthetics become a required function. The trick is to determine, or make a judgment, when an aesthetic function is required, and when it is superfluous (Parker).

To do this, one needs to define "aesthetic" to get closer to understanding the problem. Most dictionaries indicate something is aesthetic when it is sensitive to art and beauty.

At this point, one must normally exclude fine art from function analysis when it is art produced or intended primarily for beauty alone rather than utility. However, art in the form of drawings, paintings, sculpture and ceramics can be studied when it becomes useful art.

For example, the S.S. Andrea Doria took to the bottom of the sea dozens of fine art originals placed on-board for their use in attracting passengers to that ship in preference to others. Art has been useful in decorating lobbies of many hotels and corporate headquarters. And, who can question the utility of landscape gardening to enhance the pleasantness of a place to be? Normally it is the useful art—presented in the form of windows, granite doors, and similar items—which contribute to the aesthetic functions under consideration.

Returning to our definition of aesthetics—sensitive to art and beauty—we are ready to define each part and put them back together again in functional form:

Sensitivity	This relates either to the senses or the responses of the mind such as: Senses: see, smell, taste, feel, hear Mind: think, reflect, enjoy, good taste
Art	This is considered to be reflective of creative work, or the making or doing things whose form has beauty.
Beauty	This is the quality attributed to whatever pleases or satisfies in certain ways, as in: line-color-form-texture-proportion-rhythmic motion-tone

We all know that brick costs more than block. This difference in cost is allocated solely to aesthetic functions; and, when brick is selected, those functions should be necessary. A case where they would not be necessary is when brick is used inside an elevator shaft, because one cannot see it or feel it.

This example of brick shows its sensitivity to beauty. Brick becomes sensitive to art when it reflects creative work, such as in its placing and coursing. The difference in cost between a common bond and a Flemish bond brick wall, for example, is allocated solely to aesthetic function (Parker).

Differing Values

A discussion on aesthetics is not complete without mentioning the different aspects of value. Most value analysts discuss and define three aspects of economic value:

Aspect of value	Relates to
Exchange value	Worth
Esteem value	Want
Use value	Need

VE methodology concentrates on the use value of the "work" or "sell" functions. Carlos Fallon's book, *Value Analysis to Improve Productivity*, discusses value. His text is recommended reading for those who deal daily with the value imposed by aesthetics.

Fallon cautions the value analyst who strives to satisfy only need, while ignoring the desires of man. That is the situation that occurs when one arbitrarily strives to provide only use value and categorizes all aesthetic functions as gingerbread or of doubtful value.

The reference to owners' desires is a reminder of the over-worked statement, "Beauty is in the eye of the beholder." Paraphrasing this statement, it is also recognized that value is in the eyes of the buyer. Individual desires and concepts of beauty can be the paramount reason something is being purchased. Dream, for example, of the corrugated metal manufacturer who envisions all skyscrapers covered with his product. Recognize from this, that aesthetics normally is a subjective decision and, very often, an individualistic one. VE is a tool to bring more objectivity to the decisions on aesthetic, usually to gain group acceptance.

Here is a coined definition: esteem value is no more than the desire of the owner to own it. Sometimes an owner doesn't want it because it doesn't satisfy his desire—it doesn't please him aesthetically—he can't live with it. It is important to recognize that elements of esteem can serve a useful purpose; the purpose of making an owner desire it.

Consider then, that aesthetic functions become basic when desire becomes as strong as need (Parker).

Classifying Functions

In performing VE, functions are classified as either basic or secondary functions. Basic function defines a performance (work or sell) feature that must be attained in the eyes of the user or buyer. It reflects the primary reason for the existence of the item and/or the reason for which the buyer is willing to pay. A basic function answers the question, "What must it do?" As such, a basic function satisfies only user needs, not desires. In classifying function, note the following:

> There is a different point of view in performing function analysis depending upon who you are. Are you a designer or manufacturer of a product or are you a user of a product? What could be basic function to one person might not be basic function to another. Basic function of a product can change at the time and end purpose for which it is used. It is also recognized that products are often purchased (used) for other than their original basic function. Thus, a clear understanding of user need is necessary if an adequate definition of basic function is to be developed. Two examples illustrate:
>
> A screwdriver used to open a can of paint is designed to "transfer torque" in a rotational manner but is purchased to "transfer force" in a linear manner. Another example is the use of a window. It may be to serve the function, view outdoors. Yet, the same window in a bathroom, if glass fogged, is obviously not there to "provide view." It is probably there to ventilate the room or provide light.

An item or system may perform more than one basic function. This would be true in the case of one item which provides several required work functions or required work and sell functions. For example: The camper's hand ax with a flat head for driving tent stakes and a sharp blade for cutting firewood provides two basic work functions. Also, space in a building selected to house people but also selected for convenient location is an example of an expenditure for both work and sell basic functions.

Basic function should be identified in the broadest possible terms to provide the greatest potential for value improvement. This gives greater freedom to creativity in determining alternatives. It tends to overcome preconceived ideas of the manner by which the function is to be accomplished. For example, consider an operation of fastening a nameplate on a piece of equipment. Rather than the specific instruction "screw nameplate," the function would be better identified as "label equipment," since attaching a nameplate with screws is only one of many ways of "identifying equipment"—the desired end. Nameplates can be riveted, welded, hung, cemented or wired in place. The name may be etched, stenciled, or stamped on the equipment, thus entirely eliminating the nameplate. In a restricted sense, the function of a cafeteria in a building could be identified as to dispense food. A wider definition would be to indicate its function as "nourish employees." This would provide one of many more choices beyond the use of a cafeteria in a building.

Secondary function defines performance features of a system or item other than those that must be accomplished. Secondary functions are user desires rather than needs. Secondary functions are also those increments of performance in excess of necessary minimum performance levels. A secondary function answers the question, "What else does it do?" For example, the basic function of exterior paint may be to "protect surface" with a secondary function, "improve appearance." Secondary functions often result from the method chosen to satisfy a basic function. For example, a valve on a radiator "restricts flow" and is necessary only because a hot water heating design was chosen. Then, the presence of a secondary function is often incidental to the method chosen to achieve a basic function.

Function Relationships

For systems, it is common practice to describe them (1) in terms of their function and relationship within the next larger assembly, (2) in terms of their own components or subparts, or (3) in terms of their indivisibility or uniqueness. The relative position that a system or item occupies in the scheme of the total assembly is called its "level of indenture."

In VE, the significance of level of indenture is that the designation of functions as basic or secondary depends upon the indenture level. A function that exists to support the method of performing the basic function is a secondary function. But when considered by itself and with respect to itself, it is a basic function.

Systems and items may have many levels of indenture. The rule for function evaluation is to work from the top down, and to consider the item under study as the top assembly. If the function of the top assembly is dependent upon the function of the indentured item, the function of the indentured is basic. Consider the following example:

1. Figure 13 illustrates the first three levels of indenture for a manually operated fire alarm system. Figure 14 illustrates the function relationship between these levels of indenture. Observe that the system, as defined, must perform two basic functions. Rather than choosing the restrictive function of "ring bell," the broader term "make noise" was selected to permit greater freedom in developing alternative ways of making noise (i.e., horn, explosive charge, siren, etc.).
2. Both items in the second level of indenture have functions that are basic because the function of the system is dependent upon them. All other functions of items in the second level of indenture are secondary because they only exist to support the method or design selected to achieve the basic functions.
3. Similarly, in the third level of indenture, only the bells perform a basic function.

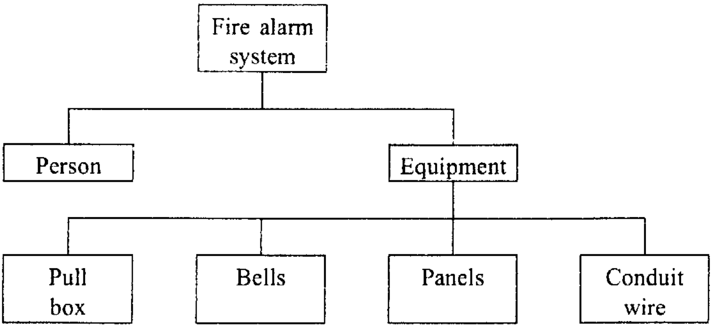

Figure 13 Levels of indenture.

Level of indenture	Component	Functions	Classification
1	Fire alarm system	Make noise	B
		Detect fire	B
		Protect buildings	S
2	Person	Detect fire	B
		Pull lever	S
	Equipment	Make noise	B
		Transfer signals	S
3	Pull boxes	Break circuit	S
	Bells	Make noise	B
	Panels	Provide power	S
		Control circuits	S
	Conduit wire	Transmit signal	S
		Transmit power	S

B = Basic, S = Secondary

Figure 14 Relationship between levels of indenture.

B. Cost and Worth of Functions

Determining Cost

VE methodology requires that one determine the present cost of performing functions. The first step to this, however, is to determine the present cost of the item, system or operation being studied. When detailed cost estimates are not available for the study subject, these should be developed. In preparing cost estimates for a VE study the following guidance is important.

Comparative Cost Technique

In performing a VE study, comparative estimating techniques are most frequently used where the prices of comparable parts, quality, and quantities are used as a guide in estimating and the emphasis is on determining the difference between estimates rather than on the accuracy of each estimate.

The cost estimating objective in VE is to determine differences in cost rather than absolute values of cost. If the as-designed alternative costs \$6.00 and the as-proposed costs \$4.50, VE is interested in determining a reasonably accurate delta, i.e., \$1.50. Whether or not the \$6.00 and \$4.50 are correct is less significant so long as the relationship between the two is correct. Comparative estimates of the as-designed and the as-proposed design can be created satisfactorily by a VE team with minimum input from an experienced estimator if the intent is only to verify the range of difference between the two designs rather than the price of either. The following ground rules should be applied:

1. Use the same data source for all unit prices of similar items within each estimate.
2. In developing quantities, use the same methodology in calculating amounts of material, scrap, breakage, and waste for each estimate. For example, if a 10 percent waste factor for brick is used in one estimate, use a 10 percent waste factor for concrete block in the second estimate.
3. Use a common basis for determining costs for overhead, profit, interest rates, and other similar factors.
4. Use a common basis in both estimates for determining labor rates, productivity, and crew sizes.
5. Consistently use the same factors for sizing equipment and loads in terms of factors of safety, spare capacity, and redundancy.

Strive for reasonableness and credibility, on the side of conservatism if necessary, to avoid inflated cost savings claims. Reasonable estimates make proposals more credible.

Allocating Cost to Function

One purchases something because it provides functions for which one is willing to pay. Unfortunately, the cost for a product is much more prevalent than is data based on cost for a function. For example, assume a detailed cost estimate of $150,000 to air condition a small building. For simplicity, also assume that the air conditioning system serves only two functions. It cools people and cools equipment (such as light fixtures). If separate cost estimates do not exist for each of these functions, then the $150,000 cost estimate must be apportioned to each function.

Where an item serves but one function, the cost of the item is equal to the cost of the function. For example, the cost of one item in a large project budget was $120,000 for a guard house. Therefore, the cost of the single basic function of the guard house, shelter person, was $120,000.

Where an item serves more than one function, the cost of the item can often be prorated to each function. For example, in the air conditioning problem shown above, one could calculate the air conditioning load contributed by people as 40 percent of the total and the load from equipment as 60 percent. Then, 40 percent of $150,000 or $60,000 would be the cost of the function, cool people. The balance, $90,000, would be the cost of cooling equipment.

If prorating is difficult, cost can be allocated to function by segregating function difference between similar items. For example, an acoustical tile suspended ceiling performs three functions: 1) hides structure, 2) absorbs sound, and 3) retards fire. By obtaining the cost of ceilings with and without the sound absorption and fire ratings, this provides the data for costing each function. If one just wanted to "hide structure" without using perforated tile, one could do that function satisfactorily for this cost.

Worth

Do not confuse the worth of products with the worth of functions. In VE, worth is only associated with necessary functions, not with the present design of the system. Worth, for VE purposes, is the least cost to provide a given necessary function.

The worth of a function is usually determined by comparing the present design for performing the function with other methods of performing essentially the same function. To aid in determining worth, one might ask the following series of questions:

1. What is the cost of the basic function as designed?
2. Should performance of the basic function cost that much?
3. If not, what is a reasonable cost?

4. What is the cost of achieving this function if some other known item is used?
5. Is this an easily accomplished function, or one that is difficult to achieve?
6. What is the price of some item that will almost, but not quite, perform the function?

In determining worth, the key rule to remember is that worth is associated with necessary function, not with item cost. To illustrate this, a task team was trying to define the function of a washing machine hose (25 cents) in order to determine its worth. A youngster who happened to be there said, it "bends water!" The team accepted that and sent the boy out to a hardware store to help determine worth by purchasing the cheapest water bender he could find. The boy came back with a plumbing "U" which at that time cost 5 cents. However, the pipe brought back was heavy and ugly. So, the purchasing men on the team called a plastic supplier who, for another 3 cents could make it lighter and softer, and for another 4 cents could make it pretty. The worth of "bending water" thus became 12 cents.

Some value specialists give worth only to basic functions, automatically letting the worth of secondary functions be zero. This view is taken because to some, secondary functions only exist because of the design solution used to satisfy the basic functions. Hence, when an alternative way to satisfying the basic functions is discovered all the old secondary functions drop out of existence. The difficulty with this method is that when a secondary function has cost and its worth is stated as zero, the value index calculation (described later in this part) becomes infinity. An index of infinity certainly indicates an area of cost savings opportunity, but it is meaningless as an index to rank the areas of cost saving opportunity.

Aids to Determining Worth

Worth can be established at various stages of design or levels of detail. At the component level, one could judge the least cost of the various functions provided by a door. For example, answer the questions: What is the least cost to seal opening, close door and lock door?

At a budget level, one frequently has available historical parameter costs and can judge cost on such things as the cost/ft^2 for an office building, the cost/bed for a hospital, or the cost/occupant for a school.

Another useful technique is to take published historical experience and switch around normally used parameters to create statistics to expose, for example, the least cost of an office building on a cost per occupant basis. Casting a new light on accepted cost data often poses startling results.

System worth also can be established on a parameter basis. Some examples: air conditioning on a cost/ton, electrical systems on a cost/connected kw load, structural systems on a cost/kip (1,000 lb of load), and plumbing on a cost/fixture unit. Then, application of these unit costs can be made to the quantities of each desirable function. For example, using the air conditioning example, asking what is it worth to "cool people" might lead one to use the lowest cost/ton ever achieved for that function. However, asking what is it worth to "cool equipment" would normally lead one to say "nothing," because cooling equipment is normally an undesirable office function unless for special purpose equipment like a computer.

Judging Value

The purpose of allocating cost and worth to function is to allow one to judge the value of the function. This permits comparing and ranking the value received for a series of functions being performed by the item under study. One ranking technique used for this is the calculation of a value index.

The value index is the ratio of the cost of each function divided by its worth. It serves to:

1. Assist in determining whether to proceed with the value study. The study should proceed only if poor value, indicated when the value index is greater than one, exists. Good value is indicated when the index is one.
2. Locate areas where the cost/worth ratio is the greatest. Generally these areas will have the greatest cost savings potential and are the better parts of the problem to select for value study.
3. Provide a factor for measuring the effectiveness of any VE efforts. Did the cost/worth ratio approach unity after the VE effort?

One shortcoming of the value index is that it does not provide dollar amounts of potential savings. In an office building, a savings in toilet accessories with a value index of 25:1 may save only $1000. However, an HVAC system with an index of 2.5:1 may save $100,000. Using graphic cost worth models in conjunction with value indexes solves this problem.

Summary

The VE discipline deals with functions, the purpose or use of an item. The VE approach first concerns itself with determining "What does it do?"—and only afterwards with the item itself. This is a radical departure from traditional cost reduction efforts where the question is, "What is it?" and the concentration on making the same item less expensive. Application of these fundamentals serves to focus the VE team's effort in the most effective direction.

VI. FUNCTIONAL ANALYSIS SYSTEMS TECHNIQUE (FAST)

A. Introduction

Functional Analysis System Technique (FAST) is a diagramming technique to graphically show the logical relationships for the functions of an item, system, or procedure. FAST was developed in 1964 by Charles V. Bytheway at the UNIVAC Division of the Sperry Rand Corporation. Prior to the development of FAST, one had to perform function analysis of an item by random identification of functions. Basic function had to be identified by trial and error and one was never quite sure that all functions had been uncovered. FAST provides a system to do a better job in function analysis. The FAST diagram should be created during the functional phase of the VE job plan by the whole VE team.

When used in conjunction with a value study, the FAST diagram serves the following purposes:

It helps organize random listing of functions. When answering the questions—What is it? What does it do? What must it do?—the study team develops many verb–noun function solutions at all levels of indenture, which the FAST diagram can help sort out and interrelate.

It helps check for missing functions that might be overlooked in the above random function identification process.

It aids in the identification of basic function or scope of the study that you wish to tackle.

It deepens and guides the involvement, visualization, and understanding of the problem to be solved and the proposed changes.

It demonstrates that the task team has completely analyzed the subject or problem.

It tests the functions through the system of determinate logic.

It results in team consensus in defining the problem in function terms, and aids in developing more creative valid alternatives.

It is particularly helpful in "selling" the resulting changes to the decision makers.

B. Levels of Indenture

Section 4 discusses levels of indenture as they relate to systems analysis and indicates that the designation of functions as basic or secondary depends upon the indenture level selected. This procedure for determining basic function was used for more than 20 years before the introduction of FAST diagram-

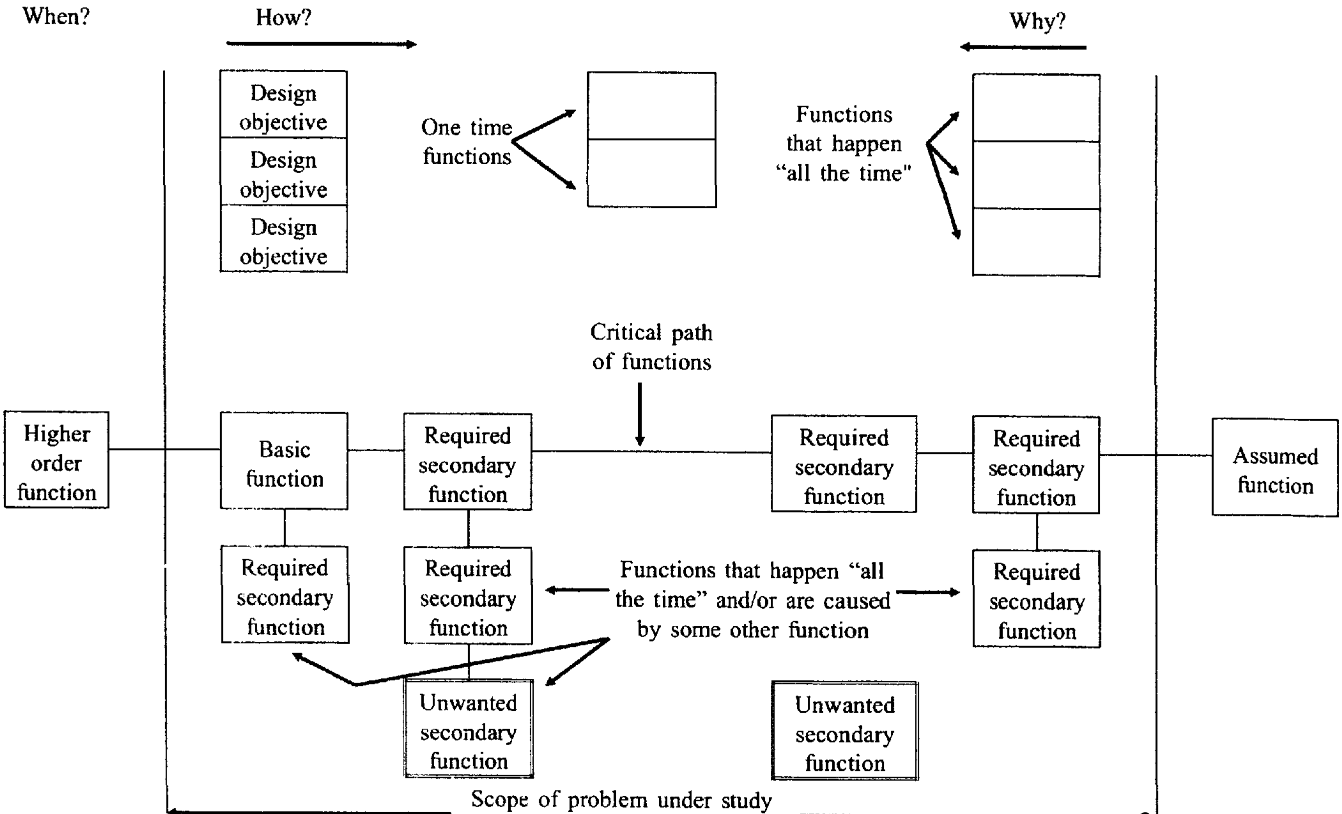

Figure 15 Diagram convention.

ming. To some, it seemed confusing to find the basic function in each and every level of indenture. It also became quite complex when the problem or item under study became large, with many levels of indenture.

Figure 15 depicts the diagramming conventions to be used in preparing a FAST diagram. The relative position of functions as displayed on the diagram are also levels of indenture. The FAST diagram is a horizontal graphical display based on system functions rather than system flowcharting or components. Level 1, the higher level functions, appear on the left side of the FAST diagram, with the lower level indentures successively shown to the right.

In most cases when conducting a value study, various levels of indenture of verb–noun functions will be initially suggested as the basic function of an item or system. A diverse value task team is bound to do this. For example, what if you were to study the Federal Food Stamp Program and in asking the team to define the basic function of the program, they developed the following three functions: 1) distribute stamps, 2) feed people, and 3) redistribute wealth. Are all of these basic functions of the program? Probably they are. Which function would you choose to assign a cost and worth to, and then develop alternatives for? Obviously, you would get very different ideas, depending upon the function you selected, and the scope of your study would vary drastically. What you have just experienced is a problem in level of indenture that is solved by FAST diagramming.

C. Diagramming Guidelines

The FAST diagram is just a tool (e.g., Figure 16). It is the process used in creating the diagram that is important, not the final diagram itself or its appearance. There is no such thing as a "right" or perfect school–book solution that each diagrammer should be able to create, even if he had perfect knowledge of the technique and theory. Yet, if the diagram logic is logical to the diagrammer, it will normally be logical to a reviewer. And, if it is not, then the FAST diagram will have served another purpose—communication of a misunderstanding in statement of the problem.

With the above in mind, however, the following guidelines should be followed in preparing a FAST diagram:

1. Show the scope of the problem under study by two vertical dashed lines, one to the extreme left and one to the extreme right of the diagram. Everything that lies between the two scope lines is defined as the problem under study.
2. Every FAST diagram will have a "critical path of functions" going from left to right across the scope lines.
3. Only required secondary functions, the basic function(s), and the higher order function should be on that critical path.

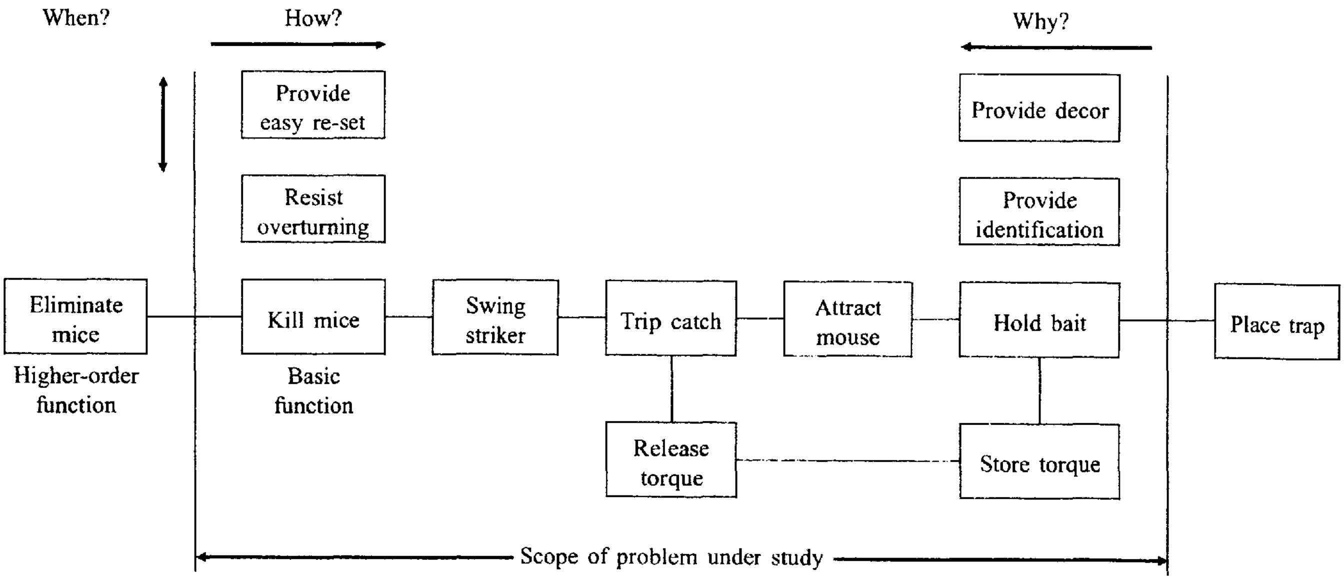

Figure 16 Mousetrap FAST diagram.

4. The higher order function will lie to the immediate left of the left scope line.
5. The basic function(s) will always lie to the immediate right of the left scope line.
6. All other functions on the critical path will lie to the right of the basic function and will be required secondary functions (not normally aesthetic or unwanted secondary functions).
7. Any "assumed functions" lie to the right of the right-hand scope line.
8. All other secondary functions which the item performs will lie either above or below the critical path of functions. These functions can be required secondary functions, aesthetic functions or unwanted functions.
9. If the function "happens at the same time" and/or "is caused by" some function on the critical path, place the function below that critical path function.
10. If the function happens "all the time" the system is doing its work; place it above the critical path function to the extreme right of the diagram.
11. If there are specific "design objectives" or "general specifications" to keep in mind as the diagram is constructed, place them above the basic function and show them as dotted boxes.
12. All "one-time functions" are placed above the critical path and in the center area of the diagram.
13. All functions that lie on the critical path must take place to accomplish the basic function. All other functions on the FAST diagram are subordinate to the critical path function and may or may not have to take place to accomplish the basic functions.

D. Diagramming Procedure

The steps recommended to construct a FAST diagram are as follows:

Function Listing

Prepare a list of all functions by assembly or system using the verb and noun techniques of identification of function. Do this by brainstorming the questions, 1) What does it do? and 2) What must it do?

Diagram Layout

Next, write each function separately on a small card in *verb* and *noun* terminology. Select a card with the function that you consider to be the basic function. Determine the position of the next higher and lower function cards by answering the following logic questions.

1. Using the "How" test, as the question of any function, "How do I (*verb*) (*noun*)?" The function answer should lie to the immediate right. Every function which has a function to its immediate right should logically answer the "How" test. If it does not, either the function is improperly described or a function is in the wrong place.
2. The second test of "why" works in the same way, but in the opposite direction. Ask the question, "Why do I (*verb*) (*noun*)?" The answer should be in the function to the immediate left and should read, "So that I can (*verb*) (*noun*)." The answer must make sense and be logical.

Critical Path

To determine whether a function belongs on the critical path, test the functions with these questions:

1. How is (*verb*) (*noun*) actually accomplished, or how is it proposed to be accomplished?
2. Why must (*verb*) (*noun*) be performed?

Support Logic Block

A support logic block is a block immediately underneath a given block at the same general level of indenture. These are functions that happen "at the same time" and/or "are caused by" some other function. They can be determined by answering these questions:

1. When is (*verb*) (*noun*) performed?
2. If (*verb*) (*noun*) is performed, what else must also happen?

Locating Scope Lines

The determination of where to place the scope lines is arbitrary. Moving the left scope line from left to right lowers the level of indenture of the problem to be studied. The basic function to be studied shifts as it always lies to the immediate right of the left scope line. Locating the right scope line determines the assumptions and "givens" one is willing to accept before starting the study. Location of both scope lines is also subject to the point of view of the owner or user of the problem.

E. Diagramming Tips

Usually only two FAST diagrams are of interest: the diagram that represents an existing plan, program, or design, and the diagram that represents the proposed concept. When diagramming something that exists, be sure not to slip off on a tangent and include alternatives and choices that are not part of the existing system. This is easy to do.

When using a FAST diagram to design or propose a new concept, restrict it to a specific concept; otherwise the answers created in diagramming become meaningless. The "method selected" to perform a function brings many other functions into existence. Therefore, it will probably be necessary to create several FAST diagrams during system design.

The choice of the level of detail of functions to be used in the FAST diagram is entirely dependent on the point of view of the diagrammer, the purpose for which it is to be used, and to whom it will be presented. For presentation of value study results to management, a very detailed FAST diagram should be simplified to a higher level of indenture.

F. Summary

1. FAST is a structured method of function analysis which results in defining the basic function, then establishing critical path functions, supporting functions and unnecessary functions
2. FAST diagrams should be constructed at a level of detail that is low enough to be useful, but high enough to support creativity in seeking alternate methods.
3. FAST diagrams are used to communicate with subject matter experts; to understand the problems of specialists in their own profession; to define, simplify and clarify problems; and to bound the scope of a problem, and to iterate the interrelated string of functions needed to provide a product or service.
4. The FAST procedure will be useful only if thinking outside the steps to prepare a diagram is performed. The value of this technique is found not in recording the obvious, but in the extension of thinking beyond usual habits.
5. A FAST diagram, as first constructed, may not completely comply with "how" and "why" logic. This is because it takes additional thinking to get everything to agree. However, when you are persistent and insist that the logic be adhered to, you will discover your understanding has expanded, and your creativity has led you into avenues that would not otherwise have been pursued. When the "how" and "why" logic is not satisfied, it suggests that either a function is missing or the function under investigation is a supporting function and not on the critical path.
6. The main benefit from using FAST diagramming and performing an extensive function analysis is to correct our ignorance factor, so that we can see the design in its true light. Once this function analysis is performed on a given topic, we can quickly see that the only reason a lower level function has to be performed is because a higher level function caused it to come into being. Essentially, whenever we establish one of these

functional relationships, visually presented by a FAST diagram, we correct our ignorance factor and open the door to greater creativity.

VII. CREATIVITY

A. Introduction

Creativity is the development of ideas that are new to the individual, although not necessarily new to someone else. It is one element in the VE methodology that brings one closer to the attainment of optimum value. It takes creativity to discover alternate designs, methods, systems or processes that will accomplish the required functions.

Objective

The objective of this phase is to generate, by creative techniques, numerous alternative means to accomplish the functions selected for cost improvement.

Key Question

Accomplishing this phase should result in answering the question, "What else will do the job (perform the basic functions)?" The completeness of the answer to this question determines the effectiveness of value work. The greater the number and quality of alternatives, the greater the likelihood of developing an outstanding solution. Additional alternatives which have not been considered will usually exist regardless of the skill and proficiency of the study team.

B. Procedure

Mind Setting

Generation of ideas or alternate solutions should not formally begin until the problem is thoroughly understood. All members of the study team should participate. However, setting a proper frame of mind with a conscious attempt to put aside any negative thinking, attitudes, or disruptions is essential.

Techniques

The most common technique used by the study team to generate ideas is brainstorming. This technique and several others are discussed in this section.

Challenging Function

The best solution may be complete elimination of the present function or item. This possibility should not be overlooked during the initial phases of this step. Perhaps some aspect can be modified which will permit elimination of the function under study. Only after determining that the function must remain, should the study team look for alternate ways to perform the same function at the lowest conceivable cost.

Imagination and Hitchhiking

Judicial thinking does not belong in this phase. Every attempt should be made during this phase to depart from ordinary patterns, typical solutions, and habitual methods. It is often the new, fresh, and radically different approach that uncovers the best value solution. The individual or group members may supplement their ideas with those of others. Everyone is expected to make a contribution, use their imagination, and hitchhike on others' ideas.

Individual Creative Capability

Analysis of function through use of creativity is a principal objective of VE, requiring that individuals create on schedule. To some, this challenge seems overwhelming. It is similar to asking one to invent a useful object by noon on Friday of every week. Fortunately, everyone possesses some degree of creative ability. Normally an individual's creative ability can be developed and improved through training and practice. While there is no precise scientific way of measuring creative action, creative behavior and potential can be subjectively evaluated.

Problem-Solving Methods

Among the many approaches to problem solving, the analytical and the creative are most often part of VE.

Analytical Approach. This approach is substantially singular in purpose. The problem is stated exactly. A direct approach to the solution is taken, proceeding through a step-by-step progression of experiments, evaluations, and mathematical manipulations to arrive at a single answer. An analytical problem is one that frequently has only one solution that will work. For example, excessive sweating is observed on the interior of windows and window frames in a large office building. In addition, the plaster adjacent to the windows has started to powder and cause paint to chip and peel, resulting in costly maintenance and inconvenience. "Find the cause of the failures" is an analytical problem. One pursues the problem through a progression of suppositions to be proved or disproved by experimentation and tests until the problem is successfully narrowed to a single cause for each failure. Once the cause is ascertained, that problem is solved.

Creative Approach. The creative approach is appropriate when there appears to be either no solution or more than one solution to a particular problem. The creative approach is an idea-producing process specifically intended to generate a number of solutions, any of which will solve the problem at hand. Although all solutions will work, one is the better solution among them. In the example cited above, the situation posed by "excessive sweating on windows and frames, plaster powdering and paint peeling" may be resolved into two problems: 1) determine the cause of trouble (analytical problem); and 2) prevent recurrence in this and future construction (creative problem). The cause, in this example, was found to be buildup of humidity in the space in contact with the low temperature of the glass, metal frames, and frame supporting system. Plaster powdered and paint peeled when moisture formed on the metal frame and supporting system. What is the solution to this portion of the problem? A number of ideas may be proposed:

Use wood-frame windows.
Use thermopane glazing.
Reduce the source of humidity buildup.
Change the frame support system.
Use Keene's cement plaster.
Install thermal insulation between the frames and supporting systems.

Any of the above may solve the problem. One of them is better than the rest. Its selection is an analytical problem, but the best solution may not even be on the list.

Creative Techniques

There are a number of creativity techniques available for problem-solving situations. Some are for use by individuals working alone, others for use by groups. All the techniques provide a method or mechanical procedure to help the user generate increased numbers of solutions. The various techniques provide formats for mental stimulation. However, during their use, it is necessary to make the conscientious effort to think creatively. The ground rules to be followed may be summarized as shown in Figure 17. The two cardinal rules for the use of all creative techniques are 1) to eliminate all judgment or evaluation in the idea-producing stage, and 2) to consider all ideas, even the most impractical. These two simple rules must never be forgotten; they must be followed if successful results are to be derived from any creative effort.

1. The first rule, the elimination of all judgement and evaluation from the idea-producing stage, allows first for a maximum accumulation of ideas for consideration. It prevents the premature death of a potentially good idea before it gets a chance to be heard. It conserves the time of the group or individual working on the problem because there is no continual shifting from creation of ideas to evaluation, as happens in an ordinary conference, or in one's usual thought pattern. In a group, this common intermixture of creation and criticism can be especially harmful. It can silence the initiative of contributors. Also, time that could be devoted to the creation of additional new ideas is devoted to discussion and frequently destructive criticism.

Do not attempt to generate new ideas and judge them at the same time. Separate these aspects by time, by place, and by different personnel, if possible.
Generate a large quantity of possible solutions. As a goal multiply the number of ideas produced in the first rush of thinking by 5 or 10. It is by generating a large quantity that we strive to obtain high quality ideas.
Seek a wide variety of solutions that represent a broad spectrum of attacks upon the problem.
Watch for opportunities to combine or improve ideas as they are generated.
Before closing the book on possible solutions, allow time for subconcious operation on the problem while conciously performing other tasks.
Consider all ideas, even the most impractical. Do not ridicule any idea.

Figure 17 Creativity ground rules.

2. The second rule, the consideration of all ideas, even the obviously impractical, is equally important. By ranging far and wide, one is encouraged to explore new ideas, thus breaking through the barriers that too often restrict our thought processes. In other words, use artificial means to force development of new and daringly creative approaches.

Specific creative techniques are:

1. *Brainstorming Technique.* Brainstorming is a problem-solving conference method that is based upon the stimulation of one person's mind by another. An average brainstorming session consists of a group of 4 to 6 people sitting around a table and spontaneously producing ideas designed to solve a specific problem.

Group Brainstorming Rules. Prior to opening the session, the group leader will set the stage by reviewing the following group brainstorming rules.

Criticism is ruled out. Adverse judgment of ideas must be withheld until later. No criticism by word of mouth, tone of voice, shrug of shoulders or any other method should be allowed.

Free-wheeling is welcomed. The wilder the idea, the better; it is easier to tame down than to think up.

Quantity is wanted. The greater the number of ideas, the more the likelihood of a winner.

Combination and improvement are sought. In addition to contributing ideas of their own, participants should suggest how ideas of others can be turned into better ideas, or how two or more ideas can be joined into still another idea.

Using a Group. Two or more people working together under these ground rules can generate more ideas than one person working alone. This is due to the fact that ideas generated by various members of the group can be modified or improved upon and be offered by other members as suggestions for solution of the problem. The efficiency of the group goes up as its size increases until it reaches the point where its operation becomes so cumbersome as to discourage some members participation. The members of the group may be selected to represent different work backgrounds. Some should have a working familiarity with the subject under study. Group members need not all know one another before the session. However, they should all come from equal levels within the organization.

Conducting the Session. During brainstorming sessions it is important not to exercise critical judgment of any offered idea. Critical judgment will tend to inhibit the thinking of the judged and will have a stifling effect upon the offering of ideas. Some brainstorming conference leaders have been known to ring a bell when a judicial statement is made during an idea producing session. With practice, people can adjust to the brainstorming method. This means following the rules and controlling the natural tendency to instantaneously evaluate ideas.

The group leader opens the session by posing a problem expressed in functional language. In brainstorming, it is important to list all ideas on a blackboard or flip sheet so that all members of the group can see as well as hear the ideas. This is difficult since the ideas usually come too fast to be recorded.

It is also important in brainstorming when general ideas are given, to ask creative questions which evolve more specific ideas. For instance, if a suggestion such as "Solicit ideas" is given, a question such as "From whom might we solicit ideas?" is usually helpful.

Attaining a Solution. Brainstorming does not always directly provide final solutions or ideas ready for immediate implementation. However, it is always capable of suggesting the final solution or giving a lead for further development of a solution.

2. *Checklist Technique.* A checklist is an accumulation of points, areas or possibilities serving to provide idea-clues or leads when checked (or compared) against the problem or subject under consideration. The objective is to obtain a number of ideas for further follow-up and development. The checklist is one of the most commonly used aids in the search for new ideas. Checklists range in type from the specialized to the extremely generalized.

Keep Checklists Open-Ended. The checklist technique can be helpful and dangerous. It can be dangerous unless open-ended. For instance, the VE job plan is a comprehensive checklist of required VE tasks. Yet each phase is infinitely open-ended. One cannot specify in detail each value management step within each phase since the individual specific actions vary with the item being studied. Checklists are aimed at solving some specific problem. They help faulty memory. They make sure we have checked those steps that have been successfully used to solve certain types of problems in the past. Unless they are kept open-ended, they can become a sure-fire way to go wrong with confidence.

Apply the Correct Checklist. Be sure to apply the correct checklist to the correct problem. A checklist on how to start a car is no good for learning how to drive. Of course, VE's most famous checklist is: What is it? What does it do? What does it cost? What is it worth? What else will do the job? What does that cost?

C. Summary

Creative problem solving techniques are the tools an individual can use to expand his creative ability. Creative techniques are forcing techniques. They are techniques to empty the mind of habitual responses and force one to use words he or she would not habitually use to talk about the situation. Up to a point the human mind is greater than the most elaborate computer. It can store an almost infinite number of data, but regrettably, it can only process and integrate up to about seven bits of these data simultaneously. Because of our mind's limitation, we find the guides in Figure 18 helpful in applying either the analytical or creative approach to problem solving and developing greater creative ability.

VIII. EVALUATION

A. Phase 5: Judicial

Objective

Following the creative step in the job plan is the judging or idea analysis step. Now is the time to judge! The purpose of this step is to select, for

Establish a specific time and place for creative thinking.
Set a deadline or quotas for creative ability.
Write down ideas as they occur.
Run over the elements of the problem several times.
Take notes on observation.
Suspend judgment. Don't jump to or be led into false conclusions.
Rearrange the elements of the problem. Get a new viewpoint.
Take a break when you are stuck.
Discuss your problem with others. Let it incubate.

Figure 18 Guide to expanding creative ability.

further analysis and refinement, the most promising ideas from the long "shopping list" of ideas that have been generated.

Key Questions

How feasible is each idea?
Will each perform the necessary function?

Evaluation

Evaluation may be accomplished either by the generating group or by an independent group. The choice is based on the perception of whether people who generate ideas can be objective enough in evaluating them. The steps in the evaluation process are as follows:

1. Feasibility Ranking. The first step is to develop a set of broad evaluation criteria by which to judge the ideas for feasibility. Normally, value teams use at least the following five factors as a rough screening process for the first idea judging: 1) state-of-the-art of the idea, 2) cost to develop the idea, 3) probability of implementation, 4) time to implement, and 5) potential benefit. The above five factors are scored by the team on a one to ten basis, with ten being the score for least cost, least time, most benefit, highest probability of implementation, and most current state-of-the-art. It is important in conducting this first screening step that no idea be discarded without being scored. Scoring will be difficult and it will be subjective. What is new technology to one person might not be so new to another, so check out judgments with qualified experts in the area of the idea under consideration.

2. Anticipating Effects. The team should try to anticipate all of the effects, repercussions, and consequences that might occur in trying to accomplish implementation of each idea as a solution. This probing should result, in a sense, in a measure of sensitivity to problems which might be inherent in changes caused by the idea. Figure 19 provides a list of questions that should

1. Will the idea work?
2. Can it be modified or combined with another?
3. What is the savings potential?
4. What are the chances for implementation?
5. What might be affected?
6. Who might be affected?
7. Will it be relatively difficult or easy to make the change?
8. Will it satisfy all the user's needs?

Figure 19 Idea analysis questions.

be asked of each idea. The answers to these questions will vary depending upon the objective of the value study and the time frame and resources available. During facility design, short term and rapid solutions will probably receive more emphasis. However, if the value study is conducted during research, planning, or development effort, longer term development and higher state-of-the value studies actually create two lists of ideas during this screening process. One list is for short term or immediate gain and the other list of ideas is for further review and development at a later point in time.

3. Comparing Alternatives. The next step in the judicial process is to select the most feasible combination of ideas and compare them. Most decisions made by people, when personal purchases are made, are based on comparison. Clothing, food, appliances—practically everything is decided by a mental comparison to determine which one will actually be bought. Comparison of ideas should be made by listing the advantages and disadvantages of each. To be fair and objective, try to list as many good points as bad points for each idea. The number of good and bad points may be equal but they will not be equal in strength or importance. After this, a serious attempt should be made to see if the team can maximize the good attributes of each idea while at the same time minimizing the bad. Often this can be done by modifying the idea or finding alternative solutions to overcome the negative factors.

4. Matrix Evaluation. Using the feasibility ranking and idea comparison techniques as a screening process, the team should select its list of best ideas that will satisfy required functions. These ideas should be further explored and evaluated using the weighted evaluation technique explained below.

5. Cost Evaluation. Selected alternatives must also be judged for their cost reduction potential. This judging may initially be based on nothing more than relative estimates comparing the elements, materials, and processes of the alternatives and the original or present method of providing the function. The surviving alternatives are then developed further to obtain more detailed cost estimates. The cost estimating for each alternative proceeds only if the preceding step still indicates it to be a good candidate. Cost estimates must be as complete, accurate, and consistent as possible to minimize the possibility of error in assessing the relative economic potential of the alternatives. Specifically, the method used to cost the original or present method should also be used to cost the alternatives.

6. Final Selection. Selection of alternatives to be developed further should be based upon the accumulated knowledge gained during the judging process. Normally, the alternative with the greatest savings potential and scoring the best in attribute trade-off will be selected for further study, refinement, testing, and comprehensive development. However, it might also be wise to select two or more alternatives to be developed as management options.

B. Weighted Evaluation

Introduction

Weighted evaluation is an aid to decision making that is particularly useful during the judicial phase of the VE job plan. Individuals are called upon daily to make decisions. When they are simple, requiring analysis and consideration of only one or two criteria and a yes/no or either/or answer, the decision can be reached quite easily. However, the decision usually requires analysis of a set of criteria, each having a different weight depending on circumstances. A good decision maker is not rigid in his/her thinking, but learns to analyze choices using proper perspectives.

Weighted evaluation is a formally organized selection process used when there is a complex decision involving many criteria which have various impacts on the selection.

Weighted evaluation is important to assure that optimum decisions are arrived at by placing proper emphasis on all important criteria. During the process it is important to discuss and determine needs vs. desires, the important from the unimportant, and trade-off vs. non–trade-off areas. The emphasis should be decisions conditioned with knowledge, experience, special information, and user input.

Procedure

The procedure for use of the weighted evaluation technique involves two sequential processes: criteria weighting and matrix evaluation. In summary:

1. Criteria weighting involves first determining what criteria are to be used to select the best idea. Next, in judging ideas, these criteria must be assigned different weight values according to their potential impact on a project, or the importance placed on them by the decision maker. The system used to determine the weights of importance to be assigned each criteria is called "paired comparison."
2. Matrix evaluation involves judging the performance of each idea against the selected criteria, scoring them, and then weighting them based on the criteria weights in order to select the most favorable idea.

Determining the Criteria to Weight

1. Objectives or required criteria that are not subject to trade-off are not to be weighted for evaluation. All of these should be met by each idea to be judged.

2. Goals, desired criteria and other features and attributes can be subject to trade-off and optimization.
3. In developing criteria or attributes to weigh in the paired comparison process, applying the following rules results in a more objective evaluation:
   a. Each criteria weighed for consideration should meet the minimum user or owner needs. That is, if safety is being compared to cost, the comparison is not between unsafe conditions versus lower costs, but increased safety over the minimum required safety versus cost.
   b. All judgments of relative importance of criteria are between minimum and maximum performance levels or between needs and desires, with the intent to determine the relative importance of each in order to optimize them later or make trade-offs.
   c. It is best that all criteria compared against each other be subjective in nature. Don't compare criteria that can be easily quantified with criteria that cannot be easily quantified.
   d. The more elements of criteria compared to each other, the better. This lessens the chance that one or two criteria elements will receive such weight that they swing the decision or govern the decision regardless of how the other criteria elements score. Don't stack the deck. Divide one important overall criteria element into subfactors whenever possible. For example, if ownership costs are really going to be the basis for decision making, regardless of other criteria, divide this criterion into subfactors such as reparability, logistic support, down time, energy cost, etc.

Paired Comparison

This is the method to objectively determine the weights of importance for each criterion. It is based on the fact that most everyone can make a simple decision involving a choice or preference between two things, and make a "yes-no," "either-or" answer.

1. The first step in criteria weighting is to list all criteria, features, or attributes that are considered to be important in the final selection of alternatives. It is important to try to list all pertinent factors. If they are not pertinent, they will eventually drop out by receiving very little or zero weight. In the example shown, the important considerations were initial cost, maintenance, energy usage, aesthetics, and reliability/performance.
2. The second step is to determine how important each of these is to the evaluator. When listed on the criteria-weighting process format each is assigned a letter of the alphabet. These assigned letters are used to compare A against B, A against C, and so on, as the criteria scoring matrix is filled out. When selecting between two criteria, the degree of importance of the selection

can also be indicated. The preference or importance of one criteria decision over another can be major, medium, minor or none. Points are assigned from 3 to 1 depending on the degree of preference. In the HVAC example:

a. When initial cost (A) was compared to aesthetics (D), it was decided that (A) was more important than (D). How much more important? It was of medium preference so it received a score of 2. And the intercept A-D in the criteria scoring matrix was recorded with an A-2 notation.
b. When a decision of importance cannot be made between two criteria (deadlocked), the two criteria can be indicated as equal by using both letters in the scoring matrix, and scoring at one point each. This was the case at intercept A-C in the above example where the evaluator, when comparing initial cost against energy usage, felt that they were both equally important and a standoff. The notation A/C was recorded in the matrix.

3. The third step, when all comparative evaluations are made, is to total the raw score of each criterion by summing the assigned letters in the matrix.
4. The fourth step is to adjust the raw scores to an assigned weight if desired. In the HVAC example, it was decided to convert the raw scores to a scale of 1–10 with 10 being assigned to the criterion with the highest raw score, and the other criteria adjusted accordingly.
5. Before using the criteria and weights developed, the total process should be reviewed. If the weights that have been developed are too closely grouped or too far apart, it is possible that they are not representative of actual desires. Some criteria may not have received any score, yet such criteria may be important enough to the team to have some impact during idea evaluation. A criterion receiving no score may be dropped if its importance is minimal. Or it may be given a minimal score and the other criteria weights adjusted accordingly.

The Evaluation Matrix

Once the criteria elements and their weights have been established, the next task is to use these in evaluating the alternatives selected from the feasibility ranking and comparison techniques. At this point, it is assumed that all of the ideas that have survived meet the minimal needs or basic function of the user or owner. The criteria elements are entered on the top of the evaluation matrix with their weights of importance just beneath.

1. The first step is to rank each criterion against each of the alternatives. The scoring system used in the analysis matrix is to assign 1 to 5 points on a scale of poor to excellent:

Poor	1
Fair	2
Good	3
Very good	4
Excellent	5

The ranking is selected (and circled) by taking into consideration how each alterative (properties and/or costs) compares with the criteria.

2. The second step consists of multiplying the rank of each with the weight of each criterion and entering the subtotal in the space provided.

3. The third step is to total the score for each alterative and rank them for selection. The idea having the highest total points is the most optimum selection of the choices made, from a subjective sense.

Judging Other Things

The evaluation matrix system has been used to judge many things by many people, with paired comparison used to determine the weights to be used. For example:

1. One can select a new car by identifying the features desired such as:

Handling/cornering/turning radius
Comfort/leg room/headroom
Appearance/style/color selection
Performance/acceleration/speed
Maintenance/repair convenience

However, it is assumed when evaluating cars, one would judge, for example, two seat cars with two seat cars. Otherwise, the number of persons it can carry is not minimum performance requirement or owner need.

2. The system was used to develop weights for the criteria to be used in judging employee eligibility for incentive awards for VE performance. This provides management with a more objective way of judging the contribution of an employee idea with respect to the employees' normal job responsibility.

3. In another management area, this technique has been used to develop performance standards, and to judge employee performance. Beginning with the employee position description, an outline of all employee tasks is developed. These are weighed by paired comparison to determine how important the performance of each task is to the others. Then the manager allocates a percentage of time for the performance of each task within quantified minimum outputs. Now, management has a system by which to calculate actual performance outputs weighed against the importance of each task. During the process of establishing the weights for each task, one might well discover

tasks that were of no importance and, when agreed upon by employee and supervisor, could be deleted from assigned position description duties, or be accomplished by someone else for less money.

C. Summary

Systematic evaluation of criteria forces the individual or team to develop their thoughts, reactions and recommendations. These can then be reviewed by the decision maker when deciding upon implementation.

1. Weighted evaluation helps to ensure that ideas receive a better evaluation than simply being rejected out-of-hand. The process causes one to discuss and determine needs vs. desires, the important from the unimportant, and trade-off vs. non–trade-off areas. All judgments made should be and are, conditioned with the evaluators knowledge, experience, special information, and owners input.
2. Weighted evaluation is a technique specially suited to selecting alternatives that optimize criteria and factors not readily measurable by costs such as aesthetics, safety, time, quality, etc. Through this technique, VE recommendations are tempered by the impact of criteria and other considerations that cannot be measured solely by dollars.

IX. DEVELOPMENT

A. Phase 6: Development

Objective. In this phase, a selected idea or ideas are fully developed with the intent of making specific recommendations to management. The process involves not only detailed technical development and testing but also an assessment of the probability of successful implementation.

Key questions.

1. Will it work?
2. Will it meet all necessary requirements?
3. Who has to approve it?
4. What are the implementation problems?
5. What are the costs?
6. What are the savings?

Procedures

General. In order to satisfy the questions above, each alternative must be subjected to: 1) careful analysis to ensure that the user's needs are satisfied; 2) a determination of technical adequacy; 3) the development of estimates of costs, implementation expenses, and schedules, including schedules and costs of all necessary tests; and 4) consideration of changeover requirements and impact.

Develop Convincing Facts. As in the Information Phase, the use of good human relations is of considerable importance to the success of the Development Phase. In developing answers to the questions above, the team should consult with cognizant personnel concerned with what the item must do, within what constraints it must perform, how dependable the item must be, and under what environmental conditions it must operate. Any technical problems related to design, implementation, procurement, or operation must be determined and resolved. Consideration must be given to impact in areas such as safety, fire protection, maintenance, and supply support.

Develop Specific Alternate Ideas. Those alternate ideas that stand up under close technical scrutiny should be followed through to the development of specific designs and recommendations. Work on specifics rather than generalities. Prepare drawings or sketches of alternate solutions to facilitate identifying problem areas remaining in the design, and to facilitate detailed cost analysis.

Cost Analysis. Prepare a detailed cost analysis for proposed alternatives to be included in the final proposal. This cost analysis should include the impact on initial costs as well as life-cycle costs (LCC).

Implementation Plan. Preparation of a realistic implementation plan during this phase is an important asset to gaining approval of recommended changes. Preparation of the plan will uncover and will force realism into the recommendations themselves as they are being prepared. An effective implementation plan must answer these questions.

How should it be implemented?
What should be changed and in what sequence?
Who should do it?
How long should it take?
Is any deadline required?
What is the implementation cost?
What are the consequences of delay?

The key to successful implementation (Phase 8, Section 11) lies in the placing of implementation steps for the necessary actions to be performed in the normal routine of business. The VE team should plan what these first action steps will be, and who will be assigned the responsibility to see that they are prepared for funding, priority assignment, and approval. It is so easy to leave a fine presentation and have everyone forget to acknowledge that they must take action. An example of a developed VE proposal follows.

X. PRESENTATION

A. Phase 7: Presentation

Objective. This phase involves the actual preparation and presentation of the best alternatives to persons having the authority to approve or empower others to approve the VE proposals. This phase of the VE job plan includes the following steps:

1. Presenting the VE proposals.
2. Presenting a plan of action that will ensure implementation.

Key questions.

1. What is recommended?
2. Who has to approve it?

Discussion

A value engineering proposal (VEP) is a challenge to the "status quo" of any organization. It is a recommendation for change. The recommendation was developed through a team effort and its adoption is dependent upon another team effort. The success of a value proposal is usually measured by the savings achieved from implemented proposals.

Regardless of the effort invested and the merits of the proposal, the net benefit is zero if the proposals are not implemented. Presenting a proposal and subsequently guiding it to implementation often requires more effort than its actual generation. This Section reviews some principles and practices that have been successfully used to facilitate the approval of VEPs.

Form

Presentation of a VEP should always be written. Oral presentation of study results is helpful to the person who is responsible for making the decision; however, it should never replace the written report. A written report normally demands and receives a written reply, whereas oral reports can be forgotten and overlooked as soon as they are presented. In the rush to wrap up a study, promote a great idea, or save the effort of writing a report, many proposals have fallen by the wayside because the oral presentation came first and was inadequate. The systematic approach of the VE job plan must be followed all the way through to include the systematic, meticulous, careful preparation of a written report. From this will evolve a more concise and successful oral presentation.

B. Presentation Strategies

Hints to improve the probability and reduce the time required for acceptance and implementation of proposals are:

Relate Benefits to Organizational Objectives

Management is more likely to approve the VEP which represents an advancement toward an approved objective. In government the potential of a VEP is not a profit but a capability. Therefore, the presentation should exploit all of the advantages a VEP may offer toward fulfilling organizational objectives and goals. When reviewing a VEP, the manager normally seeks either lower total cost of ownership, and/or increased capability for the same dollar investment. The objective may be not only savings but also some other mission related goal of the manager.

Support the Decision-maker

The dollar yield of a VEP is likely to be improved if it is promptly implemented. Prompt implementation in turn is dependent upon the expeditious approval of the responsible individuals. These individuals should be identified and the entire VE effort conducted under their sponsorship. The VE group becomes the decision maker's staff preparing information in such a manner that he can weigh the risk against the potential reward. Like any other well prepared staff report, each VEP should:

1. Satisfy questions the decision-maker is likely to ask.
2. Respect the decision-maker's authority.
3. Permit the decision-maker to preserve his/her professional integrity.
4. Imply assurance that approval would enhance his/her image.
5. Include sufficient documentation

Minimize Implementation Risk

Committing such an investment with no guarantee of success constitutes a risk that could deter acceptance of a VEP. This risk may be reduced by scheduling of test programs to provide intermediate assurances before continuing with the next step. Thus, the test program may be terminated or the proposal modified when the concept first fails to perform at an acceptable level.

Major expenditures for implementing proposed VE actions should not be presented as a lump-sum aggregate, but rather as a sequence of minimum risk increments. A manager may be reluctant to risk a total investment against total return, but may be willing to chance the first phase of an investment sequence. Each successive investment increment would be based upon the successful completion of the previous step.

1. Identify VE team
   - Introduce team
   - Acknowledge other contributors
2. Identify subject
   - Outline scope of study
3. Identify functions studied
   - Use an abbreviated fast diagram
4. Provide present cost of functions
   - Indicate the cost of the item
5. Explain methodology used
   - Indicate worth of functions
   - Relate how many ideas were considered
   - Explain weight evaluation attributes
   - Relate the performance criteria required
   - Show selection from top 2-3 candidates
6. Specific recommendations
   - Recommend specific changes
7. Expected benefits
   - Review life-cycle costs
   - Review break-even analysis
   - Review return on investment
   - Explain intangible benefits
8. Specific implementation plan
   - Propose a plan to implement
   - Indicate implementation cost and timing
   - Indicate consequences of delay
9. Ask for action
   - Offer your services
   - Be prepared to answer questions

Figure 20 Outline for oral presentation.

C. Oral Presentation Procedures

Figure 20 provides an outline format to be used in a presentation. The oral presentation can be crucial to selling a proposal. It gives the VE team a chance to ensure that the written proposal is correctly understood and that proper communication exists between the parties concerned. Effectiveness of the presentation will be enhanced if:

1. The entire team is introduced.
2. The presentation lasts no longer than 15 minutes with time for questions at the end.

3. The presentation is illustrated through the use of mockups, models, slides, view-graph, overhead projector, or flip charts.
4. The team is prepared with sufficient back-up material to answer all questions during the presentation.

XI. IMPLEMENTATION AND FOLLOW-UP

A. Phase 8: Implementation*

Objective

During this phase, management must ensure that approved recommendations are converted into actions. Until this is done, savings to offset the cost of the study will not be achieved. Three major objectives of this phase are:

1. To provide assistance, clarify misconceptions, and resolve problems that may develop in the implementation process.
2. To minimize delays encountered by the proposal in the implementation process.
3. To ensure that approved ideas are not modified or compromised such that they lose their cost effectiveness benefits.

Implementation Investment

The need to invest to save must be understood. Some degree of investment in staff time and/or funds must be provided if the VE opportunity is to become a reality. The necessary directions should be issued which require implementation actions to take place.

Expediting Implementation

The fastest way to achieve implementation of an idea is to effectively utilize the knowledge gained by those who originated it. The VE team could assist with preparation of first drafts of documents necessary to revise handbooks, specifications, A-E scopes, change orders, drawings, or contract requirements. Such drafts will help to ensure proper translation of the idea into action and will serve as a baseline from which to monitor progress of final implementation. To further ensure proper communication and translation of the idea onto paper, the VE team should review implementation actions.

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* Many authors do not show implementation and follow-up as discrete phases of the VE job plan. The author believes that implementation can be the most challenging phase of the job plan. If ideas are not effectively implemented, what is the purpose of performing the study?

Monitoring Progress

Implementation progress must be monitored just as systematically as the VEP development. It is the responsibility of management to ensure that implementation is actually achieved. Suggested procedures:

1. Designate a person to monitor all deadline dates in the implementation plan.
2. Designate a person to implement the VEP and meet the deadline dates established.
3. Conduct follow-up Phase 9.

Implementation Strategies

1. Assure that the decision maker understands the proposal. Be willing to provide additional information if required.
2. Assure that reasons for requesting a proposal are valid and based upon technical consideration, not just a critique of values. Opinions should be so stated.
3. A reason for not accepting an idea may be that "we have studied it previously and found it not a valid alternative." Examine the circumstances to assure that they are the same. Previous study is *not* a valid reason, especially if circumstances have changed.
4. New and untried proposals need careful investigation before acceptance. However, newness is *not* a valid reason for rejection.
5. Disagreement with the VE team's estimate is *not* reason for rejection. If the decision maker believes a cost discrepancy exists, he should evaluate the proposal on other merits; cost savings alone are not a valid reason for acceptance. Similarly, lack of cost savings are not a reason for rejection.
6. Redesign cost/time is not itself a reason for rejection. If substantial redesign is required, the design firm may be eligible for additional compensation if the effort was not anticipated.
7. The function of the VE team is to make recommendations. Implementing design normally rests with the designer and/or customer.
8. Proposals that have elements in common should be considered as a group. The VE team leader should present them in a logical way that results in efficient review.
9. Take into consideration the impact of VE recommendations on other areas.

B. Phase 9—Follow-Up*

Objective. This last phase of the job plan has several objectives listed below. They might seem quite diverse but when achieved in total, they will serve to foster and promote the success of subsequent VE efforts. In addition, other users, designers, and operators of similar facilities and products can benefit from the results of the study.

1. Obtain hard copies of all completed implementation actions.
2. Compare actual results with original expectations.
3. Submit cost savings achievement reports to management.
4. Enter implemented items into database for future VE.
5. Evaluate conduct of the project to identify problems that arose and recommend corrective action for the next project.
6. Initiate recommendations for potential future VE study on ideas evolving from the study just completed.
7. Screen all contributors to the VEP for possible commendations and letters of recommendation.

Key questions. Proper completion of this phase should answer the following questions:

1. Did the idea work?
2. Was money saved ?
3. Would you do it again?
4. Could it benefit others?
5. Have the savings been reported?
6. Has it had proper publicity?
7. Should any commendations be issued ?
8. Can results be published?

Discussion

A value study is not completed with implementation of an idea. Full benefit is not derived from a VEP until the follow-up phase is completed. Until then, the records on a project cannot be closed. Most of the objectives of this phase are so obvious that they are frequently over-looked. Sometimes they are not accomplished because they require effort (time-money-energy) to accomplish them. Yet, each objective is essential, for its own reason, to the continuing success of VE.

Accomplishment

It is the responsibility of management to designate some individual to complete this phase of the job plan. The list of objectives should be used as a checklist to ensure that each has been considered and accomplished.

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* Many authors do not show a separate Follow-up Phase in their work plan. Most owners do not include it in their scopes to VE contractors, and this step is frequently omitted. However, feeding back "lessons learned" to others is important for institutional learning. Implementation proposals can be entered into database for use on future studies.

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Controlling the Cost of Construction Labor

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I. INTRODUCTION

Construction labor costs are the most variable element of the project construction budget. Therefore, labor cost control is paramount to profitability for all contractors. Owners also need to control labor costs for work performed in-house, and for work performed by contractors on a reimbursable basis. In order to control costs, project management must first develop a realistic budget. A yardstick that is not exactly 36 in. long is of little use for measuring distances, and an inaccurate budget is similarly useless for measuring labor cost performance. Secondly, in order to maintain an accurate budget, project management must continually compare the actual costs to the budget to identify deviations. Once deviations are identified, project management must take swift corrective action to minimize cost overruns. Creating realistic budgets and maintaining them requires choosing an excellent and efficient cost control system for controlling construction labor costs.

There are various types of control systems. An example of a poor control system can be found in a rustic cabin with a wood stove attempting to maintain the interior temperature of the cabin. This control is conducted by

Table 1 Original Estimate: Warehouse Project, Building Concrete Labor Estimate and Actual Quantity @Day 30

Cost code	Description	Qty.	Unit	Unit cost ($)	Labor cost ($)	Day 30 actual qty.
	Column pads 5'-6"×5'-6"×1'-0"	64	Ea			
03120	Forms 4 uses	1,408	SF	1.50	2,112	Prod rpt
03110	Anchor bolts	160	EA	2.00	320	132
03210	Rebar 8-#5 bars each way	5,340	LB	0.15	801	4,380
03310	Concrete 4,000 psi	72	CY	5.00	360	56
03340	Finish	1,936	SF	0.15	290	1,510
	Frost wall 1305'×2'-0"×2'-6"	1,305	LF			
03120	Forms top 4"	870	SF	1.50	1,305	Prod rpt
03310	Concrete 3,000 PSI	242	CY	5.00	1,210	242
03340	Finish	2,610	SF	0.15	392	2,610
	Slab on grade 360'×360'×6"	129,600	SF			
03140	Forms	2,880	LF	0.50	1,440	Prod rpt
03220	6×6 #6/6 Welded wire fabric	129,600	SF	0.13	16,848	18,150
03330	Concrete 4,000 psi	2,400	CY	5.00	12,000	240
03360	Finish	129,600	SF	0.25	32,400	12,960
03150	Control joints	8,640	LF	0.50	4,320	520
03160	Expansion joints and column diamonds	1,800	LF	1.00	1,800	180
	Dock wall footings 135'×4'-0"×1'-0"	135	LF			
03120	Forms	270	SF	1.50	405	Prod rpt
03210	Rebar 3-#5 bars cont and #4 bent @18" OC	600	LBS	0.15	90	540
03310	Concrete 4,000 psi	20	CY	5.00	100	15
03340	Finish	540	SF	0.15	81	405
	Dock walls 135'×1'-6"×5'-6"	135	LF			
03130	Forms	1,485	SF	2.50	3,713	Prod rpt
03210	Rebar 4 #4 bars cont and #4 @18" OC	659	LB	0.15	99	264
03320	Concrete 4,000 psi	42	CY	7.00	294	0
03350	Finish top	203	SF	0.25	51	0
03370	Patch and rub walls	1,485	SF	0.15	223	0
	Total estimated labor cost				80,653	

the seat-of-the-pants method where when the occupants are cold, they place more firewood in the stove and adjust the dampers. In this control system, there are usually wide swings in the temperature (less control). An example of a good control system can be found in a house with a heating, ventilation, and air conditioning (HVAC) control system whose purpose is also to maintain the interior temperature at a point selected by the occupants. The HVAC control system continually monitors the temperature by using a thermostat. This measuring of temperature is the feedback portion of the system. When the house temperature falls below the temperature set by the occupants, a signal is sent to the furnace which adds heat to the house until the temperature is at the temperature set by the occupants. This adding of temperature by the furnace is the corrective action portion of the control system. In this control system, the occupants achieve more precise control. Both the feedback and corrective action must be present in a good control system or method.

There are two excellent construction labor cost control methods that create and maintain realistic budgets by utilizing the feedback and corrective action elements. They are the Earned Value method, and the Forecasting Unit Costs method. In discussing these two cost control methods, the elements will be identified as measuring inputs, measuring outputs, and report processing. Accompanying the discussions will be illustrations using data from the concrete accounts of a pre-engineered warehouse project. Also included with these discussions are a description of the warehouse project (in Appendix 1) and a labor cost estimate for the concrete accounts (in Table 1).

II. MEASURING INPUTS AND OUTPUTS

In the HVAC example, only one measurement, temperature, is required to control the system. Controlling construction labor costs requires many measurements. The ultimate goal of labor cost control is to expend the fewest dollars to complete the project. In order to achieve this goal, project management must measure the efficiency or cost-effectiveness of each dollar spent. This requires hundreds of measurements of workhours and of quantities produced, the two components of efficiency. Labor cost efficiencies are best measured as a ratio of inputs (workhours or dollars) and outputs (quantities produced).

A construction project is complex and must be broken into controllable parts. This is accomplished using a work breakdown structure. The work breakdown structure is the classification of each project element along activity levels where the activity outputs can be measured and then compared to the resources expended. Each classification is assigned a cost code for identification. A construction project has hundreds of cost codes. A study of 30 building contractors in Atlanta showed that for a two million dollar project the median number of cost codes was 400 (Halpin). The work breakdown structure must be carefully constructed and documented so that all members of the project team consistently use the correct cost codes for inputs and outputs.

Labor input is measured by workhours expended or by labor dollars spent. Workhours are measured directly using cost codes and time cards. Dollars spent are calculated by multiplying each workhour expended by the appropriate wage rate (i.e., dollars/workhour). Before the widespread use of computers, labor input was largely measured by workhours to avoid the tedious hand calculations required to calculate dollars expended by cost account. With computers, project management now has the option of using workhours or dollars to measure labor input.

Unlike construction inputs, the outputs produced by construction labor cannot be measured with a single unit of measure. Consequently, a large number of measures are used for construction outputs. Examples of these measures include cubic yards of excavation, square feet of concrete formwork, tons of structural steel, lineal feet of pipe, and number of electrical terminations. To track each classification of output, a separate cost account is required. This then requires that the input be measured for each cost account in order to match each output to the resources (inputs) that produced the output. The measurement of inputs is accomplished by observing and recording the number of workhours expended each day by cost account. If workhours are not accurately recorded in the correct cost account, the cost control system will prove to be ineffective. The accuracy of cost coding workhours is improved by the following:

Training all personnel in the use of company cost accounts to correctly code time cards
Checking of time cards for correct cost codes before recording the workhours in the labor cost control system
Maintaining a well-documented work breakdown structure

A major consideration when measuring construction quantities is whether or not an item (such as yd^3 of concrete placed or lineal ft of wire pulled) is installed in one step or several steps. Quantities installed in one step are the easiest to measure. The item is either installed or it is not installed. The project management team can physically measure the output for the reporting period. It is more difficult to measure progress when quantities are installed in several steps. Each sequential step could have its own cost account. However, this would burden the labor cost control system with too many cost accounts. A better way to handle this situation is to use the Equivalent Units method to report the partially completed units as equivalent units completed. In the Equivalent Units method, each step is assigned a weight based upon the percentage of the activity's labor budget required to complete that step. The breakdown of the effort required for each step is called the "rules of credit." Below is an example of piping rules of credit (Thomas).

	% of work
Pipe placed in the permanent location	60
Pipe end connections are welded or bolted	20
Pipe trim installed and pipe is ready for hydrotest	20

An example of a Daily Production Report that measures work progress by cost account using the Equivalent Units (rules of credit) method can be found in Table 2. The detailed description of each field in the Daily Production Report for cost account 03140 appears below.

1. The description column lists all subtasks for account 03140.
2. The field engineer or superintendent records the quantity completed each day for each of the following subtasks: erect forms, wreck forms, and clean and oil forms.
3. The subtask quantities are totaled through the report cutoff date.
4. Each subtask is weighted according to the estimated level of effort required for that subtask. These weights are the "rules of credit" and are listed for each subtask.
5. The actual quantity for the subtask is multiplied by the subtask's weight in order to obtain the subtotal of quantity completed for the account. For this example, 767 lf of edge form was erected by day 30. This amount is multiplied by 0.6, the weight for erecting edge forms, to obtain a subtotal for the account of 460 lf.
6. The subtotal for each subtask is totaled to obtain the actual quantity for the account. The total of 608 lf is the sum of 460 lf (erect form) plus 111 lf (wreck forms) plus 37 lf (clean and oil forms).

III. THE EARNED VALUE METHOD

Once the actual inputs and outputs are measured, the project management team compares the actual inputs and outputs to the project budget. This comparison occurs at both the cost code and project levels (or at any level in the Work Breakdown Structure). The actual cost cannot be compared directly to the budget cost because the actual cost is only for completed work whereas the budget cost is for the entire project. In the Earned Value labor cost control system, the budget is multiplied by the percent of work completed to calculate the earned value. The percent complete for the cost account is the actual quantity divided by the forecasted total quantity. See Eq. (1). The

Table 2 Daily Production Report: Warehouse Project, Building Concrete Formwork

Cost code	Description	Unit	Day 16	Day 17	Day 18	Day 19	Day 20	Day 21	Day 22
03120	Column pads forms								
	Erect	SF	154		154		176		154
	Wreck	SF				154		154	
	Clean & oil	SF				154		154	
03120	Frost wall forms								
	Erect	SF	200			200			270
	Wreck	SF					200		
	Clean & oil	SF					200		
03120	Dock wallfooting forms								
	Erect	SF							
	Wreck	SF							
	Clean & oil	SF							
03130	Dock walls forms								
	Erect	SF							
	Wreck	SF							
	Clean & oil	SF							
03140	Slab on grade edge forms								
	Erect	LF							
	Wreck	LF							
	Clean & oil	LF							

forecasted total quantity is the project management team's current assessment of the total quantity included in the cost account. The earned value is compared directly to the actual cost to evaluate project cost performance. Earned value is measured by either workhours or labor dollars. Earned value is also referred to as the Budgeted Cost of Work Performed (BCWP). The relationship between the earned value and the budget is expressed in Eq. (2):

$$\text{Percent complete (single account)} = \frac{\text{actual quantity}}{\text{forecasted total quantity}} \quad (1)$$

$$\text{Earned value (BCWP)} = \text{actual percent complete} \times \text{budget for the account} \quad (2)$$

As can be seen from this equation, a portion of the budget is *earned* as a task is completed up to the total budget in that account. One cannot earn more than has been budgeted. If an account has a budget of $3,200 and 100 workhours and the account is now 25% complete, then $800 and 25 workhours have been earned. Cost performance is measured by comparing the earned value to the actual cost. Earned value and actual cost can be measured in

Table 2 (Continued)

Day 23	Day 24	Day 25	Day 26	Day 27	Day 28	Day 29	Day 30	Total @Day 30	Rules of credit	Subtotal	Total quantity
	154		176			154	22	1,144	0.6	686	862
176								484	0.3	145	
								308	0.1	31	
		200						870	0.6	522	870
200			270				200	870	0.3	261	
200			270				200	870	0.1	87	
108					108		28	244	0.6	146	190
			108					108	0.3	32	
			108					108	0.1	11	
				297			297	594	0.6	356	356
								0	0.3	0	
								0	0.1	0	
			370				397	767	0.6	460	608
					370			370	0.3	111	
					370			370	0.1	37	

either dollars or workhours. Also, earned value and actual cost can be for a period or the total to-date. The actual cost comparison can be a ratio or a variance as illustrated in Eqs. (3) and (4).

$$\text{Cost variance (CV)} = \text{earned value} - \text{actual cost} \tag{3}$$

$$\text{Cost performance index (CPI)} = \frac{\text{earned value}}{\text{actual cost}} \tag{4}$$

Note that a positive variance and an index of 1.0 or greater is a favorable performance. Since progress in all accounts can be reduced to earned workhours and dollars as illustrated, then multiple accounts can be summarized and overall progress calculated as shown in Eq. (5).

$$\text{Percent complete multiple accounts} = \frac{\text{earned value all accounts}}{\text{budget cost all accounts}} \tag{5}$$

The estimated cost at completion (EAC) is determined by predicting the overall cost performance index at the completion of the cost account. There are several sophisticated forecasting techniques that are explained in management science texts, but few constructors are comfortable with them and their reliability appear no better than utilizing a few simple approaches. One fact is certain. No two methods, sophisticated or otherwise, produce the same answer. Three basic approaches are provided here. (Skills and Knowledge of Cost Engineering, p. 11–17).

A. Method 1

Method 1 assumes that work from this point forward will progress at the budget (CPI = 1) whether or not this performance has prevailed to this point. See Eq. (6)

$$\text{Estimate at completion (EAC)} = (\text{actual cost to-date}) + (\text{budget—earned value}) \quad (6)$$

B. Method 2

Method 2 assumes that the performance to-date will continue to prevail. See Eq. (7).

$$\text{Estimate at completion (EAC)} = \frac{\text{budget}}{\text{CPI}} \quad (7)$$

C. Method 3

Method 3 utilizes historical curves that show the normal variation in the CPI as the cost account progresses. The forecaster simply makes the best extrapolation possible using the typical shapes of such curves and whatever other information may be available to the forecaster to make the projection. It is recommended that no single forecasting method be used. Rather, include a forecast by each of the above methods in order to provide a range of possibilities.

Labor costs are determined by both the quantities installed and the labor unit rate. The labor unit rate is expressed in either dollars/unit or in workhours/unit. Multiplying the workhours/unit yields the dollars/unit. Overall cost performance depends on both quantity variances and unit rate variances. As can be seen from the calculation of earned value, cost overruns occur when actual quantities installed total more than the budgeted quantities. This occurs when the budget is based upon an inadequate scope, when there are mistakes in the estimate takeoff, when scope creep occurs after the budget is prepared, when the field force installs more quantities than what was required and when there is rework due to poor workmanship. Cost overruns also occur when the actual unit rate (dollars/unit or workhours/unit) is greater than the budget unit rates. The credit value is the budget unit rate multiplied by the actual quantities of work installed (Skills and Knowledge of Cost Engineering, p. 9–5). The credit value represents what the cost would have been if the actual quantities were installed at the budget unit rate. The credit value is computed using Eq. (8) and the unit of measure can be dollars or workhours. Comparing the credit value to the actual cost measures the performance of the unit rate alone without the confounding effect of changes in quantities. Use the unit cost (dollars/unit) for the budget unit rate to calculate credit dollars (C$). For an analysis by workhours, use the production rate (workhours/unit) to calculate credit workhours (CWH). The Unit Cost Index is the ratio of the credit dollars (C$) to the actual dollars. See Eq. (9). The Productivity Index is the ratio of the credit workhours (CWH) to the actual workhours. See Eq. (10).

$$\text{Credit value} = \text{actual quantity} \times \text{budget unit rate} \tag{8}$$

$$\text{Unit cost index (UCI)} = \frac{\text{credit dollars}}{\text{actual dollars}} \tag{9}$$

$$\text{Productivity index (PI)} = \frac{\text{credit workhours}}{\text{actual workhours}} \tag{10}$$

A significant feature of an earned value analysis is that the calculated earned value can be compared to the scheduled value to measure schedule performance. The scheduled value is the value in dollars or workhours of work scheduled. It is also known as the Budgeted Cost of Work Scheduled (BCWS). The scheduled value is computed using either Eq. (11) or (12).

$$\text{Scheduled value (BCWS)} = \text{scheduled percent complete} \times \text{budget for the account} \tag{11}$$

or

$$\text{Scheduled value (BCWS)} = \text{quantity scheduled} \times \text{budget unit rate} \tag{12}$$

Schedule performance is measured by comparing the earned value to the scheduled value. This comparison can be a variance, as in Eq. (13), or a ratio, as in Eq. (14).

$$\text{Schedule variance (SV)} = \text{earned value} - \text{scheduled value} \tag{13}$$

$$\text{Schedule performance index (SPI)} = \frac{\text{earned value}}{\text{scheduled value}} \tag{14}$$

Table 3 Schedule Report: Warehouse Project, Building Concrete BCWS @ Day 30

Cost code	Description	Labor budget ($)	Start date	Dur.	Sched. days @30	BCWS @30 ($)
	Column pads 5'-6" x 5'-6" x 1'-0"					
03120	Forms 4 uses	2,112	18	16	13	1,716
03110	Anchor bolts	320	20	11	11	320
03210	Rebar 8 #5 bars each way	801	20	11	11	801
03310	Concrete 4,000 psi	3605	22	11	9	295
03340	Finish	290	22	11	9	238
	Frost wall 1305' x 2'-0" x 2'-6"					
03120	Forms top 4"	1,305	16	15	15	1,305
03310	Concrete 3,000 psi	1,210	19	10	10	1,210
03340	Finish	392	19	10	10	392
	Slab on grade 360' x 360' x 6"					
03140	Forms	1,440	26	20	5	360
03220	6 x 6 #6/6 Welded wire fabric	16,848	28	15	3	3,370
03330	Concrete 4,000 psi	12,000	29	15	2	1.600
03360	Finish	32,400	29	15	2	4.320
03150	Control joints	4,320	31	15	0	0
03160	Expansion joints and column diamonds	1.800	28	15	3	360
	Dock wall footings 135 x 4'-0" x 1'-0"					
03120	Forms	405	21	13	10	312
03210	Rebar 3-#5 bars cont and #4 bent @ 18" OC	90	23	8	8	90
03310	Concrete 4,000 psi	100	24	8	7	88
03340	Finish	81	24	8	7	71
	Dock walls 135' x 1'-6" x 5'-6"					
03130	Forms	3,713	26	15	5	1,238
03210	Rebar 4-#4 bars cont and #4 @ 18" OC	99	28	10	3	30
03320	Concrete 4,000 psi	294	30	10	1	29
03350	Finish top	51	30	10	11	5
03370	Patch and rub walls	223	32	10	0	0
Totals		80,653				18,150

Note that a positive variance and an index of one or greater is a favorable performance.

In Table 3, the Schedule Report is used to calculate the Scheduled Value (BCWS) at day 30 of the project. The end of day 30 is the cutoff date for the example used in this chapter. The detailed description of each field in the Schedule Report for cost account 03140 appears below.

1. The labor budget is listed for each account. This is $1,440 for account 03140.
2. The start date is expressed as the beginning of the day. The slab edge forms are scheduled to start at the beginning of day 26.
3. The number of work days scheduled by the cutoff date, day 30, is 5 for account 03140. The five days are days 26 through 30 inclusive (26, 27, 28, 29, and 30).
4. The BCWS is calculated by multiplying the budget by the percentage of work that should have been accomplished by the cutoff date. For this example, the assumption is that an equal amount of work is scheduled for each day. Therefore, the scheduled percentage complete is equal to the scheduled days at day 30 divided by the total duration. The scheduled percent complete for account 03140 is 5 days divided by 20 days, or 25%. The BCWS is 25% multiplied by $1,440, or $360.

In Table 4, the Labor Cost Report Using Earned Value analyzes labor cost and schedule performance using the Earned Value method. The detailed description of each field in the Labor Cost Report Using Earned Value Report for cost account 03140 follows.

1. The actual quantity is transferred to this report from the actual quantities provided in Table 1, or from the quantities calculated on the Daily Production Report, Table 2. Note that some cost accounts appear in more than one work package. The cost account totals on this report is the summary of all work packages. For cost account 03140, the actual quantity is calculated at 608 lf. See the Daily Production Report in Table 2.
2. The budget quantity is transferred to this report from the Labor Estimate. For cost account 03140, the budget quantity is 2,880 lf.
3. The estimate at completion (EAC) quantity is the budget quantity plus or minus any changes or corrections. There are no changes or corrections for cost account 03140.
4. The labor budget is transferred from the labor estimate. For cost account 03140, the labor budget is $1,440.
5. The actual cost of work performed (ACWP) is gathered from the daily time cards. For cost account 03140, the ACWP is $288.
6. The budgeted cost of work performed (BCWP) is also known as the earned value. The BCWP is calculated by multiplying the budget by the

Table 4 Labor Cost Report Using Earned Value: Warehouse Project, Building Concrete

Cost code	Description	Unit	Actual quantity	Budget quantity	Forecast quantity	Labor budget ($)
03110	Anchor bolts	EA	132	160	160	320
03120	Form footings	SF	1,922	2,548	2 602	3,822
03130	Forms walls	SF	356	1,485	1,782	3,713
03140	Form edge of slab	LF	603	2,880	2,880	1,440
03150	Control joints	LF	520	8,640	8,640	4,320
03160	Expansion joints & column dia.	LF	180	1,800	1,800	1,800
03210	Rebar #3 to #7	LBS	5,184	6,599	6,851	990
03220	Welded wire fabric	SF	18,150	129,600	129,600	16,848
03310	Place footing concrete	CY	313	334	338	1,670
03320	Place wall concrete	CY	0	42	50	294
03330	Place slab on grade concrete	CY	240	2,400	2,400	12,000
03340	Finish top of footings	SF	4,525	5,086	5,194	763
03350	Finish top of walls	SF	0	203	244	51
03360	Finish slab on grade	SF	12,960	129,600	129,600	32,400
03370	Patch & rub walls	SF	0	1,485	1,782	223
						80,653

percentage of work actually completed. The actual percent complete is the actual quantity divided by the forecast quantity. For account 03140, the actual percent complete is 608 lf divided by 2,880 lf, or 21.11%. The BCWP is $1,440 multiplied by 21.11%, or $304.

7. The credit dollar (C$) is equal to the budgeted unit cost multiplied by the actual quantity. This is the amount that would have been spent to produce the actual quantity at the budget unit cost. The budget unit cost is the budget dollars divided by the budget quantity. For cost account 03140, the budget unit cost is $1,440 divided by 2,880 lf, or $0.50 per lf. The C$ is $0.50 per lf multiplied by 608 lf, or $304. Note that the C$ is equal to the BCWP. This will always be the case when the forecast quantity is equal to the budget quantity.

8. The cost performance index (CPI) is a measure of the cost performance. It is calculated by dividing the BCWP by the ACWP. Indexes greater than one indicate good cost performance. Indexes of less than one, point towards

Table 4 (Continued)

Actual cost of work perf. ($)	Budgeted of cost of work perf. ($)	Budgeted cost of work schedule ($)	Credit dollars ($)	Estim-ate at compl. ($)	Cost perform. Index	Schedule perform. Index	Unit cost index
285	264	320	264	346	0.926	0.825	0.926
3,200	2,823	3,333	2,883	4,332	0.882	0 847	0.901
682	742	1,238	890	3,416	1.087	0.599	1.304
288	304	360	304	1,364	1.056	0.844	1.056
267	260	0	260	4,436	0.974		0.974
205	180	360	180	2,050	0.878	0.500	0.878
805	749	921	778	1,064	0.930	0.813	0.966
2,425	2,360	3,370	2,360	17,316	0.973	0.700	0.973
1,670	1,546	1,593	1,565	1,804	0.926	0.971	0.937
0	0	29	0	350			
1,375	1,200	1,600	1,200	13,750	0.873	0.750	0.873
638	665	701	679	732	1.042	0.948	1.064
0	0	5	0	61			
3 522	3 240	4,320	3,240	35,220	0.920	0.750	0.920
0	0	0	0	267			
15,363	14,332	18,150	14,602	86,507	0.933	0.790	0.950

poor cost performance. For cost account 03410, the CPI is equal to $304 divided by $288, or 1.056 which indicates good performance.

9. In Table 4, the estimated cost at completion (EAC) is computed assuming that the cost performance to-date will continue until the cost account is completed. The EAC is calculated by dividing labor budget by the CPI. The CPI is equal to 1.00 for accounts that have no actual data. For cost account 03410, the EAC is equal to $1,440 divided by 1.056, or $1,364.

10. The schedule performance index (SPI) is a measure of schedule performance. The SPI is the ratio of the BCWP to the BCWS. Indexes greater than one indicate good schedule performance and indexes of less than one point towards poor schedule performance. For cost account 03410, the SPI is equal to $304 divided by $360, or 0.844 which indicates poor schedule performances, i.e., the edge forms are behind schedule.

11. The unit cost index (UCI) is a measure of unit cost performance. The labor unit cost is a combination of both labor productivity and wage rates.

Variances between the budget and actual unit cost are generally caused by differences in productivity. Therefore, the UCI is an indirect measure of labor productivity. The UCI is the ratio of the C$ to the ACWP. Indexes greater than one indicate good unit cost performance and indexes of less than one, point towards poor unit cost performance. For cost account 03410, the UCI is equal to $304 divided by $288, or 1.056. Note that the UCI is equal to the CPI for this account. Since there is no variance between the budget and actual quantities, the overall cost performance is determined solely by the unit cost variance.

IV. FORECASTING UNIT COSTS METHOD

The Forecasting Unit Costs labor cost control system is another method for the project management team to compare the actual inputs and outputs to the project budget. This method makes comparisons at both the cost code and project levels (or at any level in the Work Breakdown Structure). In the Forecasting Unit Costs labor cost control system, actual costs to-date are used to calculate actual unit costs (or production rates if workhours are used to measure inputs). The actual unit costs are then analyzed to forecast the unit costs at the completion of the account. The estimated cost at completion (EAC) is calculated by multiplying the estimate at completion unit costs by the forecasted quantities. The EAC is then compared to the budget to determine cost performance. Note that at the account level, to-date unit costs can be compared directly to the budget unit costs to determine performance.

The estimated cost at completion (EAC) is analogous to finding the EAC in the Earned Value method. It is determined by predicting the overall unit rates at the completion of the cost account. The three basic approaches are restated here for the Forecasting Unit Costs method.

A. Method 1

Method 1 assumes that work from this point forward will progress at budget unit rates whether or not these rates have prevailed to this point. See Eq. (15).

$$\text{Estimate at completion (EAC)} = \text{actual cost to-date} + (\text{to go quantity}) \times (\text{budget unit rate}) \tag{15}$$

B. Method 2

Method 2 assumes that the unit rate prevailing to-date will continue to prevail. See Eq. (16).

$$\text{Estimate at completion (EAC)} = \text{total quantity} \times \text{actual unit rate} \tag{16}$$

C. Method 3

This method utilizes historical curves that show the normal variation in unit rates as the cost account progresses. The forecaster simply makes the best extrapolation possible using the typical shapes of such curves and whatever other information may be available to the forecaster to make the projection.

As with the Earned Value method, it is recommended that no single forecasting method be used. Rather, include a forecast by each of the above methods in order to provide a range of possibilities.

The Labor Cost Report Using Forecasted Unit Costs, which analyzes labor cost performance using the forecasting unit cost method, can be found in Table 5. The detailed description of each field in the Labor Cost Report Using Forecasted Unit Costs Report for cost account 03140 follows.

1. The actual quantity is transferred to this report from the actual quantities provided in Table 1, or from the quantities calculated on the Daily Production Report, Table 2. Note that some cost accounts appear in more than one work package. The cost account totals on this report is the summary of all work packages. For cost account 03140, the actual quantity is calculated at 608 lf. See the Daily Production Report in Table 2.
2. The budget quantity is transferred to this report from the Labor Estimate. For cost account 03140, the budget quantity is 2,880 lf.
3. The forecasted quantity is the budget quantity plus or minus changes or corrections. There are no changes or corrections for cost account 03140.
4. The percent complete is the actual quantity divided by the forecast quantity. For account 03140, the actual percent complete is 608 lf/2,880 lf, or 21.1%.
5. The actual cost of work performed is gathered from the daily time cards. For cost account 03140, the actual cost of work performed is $288.
6. The labor budget is transferred from the labor estimate. For cost account 03140, the labor budget is $1,440.
7. The actual unit cost is the actual dollars divided by the actual quantity. For cost account 03140, the actual unit cost is $288 divided by 608 lf, or $0.4737 per lf. Note that the report is formatted to show only two decimal places.
8. The budget unit cost is the budget dollars divided by the budget quantity. For cost account 03140, the budget unit cost is $1,440 divided by 2,880 lf, or $0.5000 per lf. By comparing the budget unit cost to the actual unit cost the project management team can determine the cost performance of the account. The project management team has to take into account that cumulative to-date unit rates at the beginning of an account are typically higher than the unit rate at completion.
9. In Table 5, the estimated cost at completion (EAC) is computed assuming that the actual unit cost to-date will continue until the cost account is com-

pleted (Method 2). Therefore, the forecasted unit cost is equal to the actual unit cost. For cost account 03410, the forecasted unit cost is $0.4737 per lf. Method 2 is just one of the methods used to forecast the final unit cost. The accuracy of the forecast generally improves as more information is used in the forecast.

10. The EAC is calculated by multiplying the forecast quantity by the forecast unit cost. For cost account 03410, the EAC is equal to 2,880 lf multiplied by $0.4737 per lf, or $1,364.

Variance analysis techniques are utilized in the Forecasting Unit Costs method to determine unit cost performance. This is analogous to using the credit value in the Earned Value method. Variance analysis apportions the total variance between the budget and the EAC into the variances caused by each of the three components of labor costs; the quantity of work, the production rate, and the wage rate. Each variance is expressed in dollars and the sum of the variances caused by each component is equal to the total variance. Knowing which combination of components is responsible for the total variance, points the project management team towards the appropriate corrective

Table 5 Labor Cost Report Using Forecasted Unit Costs: Warehouse Project, Building Concrete

Cost code	Description	Unit	% compl.	Actual quantity	Budget quantity	Forecast quantity
03110	Anchor bolts	EA	82.5	132	160	160
03120	Form footings	SF	73.9	1,922	2,548	2,602
03130	Forms walls	SF	20.0	356	1,485	1,782
03140	Form edge of slab	LF	21.1	608	2,880	2,880
03150	Control joints	LF	6.0	520	8,640	8,640
03160	Expansion joints & column dia.	LF	10.0	180	1,800	1,800
03210	Rebar #3 to #7	LBS	75.7	5,184	6,599	6,851
03220	Welded wire fabric	SF	14.0	18,150	129,600	129,600
03310	Place footing concrete	CY	92.6	313	334	338
03320	Place wall concrete	CY	0.0	0	42	50
03330	Place slab on grade concrete	CY	10.0	240	2,400	2,400
03340	Finish top of footings	SF	87.1	4,525	5,086	5,194
03350	Finish top of walls	SF	0.0	0	203	244
03360	Finish slab on grade	SF	10.01	12,960	129,600	129,600
03370	Patch & rub walls	SF	0.0	0	1,485	1,782

action. The equations required for variance analysis are summarized in Table 6. In order to use variance analysis, the forecast unit cost must be divided into its wage rate and production rate components.

A problem with variance analysis is that the joint variances can confuse the overall labor cost analysis. The solution to this problem is to prorate the joint variances to the main effect variances (quantity, wage rate, and production rate) based on the magnitude of the main effect variances. Variance analysis can also be performed on the quantity and production rate components for labor cost systems that use workhours to measure labor input. As a practical note, variance analysis is sensitive to rounding. The variance analysis calculations are best performed on a computerized spreadsheet with no rounding of intermediate steps. If the calculations are performed by hand, all intermediate steps should be carried out to four significant figures.

See Table 7 for the Summary Variance Analysis Report for the example project data. The detailed description of each field in the Summary Variance Analysis Report for cost account 03140 follows.

Table 5 (Continued)

Forecast quantity	Actual cost of work perf. ($)	Labor budget ($)	Estimate at compl. ($)	Actual unit cost ($)	Budget unit cost ($)	Forecast unit cost ($)
160	285	320	346	2.16	2.00	2.16
2,602	3,200	3,822	4,332	1.66	1.50	1.66
1,782	682	3 713	3,416	1.92	2.50	1.92
2,880	288	1,440	1,364	0.47	0.50	0.47
8,640	267	4,320	4,436	0.51	0.50	0.51
1,800	205	1,800	2,050	1.14	1.00	1.14
6,851	805	990	1,064	0.16	0.15	0.16
129,600	2,425	16,848	17,316	0.13	0.13	0.13
338	1,670	1,670	1,804	5.34	5.00	5.34
50	0	294	350		7.00	7.00
2,400	1,375	12,000	13,750	5.73	5.00	5.73
5,194	638	763	732	0.14	0.15	0.14
244	0	51	61		0.25	0.27
129,600	3,522	32,400	35,220	0.27	0.25	0.27
1,782	0	223	267		0.15	0.15
	15,363	80,653	86,507			

Table 6 Variance Analysis Formulas

Estimate at completion	$(Q + C_Q)(W + C_W)(P + C_P)$
Budget	QWP
Quantity variance	$C_Q \times W \times P$
Wage rate variance	$Q \times C_W \times P$
Production rate variance	$Q \times W \times C_P$
Quantity—Wage rate joint variance	$(-1) \times C_Q \times C_W \times P$
Quantity—Production rate joint variance	$(-1) \times C_Q \times W \times C_P$
Wage—Production rate joint variance	$(-1) \times Q \times C_W \times C_P$
3-way joint variance	$C_Q \times C_W \times C_P$

where
- Q = budget quantity
- W = budget wage rate
- P = budget production rate
- C_Q = change in quantity = (budget quantity) – (EAC quantity)
- C_W = change in wage rate = (budget wage rate) – (EAC wage rate)
- C_P = change in production rate = (budget production rate) – (EAC production rate)

Table 7 Summary Variance Analysis Report: Warehouse Project, Building Concrete

Cost code	Description	Labor budget ($)	Estimate at compl.	Total variance ($)	Quantity variance ($)
03110	Anchor bolts	320	346	(26)	0
03120	Form footings	3,822	4,332	(510)	(82)
03130	Forms walls	3,713	3,416	297	(1,695)
03140	Form edge of slab	1,440	1,364	76	0
03150	Control joints	4,320	4,436	(116)	0
03160	Expansion joints & column dia.	1,800	2,050	(250)	0
03210	Rebar #3 to #7	990	1,064	(74)	(39)
03220	Welded wire fabric	16,848	17,316	(468)	0
03310	Place footing concrete	1,670	1,804	(134)	(20)
03320	Place wall concrete	294	350	(56)	(56)
03330	Place slab on grade concrete	12,000	13,750	(1,750)	0
03340	Finish top of footings	763	732	31	(17)
03350	Finish top of walls	51	61	(10)	(10)
03360	Finish slab on grade	32,400	35,220	(2,820)	0
03370	Patch & rub walls	223	267	(45)	(45)
		80,653	86,507	(5,855)	(1,964)

1. The labor budget is transferred from the labor estimate. For cost account 03140, the labor budget is $1,440.
2. For cost account 03140, the Estimate at Completion is $1,364 (Table 5).
3. The total variance is the budget minus the Estimate at Completion. For account 03140, the total variance is $76. A positive variance indicates that less money will be spent in the account than was budgeted.
4. The budget quantity is transferred to this report from the Labor Estimate. For cost account 03140, the budget quantity is 2,880 lf.
5. The budget wage rate and the budget production rate come from the original estimate. For account 03140, the values are $18.75/workhour and 0.02667 workhours/lft.
6. The forecast quantity is the budget quantity plus or minus any changes or corrections. There are no changes or corrections for cost account 03140.
7. The forecast unit cost is divided into its wage rate and production rate components. The actual unit cost (including the actual wage rate and the actual production rate) is assumed to continue until the cost account is completed (Table 5). For account 03140, the forecast (actual) wage rate is $18.77/workhour and the forecast (actual) production rate is 0.02524 workhours/lf.

Table 7 (Continued)

Wage variance ($)	Prod. variance	Budget quantity	Budget wage rate	Budget prod. rate	Estimate at compl. quantity	Estimate at compl. wage rate	Estimate at compl. prod. date
(1)	(25)	160	18.75	0.10667	160	18.80	0.11489
(2)	(426)	2,548	18.75	0.08000	2,602	18.76	0.08875
(20)	2,012	1,485	18.75	0.13333	1,782	18.85	0 10168
(2)	77	2,880	18.75	0.02667	2,880	18.77	0.02524
(35)	(82)	8,640	18.75	0.02667	8,640	18 90	0.02717
(5)	(245)	1,800	18.75	0.05333	1,800	18.80	0.06058
(3)	(33)	6,599	19.85	0.00756	6,851	19.90	0 00780
(43)	(4245)	129,600	19.85	0.00655	129,600	19.90	0.00671
(36)	(77)	334	14.20	0.35211	338	14.50	0.36801
(0)	(0)	42	14.20	0.49296	50	14.40	0.48611
(42)	(1,708)	2,400	14.20	0.35211	2,400	14.25	0.40205
(4)	51	5,086	16.02	0.00936	5,194	16.10	0.00876
(0)	(0)	203	16.02	0.01561	244	16.10	0.01553
(163)	(2,657)	129,600	16.02	0.01561	129,600	16.10	0.01688
(0)	(0)	1,485	16.02	0.00936	1,782	16.10	0.00932
(354)	(3,537)						

Table 8 Variance Analysis Calculations

Budget quantity = 2,880 lf
Budget wage rate = \$18.75 per workhour
Budget production rate = 0.0267 workhours per lf
(Budget quantity) – (EAC quantity) = 2,880 – 2,880 = 0 lf
(Budget wage rate) – (EAC wage rate) = \$18.75 – \$18.77 = (\$0.02) per workhour
(Budget production rate) – (EAC production rate) = 0.02667 – 0.02524 = 0.00143 workhours/lf
Quantity variance 0 lf × \$ 18.75/wh × 0.02667 wh/lf = \$ 0.00
Wage rate variance 2,880 lf × (\$ 0.02)/wh × 0.02667 wh/lf = \$(1.54)
Production rate variance 2,880 lf × \$18.75/wh × 0.00143 wh/lf = \$77.22
Quantity—wage rate joint variance (–1) × 0 lf × (\$ 0.02)/wh × 0.02667 wh/lf = \$ 0.00
Quantity—production rate joint variance (–1) × 0 lf × \$18.75/wh × 0.00143 wh/lf = \$ 0.00
Wage rate—production rate joint variance (–1) × 2,880 lf × (\$ 0.02)/wh × 0.00143 wh/lf = \$ 0.09
Three-way joint variance 0 lf × (\$ 0.02)/ wh × 0.00143 wh/lf = \$ 0.00
Adjusted quantity variance = \$0.00 + \$0.00 = \$0.00
Adjusted wage rate variance = (\$1.54) + \$0.00 = (\$1.54)
Adjusted production rate variance = \$77.22 + \$0.09 = \$77.31

8. The calculations for the quantity variance, wage variance, and production rate variance are shown in Table 8. For account 03140 the only joint variance is the Wage Rate–Production Rate Joint Variance of \$0.09. The sum of the absolute values of the wage rate and production rate variances is \$78.76. Prorating the joint variance based upon the magnitude of the main variances adds \$0.00 (2%,, or \$1.54 divided by \$78.76, of the joint variance) to the wage rate variance and \$0.09 (98%, or \$77.22 divided by \$78.76, of the joint variance) to the production rate variance.

V. SUMMARY

Which method, Earned Value or Forecasting Unit Costs, is best for controlling construction labor costs? Each method analyzes the construction project and identifies the deviations from the budget for corrective action by the project management team. Using the assumptions stated in this paper yields identical estimates at completion for each method. While both methods, when diligently applied, will control project costs and produce identical estimates at completion, each one has a unique advantage. The earned values in the Earned Value Method can be compared to the value of work scheduled as part of an integrated project control system. The advantage of the Forecasting Unit Costs method is that it is familiar to most contractors.

VI. APPENDIX—DESCRIPTION FOR THE WAREHOUSE PROJECT

1. The warehouse is a 360 ft by 360 ft pre-engineered metal building. Columns are located at 51 ft on center.
2. Each column pad is 5 ft-6 in. by 5 ft-6 in. by 1 ft-0 in. . Also, there is a frost wall (3 ft-6 in. deep by 1 ft-0 in. wide) around the perimeter of the building except at the dock walls. The footing for the dock wall is 4 ft-0 in. wide by 1 ft-0 in. high, and the dock wall is 5 ft-6 in. high by 1 ft-6 in. thick.
3. Rebar is as follows: column pads-5400 lb, frost wall-9000 lb, dock footing-2400 lb, and dock walls-1700 lb.
4. The building floor slab is 6 in. thick, reinforced with 6 × 6 6/6 wire mesh and on 4 in. of drainage fill.

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Controlling the Cost of Quality

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I. INTRODUCTION

Is it really necessary to control the cost of quality? A large number of architectural, engineering, manufacturing, and construction firms throughout the world do not realize the benefits from controlling the cost of quality and therefore are reluctant to change their existing management systems. They often misunderstand the process, lack determination, or are just resistant to change and end up absorbing costs that could have been minimized in the first place. Engineering and Construction firms frequently get around to implementing such programs after an owner demands it or a crisis evolves. Nonetheless, consultants repeatedly preach how the quality revolution has transformed many other industries and the construction industry continues to struggle with its use and implementation. "Both the construction industry and design industries are way behind the curve on quality management from what they should be" charges Bob Predmore, Motorola Corporation's Phoenix based director of construction for the semiconductor unit for North America [1].

Once the benefits of a quality program are understood, it is important to be able to justify the costs of the investment to upper level management or

$$CQ = PC + PNC$$

where

CQ	=	Cost of quality
PC	=	Price of conformance
PNC	=	Price of nonconformance

Figure 1 Cost of quality = price of conformance + price of nonconformance.

shareholders within the first few years, particularly if the company is international [2]. In order for companies to properly implement a quality program, corporate owners and leaders must have a clear picture of its feasibility in terms of benefits and costs, as well as having a team consensus among employees. It is also important for all individuals to view total quality management (TQM) and cost of quality (CQ) programs as a long-term process requiring patience, tenacity, and commitment over a period of several years, rather than an immediate panacea for company ills.

In studying the cost of quality it is interesting to note that numerous business icons such as Deming, Crosby, Ishikawa, Juran, and Dumas have tried to define total quality management in their own particular way. Regardless of their views, quality is dynamic for every industry and universally connotes superiority and excellence. Despite differing views on the quality process, there is a common theme about the cost of quality among the various methods.

The Cost of Quality of (CQ) is shown in Figure 1 [3]. In short, an organization pays for quality whether the cost is a function of conforming to quality standards or not conforming. Note that a price of conformance always exists, and the price of nonconformance (which is usually larger) is reduced upon implementing TQM or QI.

The primary purpose for tracking quality costs in this manner is to provide a tool for tracking corrective action progress, therefore, it is imperative that consistent data be used in calculating costs. Figure 2 shows that over several years significant cost values are reduced when PNC is reduced, hence the cost of quality is controlled. Both PC and PNC include all costs associated with the design, implementation, operation, maintenance, cost of resources, system costs, and product and service failures. This basic idea can be applied to numerous industries with the same basic structure.

Why are Quality Costs important? First, the costs are inordinately large. In 1978 the UK Government estimated quality costs to represent 10% of the UK's gross national product. Second, 95% of the cost is usually expended on appraisal and failure. These expenditures add little to the value of the product or service, and the failure costs, at least, may be regarded as avoidable. Third,

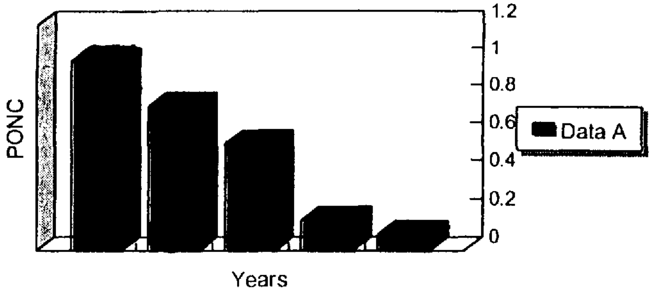


Figure 2 Reduction price of nonconformance. *Source*: Derived from Thorne, H. C. (1990), *AACE Transaction*, p. 5.

unnecessary and avoidable costs make goods and services more expensive. Fourth, despite the fact that these costs are large and avoidable, it is apparent that most companies are unaware of the costs.

In 1982, the Business Roundtable sponsored the Construction Industry Cost Effectiveness Project (CICEP) which reported that after an analysis of rework on nine multimillion dollar industrial projects, the cost of rework averaged over 11% of the cost of the projects [4]. Although this figure is shocking, it is even more astonishing that the figures did not include costs to the owner, impact costs from inefficiencies and impact costs from accelerating the schedule to make up for lost time. The total cost of the mistakes, which amounts to approximately 25% of the total cost of the product, is typically received by the owner. Fluor Daniel Quality Expert and noted author for TQM in construction, Roger D. Hart, firmly believes that "research has shown that a 2 to 3% investment in quality on the front end of a project can result in savings between 20 to 30% in the end."

II. THE COST OF QUALITY (CQ) [5, 6]

A. Definition

The cost of quality is the total value ascribed to efforts resulting in a product or service that achieves customer/client satisfaction of requirements. This includes not only conformance to requirements, but also the costs of nonconformance.

The above definition provides a basis for analyzing the total expenditures an organization bears in pursuing a policy of quality output. Intrinsic in the definition is the recognition that nonconformance costs might, and often do, include intangible costs such as lost opportunity revenue resulting from client dissatisfaction and subsequent loss of new work or orders.

When analyzing total costs it is best to categorize them according to function, that is, to choose labels that best describe the efforts undertaken to produce good quality goods and services. The specific cost categories can be at the discretion of the manager but generally fall into four classifications:

Price of Conformance (PC)

1. Prevention of poor quality (PPQ) costs
2. Evaluation costs

Price of Nonconformance (PNC):

3. In-house quality failure costs
4. Customer/client-generated costs of quality failure

B. Prevention Costs

Planning

Planning for prevention of poor quality output must be an integral part of the Total Quality Management program of the firm. Policies must address specific rules and procedures to be used "on the floor" by all personnel, and should have as a primary objective their inculcation into the organizational culture of the firm. Of paramount importance is top management's continuous visible support, which should also become part of the culture. Costs for planning revolve around initial investment in time plus maintenance activities on a recurring basis.

Training

The ability of an organization to prevent poor quality output of goods or services, or, conversely, to assure good quality, has training as its basis. It is not enough, however, to provide a training program; top management must actively support and nurture the program by allocating resources sufficient to institutionalize the means and path toward fulfillment of the training objectives. The goal is to have personnel derive the knowledge and skills necessary to practice good quality methods and techniques. Costs for training can be quantified in terms of time spent on the designed training activities.

Equipment

The capital costs of equipment necessary to carry out a PPQ program can be readily quantified once the planning has been accomplished and the training requirements established. Equipment types that may be considered include audiovisual, measurement, software, and hardware. Also included are equipment maintenance costs.

Capability Studies

In-house. Prevention of poor quality (PPQ) costs cannot be managed by an organization if the capabilities to do so are not present in sufficient quantity and quality. The determination of capabilities should be accomplished by an internal audit, informal or otherwise, depending on the size and complexity of the quality program scope. Inputs of every department are essential, and should comprise the main topic elements defined in the previous sections.

Vendors/Subcontractors. Obviously PPQ costs are at times a function, in main part, of the quality of products and services capable of being produced and supplied by vendors and subcontractors. Surveys should be conducted periodically of these sources concentrating on their quality control programs. It is important to evaluate these programs in order to estimate any cost implications arising from ineffective control.

C. Costs

Design Reviews

The purpose of these reviews is to ensure customer/client satisfaction of requirements. Included are reviews of the budget(s) involved and cost estimates. The costs that should be quantified for these efforts encompass time and materials.

Inspection

For product-oriented companies this effort involves determination of whether or not the product meets customer/client requirements. For service-oriented companies such as architect-engineer firms the efforts might include field inspection for the owner/client to determine if the on-going construction work meets specification and design criteria. In this case the term "quality assurance" is used. The term "quality control" is normally used to denote contractor efforts. Costs in this case are on a time and material basis plus any subcontracts (e.g. testing laboratories).

Inspection Equipment and its Maintenance

Present day testing and inspection equipment can be extremely expensive to procure and maintain in proper working order. Capital costs, depreciation, and time and material for maintenance are normal costs to be allocated to these functions.

Reporting Requirements

Costs to prepare and process information obtained from evaluation data-gathering can be a significant but necessary expense. It is necessary if the effort is to affect the quality, in a positive way, of the product or service being offered. Categories of costs include time and material.

D. In-House Quality Failure Costs

These types of costs refer to costs incurred prior to delivery of the product or service to the client.

Rework and Scrap

Costs incurred due to wasted effort and material. Corrective actions are also included since they would not have otherwise been required.

Inventory Impact

Failures breed requirements for inventory increases due to production fluctuations. The cost to maintain a larger inventory is a direct result of this type of in-house quality failure.

Engineering Design Impact

The failure of the product in-house can sometimes be traced to poor design or misinterpretation of customer requirements. The resultant redesign costs can become significant in these cases.

Administrative Impact

1. Poor quality in-house administrative procedures can result in the absorption of costs brought about by late payment of invoices and the subsequent loss of prompt payment discounts.
2. Ineffective quality procedures in collecting accounts receivable can result in adverse cash flow effects.
3. Poor inventory management techniques can result in suboptimal inventory levels with attendant maintenance costs.

E. Customer/Client–Generated Costs of Quality Failure

These types of costs refer to costs incurred after delivery of the product or service to the client.

Recall and Rework

These types of costs are similar to those in-house quality failure costs mentioned above, with the additional factors to be considered mentioned below. Recall costs reflect the need to notify clients or customers of a problem with the product and provisions for repairs or replacement at a specific location(s).

Warranties

Warranty costs are costs brought about by repair or replacement of the product. This occurs when the product does not perform in accordance with specifications or it's intended use.

Field Service Technician Costs

These are costs arising from the need to field technical personnel who service products that malfunction or become otherwise inoperative. The amounts can be substantial and consist of outlays in the following categories:

1. Training
2. Equipment
3. Salaries, overhead, and expense

Costs can vary dramatically depending on whether the product must be serviced on site or at the home facility.

Liability Costs

In cases where the product fails to meet specifications or safety requirements, liabilty suits may ensue. Costs of legal representation, litigation, and judgments against the company can be substantial.

Intangibles

Perhaps the most far reaching and long term effects of product or service external (in the field) failure are those that can't be quantified. Complaints and loss of customer good will can only lead to lost revenue and erosion of reputation. Allied to this is strained distributor relations.

Costs to the customer should also be considered. Examples of such costs include: those funds expended to return defective materials or products; lost time and revenues due to downtime.

III. IMPLEMENTING A QUALITY COST CONTROL PROGRAM

Companies must have tangible means of tracking costs of quality (CQ). This may range from a simple inspection to sophisticated systems surpassing the requirements of BS 5750/ISO 9000 series [7]. The first step must begin with a firm commitment from upper management to implement a quality program. This may be in the form of a company mission statement, management philosophy, or corporate goals. Regardless of the form used, the entire scope of the TQM program must be accepted at the highest corporate levels to insure a firm commitment from all employees. Once a concentrated effort is put forth a *quality circle group*, including department heads, is gathered to brainstorm on specific items that keep them from doing their job correctly the first time, i.e., what it costs to do things wrong, and what it costs to fix the problems. In developing these systems it is critical to assure all employees that the system will not be used as a tool for punishment but a tool for improvement. All of the ideas should be organized in a manner similar to Figures 3, 4, and 5. In defining these requirements it is essential to be as definitive as possible to eliminate ambiguity among items. For instance, the word "small" does not adequately specify the size of a group [8].

Other vague words such as inexpensive, cheap, hot, cold, short, and long do not clearly define an object's structure or its cost. This is why a clear and concise description of costs in a standard cost estimating form is necessary for eliminating uncertainty and increasing efficiency. This process of developing costs should be repeated in the various departments once everyone has come to a clear understanding. The example spreadsheets shown in Figures 3, 4, and 5 may be developed using software such Lotus 1-2-3 or Microsoft Excel and serve as a framework or shell for tracking progress. They indicate the kinds of costs associated in tracking and controlling quality. They follow the basic Labor, Material, and Equipment estimating format but can be subdivided into such categories as salary, wage scale, TQM or rework categories, discipline, phase, and critical areas depending on the various needs.

Once tracking systems are in place senior management must utilize these tools to properly evaluate the return on the quality investment. This would require individual and global project evaluations of quality, including evaluating whether to use technological advances versus existing personnel and equipment. Efficient management decisions must address how many inspections and what degree of detail is necessary for delivering a quality product, on time and within budget.

Specific industries such as the construction industry and automotive industry use unique tracking systems such as the Quality Performance Management System (QPMS) and Critical Path Method (CPM) in construction, and the Q-1 system in the auto industry. These types of schedules are generated using scheduling software packages such as Primavera and Microsoft Project. Like the other charts, they serve as a quality checklist for inspection and construction "punch-list" activities. The spreadsheets should be used at incremental review periods within the fiscal year to asses the progress of quality and costs in addition to the early design stages of a product for use with value engineering techniques. These procedures should include a "sign-off" stage to commit individual responsibility on a project. The signature process as shown in Figure 6 holds individuals accountable for their short-term and long-term actions. Once a firm grasp on the cost of quality is obtained, a cost to benefit ratio should be developed to determine the validity of individual items.

In forming these lists, quality control groups should closely examine the costs of quality for operations such as inspections, auditing, training, testing, equipment, new procedures, guarantee, and warranty undertakings and establish acceptance criteria. Many built-in inefficiencies such as excess materials and excess production starts may originate in engineering and manufacturing.

Undoubtedly, the spreadsheet should be tailored to a company's individual needs and structure allowing for justification of all costs. In implementing the program and deciding on which categories to use for tracking, the quality circle or team should utilize as many of the existing systems that are feasible by enhancing proven systems and augmenting existing systems where necessary. This is critical to industries such as construction and manufacturing where daily record keeping is second nature and tracking costs are minimized.

With the ability to integrate computer systems with LAN (Local Area Network) technology this principle of tracking quality in numerous areas can be applied across divisions of an organization by linking computers together in a network. Since spreadsheets can be summarized at any level, individual departments such as marketing, finance, manufacturing, engineering, and human relations can be isolated and tracked during a particular time frame and linked backed to Accounting. Additional areas, such as divisions, plants, jobs, or regions may also be tracked depending on the organization's structure. If hours and contractual information are tracked through a database program, the information from the time and material expended can be linked to the quality control program allowing quality to be expressed as a percentage of billing hours of a job. This type of database software can also be used to house historical information related to quality that would be helpful in analyzing shifts and trends over several years.

Three-dimensional bar charts, area charts, and pie charts can be easily developed using appropriate software to help interpret the statistics and provide a clear picture for management (See Charts A, B, C, D). They act not only as a log but also as a indicator of trends in the form of an audit.

Once a system is in place for tracking costs, estimates of budgeted costs of quality can be tracked against actual costs of quality. Furthermore, economic and statistical principles such as depreciation, cost benefit analysis, forecasting the time value of money with linear and multiple regression models, probability, and profitability can be used in conjunction with a CQ program to get a broad perspective and allow for sound business plans.

Specifically, Figure 3 represents a typical chart for calculating the price of conformance (PC) elements. The time frame (Week 1 in Figures 3, 4, and 5) for tracking quality is dependant on the type of department and the desire of management. Figure 4 represents the price of nonconformance (PNC) elements and should focus on the quality of the product and service to the

(text continues on p. 655)

Figure 3 PC Elements—Manufacturing and Engineering Corporation

Company Name: ________________

Date: ________________

Time period tracked Week 1

Marketing	Quantity	U of M ($)	Labor ($)	Material ($)	Subcon-tract ($)	Equip-ment ($)	OH&P ($)	Total ($)
Customer evaluation	12	ea			50.00		10.00	720.00
Procedures								0.00
Training								0.00
Forms design								0.00
Customer survey								0.00
Market survey								0.00
Sales support								0.00
Legal and product safety reviews								0.00
Credit authorizations								0.00
Product application testing								0.00
Product certification								0.00
Price verification								0.00
Price authorizations								0.00
Quality improvement activities								0.00
Subtotal Marketing Week 1								720.00
Finance								
Control reports								0.00
Control budgets	10	Days			50.00		10.00	600.00
Budget forecast revisions								0.00
Major cash expenditure projections								0.00

Operation plans								0.00
Disaster recovery plan								0.00
Monthly closing time schedules								0.00
Financial report time schedules								0.00
Delegations of authority								0.00
Chart of accounts								0.00
Audit trails								0.00
Expense accruals								0.00
Purging inactive accounts								0.00
Backup copy of customer files								0.00
General office manuals								0.00
General office letters								0.00
Subtotal Financial Week 1								600.00
Human resources								
Prescreen employee applications	50	Hours		1.00	65.00		13.20	3,960.00
Interviewing								0.00
Personnel testing								0.00
Reference checking								0.00
Orientation								0.00
Medical/benefits program								0.00
Safety program								0.00
Performance appraisal								0.00
Personnel records audit								0.00
Tracking of injuries								0.00
Subtotal Human Resources Week 1								3,960.00

Figure 3 (Continued)

Manufacturing	Quantity	U of M ($)	Labor ($)	Material ($)	Subcontract ($)	Equipment ($)	OH&P ($)	Total ($)
Preventative maintenance	1	Lump sum			6,110.00		1,222.00	7,332.00
Supplier evaluation								0.00
Equipment calibration								0.00
Process capability studies								0.00
Purchase order review								0.00
Quality improvement activities								0.00
Customer requirements review								0.00
Incoming inspection/testing								0.00
Laboratory analysis and test								0.00
Drawing checking								0.00
Subtotal manufacturing								7,332.00
Engineering								
Preparation of design manuals	80	Hours	50.00				10.00	4,800.00
Vendor surveillance and rating/qualification								0.00
Design reviews and checking								0.00
Safety review								0.00
Maintaining engineering files								0.00
Checking of purchase orders/equipment								0.00
Field checking of piping isometrics								0.00
Quality improvement activities								0.00
Quality measurement and reporting								0.00
Subtotal Engineering								4,800.00

Figure 4 PNC Elements—Manufacturing and Engineering Corporation

Company name:								
Date:								
Time period tracked:	Week 1							
Marketing	Quantity	U of M ($)	Labor ($)	Material ($)	Subcon-tract ($)	Equip-ment ($)	OH&P ($)	Totals ($)
Product waivers	12	ea	50.00	0.00	0.00	0.00	10.00	720.00
Price reductions	1	ea	0.00	0.00	5,000.00	0.00	1,000.00	6000.00
Packaging waivers								0.00
Returned sales calls								0.00
Returned freight costs								0.00
Debit-credit processing costs								0.00
Bad debts								0.00
Expediting								0.00
Incorrect order entry								0.00
Past due accounts receivable								0.00
Complaint processing costs								0.00
Invoicing errors								0.00
Field service calls								0.00
Customer reimbursement for downtime								0.00
Demurrage								0.00
Order amendments/changes								0.00
Explanation/investigation time								0.00
Computer reruns								0.00
Off-specification material								0.00
Litigation								0.00
Subtotal Marketing Week 1								6,720.00

Figure 4 (Continued)

Finance	Quantity	U of M ($)	Labor ($)	Material ($)	Subcon-tract ($)	Equip-ment ($)	OH&P ($)	Totals ($)
Reprocessing accounting records								0.00
Recalculating financial numbers	20	Times			10.00		2.00	240
Restating prior period numbers								0.00
Rerunning statements								0.00
Reprinting financial reports								0.00
Debugging computer programs								0.00
Late shipment of customer orders								0.00
Duplicate vendor payments								0.00
Payroll errors								0.00
Out of period adjustments/corrections								0.00
Supplier pricing/volume errors								0.00
Bad debts								0.00
Billing errors								0.00
Overdue accounts receivable								0.00
Incorrect information to management								0.00
Rush jobs								0.00
Last minute revisions								0.00
Overtime work								0.00
Untimely reports								0.00
Excessive dry runs of presentations								0.00
Computer and copier downtime								0.00
Subtotal Financial Week 1								0.00
Human resources								0.00
Turnover rates	1	Ea			100.00		20.00	120.00

Grievance tracking								0.00
Untimely filling of positions								0.00
Cost of injuries								0.00
Subtotal human resources week 1								120.00
Manufacturing								
Deviation from zero-based yields/usage's								0.00
Unexpected downtime	50	Hours			200.00		40.00	12,000.00
Excess inventories-materials, supplies, etc.								0.00
Failure analysis/troubleshooting								0.00
100% test to sort								0.00
Rerun of off specification product								0.00
Corrective maintenance on failed equipment								0.00
Price discounts								0.00
Returned goods, replacement, and reproc.								0.00
Freight costs								0.00
Personnel/travel/handling								0.00
Expediting/premium freight costs								0.00
Production losses due to suppliers								0.00
Delays due to equipment/supplies								0.00
Product liability costs								0.00
Turnover of employees								$0.00
Excess unemployment insurance								$0.00
Excess worker's compensation								$0.00
Demurrage								$0.00
Work orders lacking adequate information								$0.00
Injuries								$0.00
Subtotal manufacturing								$12,000.00

Figure 4 (Continued)

Engineering								
Change orders/brochure revisions								0.00
Engineering and drafting time on redesign								0.00
Material review	15	Hours			95.00		19.00	1,710.00
Time spent expediting purchase orders								0.00
Premium freight due to late drawings								0.00
Early delivery bonus incentive								0.00
Engineering time spent on failure analysis								0.00
Repair and redesign due to incorrect material								0.00
Troubleshooting problems in the field								0.00
Waste fabrication								0.00
Equipment failure due to incorrect design								0.00
Design changes after initial approval								0.00
Cost of unused material that is scrapped								0.00
Delays caused by incomplete drawings								0.00
Time spent on equipment warranty work								0.00
Subtotal engineering								1,710.00

Figure 5 CQ Summary—Manufacturing and Engineering Corporation

Company name:

Date:

Time period tracked: **Week 1**

Department	PC ($)	PNC ($)	CQ ($)	Week 2 ($)	Week 3 ($)	PC/Sales	PNC/Sales
Marketing	720.00	6,720.00	7,440.00	6,300.00	6,400.00	0.528	0.684
Finance	600.00	0.00	600.00	10,000.00	11,000.00		
Human resources	3,960.00	120.00	4,080.00	7,700.00	12,000.00		
Manufacturing	7,332.00	12,000.00	19,332.00	18,000.00	17,000.00		
Engineering	4,800.00	1,710.00	6,510.00	5,500.00	4,000.00		
Totals	5,280.00	6,840.00	12,120.00	8,000.00	3,000.00		

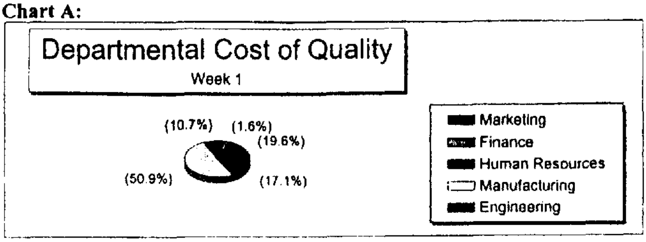
Company name:

Department: Marketing Signature

Date: Return date

Time period tracked:	Week 1					
Activity description	Prevention		Appraisal		Failure	
Activity #1						
Activity #2						
Activity #3						

Chart A:



$10,000.00

Chart B:

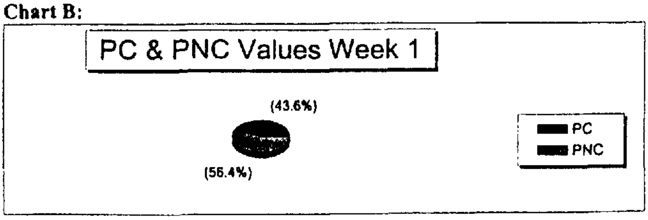


Chart C:

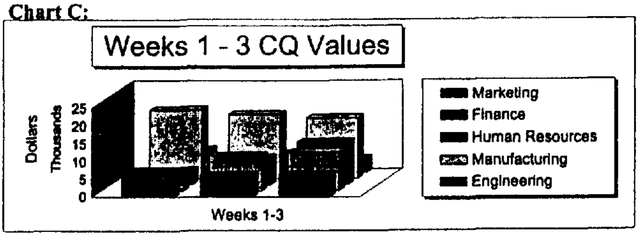


Chart D:

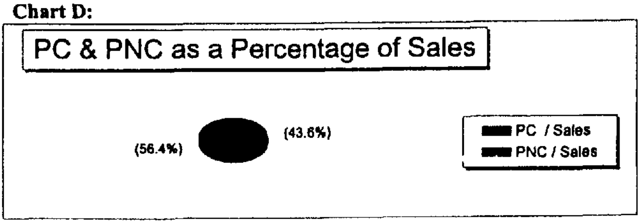


Figure 6 TQM Questionnaire

customer. Companies may also find competition comparison surveys and customer surveys extremely helpful in defining items. These awareness surveys will not only bring about new ideas and foster closer relationships with existing customers, but also provide a tangible means of measuring satisfaction. In defining these nonconforming quality costs some companies find it easier to divide items into internal customer needs vs. external customer needs.

Regardless of the method used, cost engineers and quality managers must include all costs associated with specific items. This includes the costs associated with the failure of a product, customers assistance, the cost of making adjustments for repair or rework, and the cost of preventative measures. Figure 5 summarizes the CQ, PC, & PNC. Chart A (Pie Chart) shows the departmental cost of quality. Chart B (Pie Chart) shows the PC & PNC Values for Week 1. Chart C (3-D Bar Chart) displays the departmental CQ Values over weeks 1–3. This type of summary report is usually given to the vice president or controller of quality on a quarterly basis. Chart D shows the PC & PNC as a percentage of total sales. These graphs and charts are only a few of the examples that could be used as management tools in controlling the cost of quality.

Once the groups agree on the list of quality costs, a quality assurance specialist should brief all of the divisional managers on the concept of cost categories, elements, examples, reasons for quality costs, and the methodology that will be used to collect, identify, and analyze the costs. In addition, the quality assurance specialist will provide the managers with information to distribute to the remaining employees for additional briefing. Some organizations find it helpful to develop a questionnaire similar to Figure 6 to distinguish quality between prevention, appraisal, and failure activities. This process allows a common understanding between all participants and establishes a complete tracking program.

After the end of the first year a baseline CQ program should be established and significant corrective actions should be taking place to hold employees accountable for quality. Nonetheless, management should be aware that an increase in awareness will uncover new areas to control quality. After approximately 3–5 years, the PNC should be reduced to 10% of its original value. Total costs should be reduced, relationships improved, and service enhanced. If quality costs are compared on a larger scale, such as between industry groups or even multinational corporations, it is important to be comparing costs with the same criteria in mind.

Innovative organizations often provide unique incentives to employees in the form of a reward. Some large organizations provide cash rewards for the "Quality Team of the Year" by using criteria such as team work and results achieved [9]. Other creative organizations provide incentives in the form of play money that is cashed in for office prizes. Prestigious industry awards such as the Malcom Balridge National Quality Award (MBNQA) distinguish quality engineering and construction industry leaders. Regardless of the methods used, the most important aspect of CQ and TQM is total quality as a result.

IV. CONTROLLING THE COST OF QUALITY IN THE CONSTRUCTION INDUSTRY

In construction, the cost of quality work is frequently overlooked by contractors and design firms in terms of other priorities such as time, cost, customer demands, and increasing competition; this neglect of quality cost control quickly causes a decrease in market share. The construction industry often relies heavily on contractual obligations, specifications, drawings, federal and state codes, standards, regulations, guarantees, and warranties as a means for measuring quality and pricing quality. In order to reduce the construction costs of quality these guidelines should be considered a minimum level of quality standards and costs, rather than goals. Ultimately, companies should strive for zero defects from self-imposed rules, regulations, and actions. By obtaining a level of zero defects, the construction costs of nonconformance can approach zero resulting in a higher quality product and lower costs of quality (see Figure 2). The vast portion of the costs of nonconformance for construction can be reduced with a sound design from the start. A complete design provides a clear picture to all parties minimizing delays, questions in the form of RFIs (Request For Information), changes, and claims.

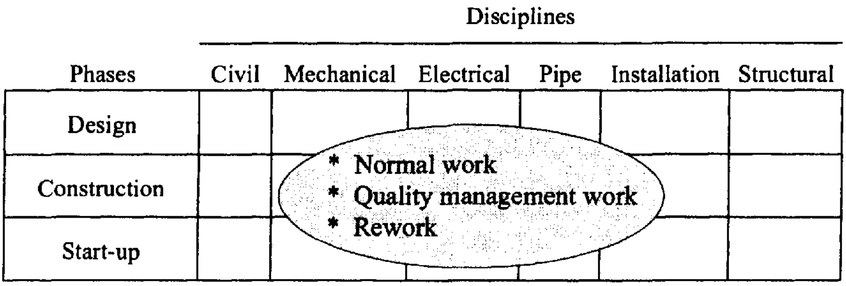
The industry tool Quality Performance Management System (QPMS) classifies construction costs during the design and construction of the projects allowing management to pinpoint deviations at various phases and within specific categories [10]. Noted construction author William B. Ledbetter summaries the principal elements of the Quality Performance Management System (QPMS) (see Table 1) [11]. Once a project is divided into its major phases and disciplines, the following three types of cost must be captured:

1. The normal cost of performing work (which is the productive work)
2. The quality mangement costs (by major activity)
3. The cost of rework (by primary cause)

By exposing quality construction costs distributed by phase and among disciplines with a chart such as Table 1, contractors can regulate the overall cost of quality.

The following examples display the means and methods of controlling the cost of quality for construction throughout the design–build process. The examples should not be considered as an all encompassing "to do" list, but rather suggestive actions for all parties regulating quality construction costs.

Table 1 Interrelationships Between Project Phases and Major Disciplines



Controlling the cost of quality in construction is an ongoing process from conceptual design to final building "punch-lists." Controlling quality costs from the start of the project at the preconstruction level provides essential quality guidelines and parameters. Although the level of detail may not be available at various design stages it is essential to effectively convey the scope and the intent of the project to define minimum conformance costs. This defintive approach to quality construction costs throughout the project will continue to mimimize the cost of nonconformance for the entire design build team and owner. As engineers and architects prepare conceptual and design development drawings and specifications they should work closely with cost estimators for value engineering services to obtain the highest quality product at reduced quality costs. Cost estimating at various levels, such as the conceptual level, 30%, 60%, 95%, and 100% Bid Documents stage, allows for strict adherence to requirements and provides the proper evaluation tool for negotiations and funding. For example, in displaying man-hours expended in terms of productivity/task in the estimate, one is able to develop work breakdown structures and relationships in terms of a schedule to regulate the cost of quality in terms of man-hours over time. Complete design reviews among all consultants as well as individual in-house reviews on important topics throughout the design process allow for a tighter control of design and quality construction costs. Furthermore, constructability and value engineering reviews provide feedback in adjusting the project. Carefully defining and understanding requirements at early stage minimizes confusion and improves communication among the entire team.

If possible, the entire project life cycle process should be examined for opportunities for integration in order to fully control quality costs. This begins with integrating Computer Aided Design (CAD) software with the estimating and scheduling software to show the immediate impact on cost and schedule. By integrating the design, cost, and scheduling processes total control of the projects quality costs can be developed throughout the project. This process allows for rapid reproduction of models producing numerous alternatives for quality savings for all parties. If computer integration is not possible, manual combination of design, cost, and schedule is necessary for controlling total quality costs.

In understanding how to regulate the cost of quality in construction it is critical to view the construction quality costs as a smaller part of the entire cost of the project that affects the quality costs of other direct and indirect items such as operation, maintenance, and life-cycle costs. If all of the quality costs are not accounted for throughout the project investment analysts cannot truly asses the profitability of a project.

Since the design and construction budget is contingent on the quality of the drawings, specifications, and estimate, a failure to address quality costs early on can cause numerous problems in the future. A lapse in quality, clarity, and detail in the project documents or estimate can quickly cause a project to fail, go over budget, provide an unrealistic assessment of project costs, and cause costly legal battles. In essence, the quality of estimate is representative of the quality of the documents used to prepare it. What may seem like minor details in quality or a slight misunderstanding of documents could carry over into the construction stage causing further questioning and doubt. For example, if a specification writer states that "the exposed surface of concrete walls are to be rubbed", he or she may be implying the filling of all voids, patching, removal of fins, and rubbing the concrete surface with carborundum stones and water until the surface is smooth [12]. However, according to a competitive contractor who is looking to reduce their bid and meet the requirements, this could mean lightly rubbing the surface with a soft cloth. Furthermore, this light rubbing could cause the walls to deteriorate and fail. There is a maxim of law which reads in Latin, "Expressio unius est exclusio alterius," or, the express mention of one thing implies the exclusion of the other. Engineers, architects and specification writers must be careful when itemizing not to eliminate other items. In situations where items may be subject to interpretation, specifications and contracts should use, "examples such as . . . x, y, z" to eliminate confusion. This concrete misinterpretation may seem like a small discrepancy to some, but on larger and more competitive jobs this could make an enormous difference. In specifying the quality of results engineers must carefully determine when to allow the contractor to submit their own design and the results they are willing to guarantee, when to provide an outline specification, and when to dictate the results. Both the complexity of design and the quality intended should help govern their decisions. There may be situations in which the engineer may need to incorporate all-inclusive statements within the specifications to save time and effort such as the statement "as approved by the engineer." The intent is to leave out the details about the work and quality of the results to be settled between the engineer and contractor as the job progresses. However, in using these types of time saving techniques, it is essential that engineers and contractors cooperate rather than battle over what is considered reasonable quality and costs. These types of disclaimers can also lead to unrealistic bids due to increased costs from uncertain bid items.

If "first class" or the "best" quality is intended on a job than it should be spelled out in the contract documents so the intention is clear to all parties and if a legal battle ensues that there will be no doubt left to a third party. Owners may also consider using incentive clauses within contracts to obtain the same results of quality for individual or total projects. This incentive for all parties often motivates clients and improves communication between the owner, engineer, architect, and contractor rather than opposing each other. Construction quality, or conformance to requirements, does not necessarily imply the most expensive materials, labor, equipment, and technology. Rather, the question of quality should address its conformance and profitability in terms of the final result.

If errors and confusion in design or costs continue to the bidding stage, estimates will not reflect the building documents and engineers, architects, and owners will be forced to cut costs. This haphazard approach to cutting costs at the postbid stage does not fully explore the ramifications and may cause further costs and a reduction in quality. Ultimately, these errors will drive the cost of quality up and exacerbate an adverse situation between designers and builders.

In determining the type of contract at the prebidding stage, whether it is a unit price, lump sum, indefinite quantities, or variations of cost plus, an owner must consider the maximum level of quality desired in the time frame and budget allotted. This will also be contingent on the available resources of both parties, amount of risk, and the surety of the documents and parties.

Once the contract is under way, contractors tend to become inundated with shop drawings, submittals, product data, schedules, charts, reports, charts, and diagrams. Due to the maelstrom of paperwork and deadlines, important quality details tend to be overlooked. In order to control quality construction costs early on, contractors must schedule and staff projects appropriately. Demonstrating a commitment to quality in early schedules and management plans will pay dividends in the latter portion of the project by saving time, money, and effort. Once a product is approved quality materials must arrive, as specified, in a timely manner to ensure requirements are met. Upon arriving the materials must be properly stored and protected prior to installation. Often times owners and contractors may provide or require a quality control engineer or quality assurance specialist to monitor building installation quality as it progresses. This guarantees quality from start to finish and provides another level of inspection aside from standard testing by others. The cost associated in working closely with certified authorities, testing agencies, fabricators, and manufacturers will also act as objective measure of the contractors quality costs spent. In turning over a project to the owner it is necessary for the contractor to fully explain the operation and maintenance of the project to minimize future quality costs of the owner and the tenants. Although construction quality costs will differ from architect, engineer, consultants, contractor, and owner as shown in Section III, the total quality management process allows for the control of construction quality costs from start to finish resulting in higher quality and reduced costs.

V. INDUSTRY TRENDS

In its quest for eliminating costs of nonconformance, Motorola Corporation's semiconductor division in Phoenix sets a goal of "zero rejects" in it's chip making plants and now mandates that suppliers have a similar program. In executing this process they have helped other companies. Phoenix based mechanical contractor J. B. Rodgers has also implemented a TQM program at Motorola's urging, sending employees to Motorola's renowned "Motorola University." Forty percent of Rodger's business will come from Motorola and the firm has a profit margin of two to three points higher than typical firms.

The state and federal governments will also play a key role in controlling future costs of quality. Several organizations such as the Federal Transit Administration have been using Quality Plans for several years requiring contractors and manufacturers to be a part of the Quality Plans [13].

VI. SUMMARY

Controlling the cost of quality is a worthwhile undertaking that can eliminate errors and waste, allowing management to save money and protect its reputation. The process exposes a company's strengths and weaknesses in terms of quality allowing for management to take appropriate preventative and corrective measures. By empowering employees with the responsibility for quality in their actions, the process provides a method of accountability and a means for incentives. Furthermore, controlling the cost of quality enhances existing systems such as inspection and reviews allowing for efficient and cost-effective business. Although the justification for short term costs may not be evident at first, the long-range process of controlling the cost of quality will provide higher revenues, higher margins, better service, tighter quality control, and improved relations.

GLOSSARY OF TERMS

Acceptance criteria Specified limits placed on characteristics of a product, process, or service defined by codes, standards, or other requirement documents.

Quality Conformance to requirements.

Quality circle group a group of workers who meet periodically to discuss problems and offer suggestions for improving production or product quality.

TQM Total quality management.

QI Quality improvement.

Cost of quality (CQ) The sum of the price of conformance (PC), and the price of nonconformance (PNC).

Price of conformance (PC) Cost to get things done right the first time. Price may increase slightly when quality improvement is established, but it is almost always below 5% of sales.

Price of nonconformance (PNC) The cost of doing things wrong, which must be eliminated. It is the major element in a firm's cost of quality and typically averages about 20% of sales. It often equals or exceeds a firm's before tax profits (see Figure 2).

ISO 9000 A generic series of standards or guidelines written by the International Standards Organization on quality assurance to help harmonize the large number of national and international standards. The standards are intended to be used universally in contractual and noncontractual situations and focus on operational techniques and managerial activities used to fulfill customer expectations and requirements [14].

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Controlling the Cost of Safety

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It is not the purpose of this chapter to cite the actual details or costs involved in providing and maintaining a safe working environment, but rather to indicate the methodology of arriving at an accurate estimate of these costs, to provide some background into the subject of safety and as to where safety-related costs occur as well as to give some indications as to where money might be saved. In doing this, the subject has been generally divided into two broad areas:

1. Those costs related to safety during the *conception, design, and construction* of the facility
2. The subsequent *operation and maintenance* of the facility

Some suggestions have been made that the money expended for safety should be considered as a profit center and that there should be a return on all such expenditures. It is usually very easy to identify the money spent; but it is sometimes extremely difficult to add up the savings achieved, other than by using approximations projected from historical data.

Money spent on safety over and above that necessary to provide an operable plant provides no direct monetary return. It is not good business to spend excess money, although the human implications generally offset the strictly financial considerations.

We must, however, not fall into a trap of evaluating the cost of safety against the risk of accidents and loss of human life. In today's social environment, this is simply not acceptable. It is felt by practically everyone that humanitarian factors will always justify the cost of eliminating worker injury. In general, we should do whatever is necessary to protect the employees, the public, and the investment in the facility.

Therefore the choice is most often made to proceed with these expenditures. Deciding this is a matter, ultimately, of qualitative judgment. Ultimately we will reach that level of expenditure where additional money spent on safety provides no business or humanitarian benefit whatsoever. We must be alert to this fact and make project decisions accordingly. Safety is achieved by good design and by good training, procedures and practices in construction and operation of the plant.

I. DESIGN AND CONSTRUCTION OF A FACILITY

A. Methodology

In estimating the costs of the various safety-related items for the design and construction of a facility there must first be a clear definition of what is to be included and how these items will be shown in the estimate. The estimate must be tempered by how the work will be done and what conditions exist at the time.

We still suffer from the idea that many of the costs of safety are included, by implication, in the individual estimates for the elements to which they apply. If historical data for the design effort is used for the estimate, then safety provisions might automatically be taken care of. For example, if construction man-hours were conditioned with the proper productivity, then the appropriate safety costs would already be included. With new legislation and regulations, this practice may no longer be acceptable. Of course, there are some line items which have always maintained a distinct safety identity such as workers compensation and other safety-related insurance costs and the costs of a full-time safety representative or group on the jobsite.

Estimates for the cost of safety now must address an increasingly complex set of factors including toxic materials, drugs, asbestos, hazardous waste, and mandated training in addition to those items previously considered as part of a safety program. Even so, there are many instances in which the normal costs are so intertwined with those relating to safety that it is impossible or impractical to separate them.

There are currently some indications that, at least from the standpoint of governmental regulations, some quantitative evaluation may be introduced to try to measure the danger of threats to safety and environmental health. Curtailment of new regulations has been proposed with a mandate to require a risk analysis and cost-benefit calculation to justify additional regulations costing over a specified sum to implement. While the outcome of this legislation is uncertain and while there are some dangers, it appears to be an attempt to bring some relief from spurious introduction of unrealistic standards and flawed priorities.

Historical cost information and "lessons learned" from prior like projects must be factored into the scope and work plans as the basis for any estimate. Escalating costs call for identifying these safety costs separately. This is particularly true because safety enjoys a unique position in the estimate. It is very difficult for anyone to argue against something introduced based on enhanced safety.

Major accidents are associated with four key areas: 1) technology, 2) management systems, 3) human factors and 4) external causes. Risk management and budgetary provisions must take each of these in consideration.

It is obvious that to produce an accurate and meaningful estimate of the costs of safety, this estimate must be based on a meaningful scope as well as a plan for carrying out that work.

B. Safety Management Program Plan

The most important aspect of safety management stems from the environment created and maintained by the respective senior managements of the various firms involved in a project. Senior management is responsible for making sure that identified specialists are knowledgable in project safety technology and that their expertise is incorporated and utilized in the Safety Management Program. The key to all of this is the example set by senior management of the contracting firm. As has been previously pointed out, safety is largely a matter of attitude and this attitude is created and nurtured from the top. Safety should always be considered a job requirement. This attitude should be reflected in the Safety Management Program Plan which is developed from a safety strategy developed for the specific project.

Hazards that must be considered in a prioritized order of magnitude include those caused by 1) detonating reactions, 2) ruptures and fires, 3) leaks and small fires and 4) low temperature and low-pressure operations which, in general, have a low potential for disaster.

Once the Safety Management Program Plan has been written, the estimate for the work included proceeds entirely in line with how the rest of the estimate is done. Each element may be considered and priced with care taken to assure that everything is included. Checklists are helpful in providing this insurance.

In addressing the cost of safety or those provisions which must be made in the estimate for safety-related items, we may divide these into the traditional project categories of 1) the conceptual phase, 2) engineering phase, 3) procurement phase, 4) construction and testing phase and 5) start-up phase.

The Safety Management Program plan should be specific in outlining the explicit rules and standards expected for the facility, both in the formative stage and during operation. It is only by specifying these expectations that a basis for estimating costs can be established with an acceptable degree of accuracy.

II. SAFETY CONSIDERATIONS IN THE CONCEPTUAL PHASE

Choice of site, choice of type of process and size of plant, adequacy of approved funds and schedule time allowed and even such items as the type of control or automation are significant to the ultimate cost of safety. As the level of automation increases, the number of workers in the plant may be reduced. This lessens the total exposure to potential operational dangers. On the other hand, it will probably increase the initial cost of the facility.

A. Identification of Hazards

A significant task at this point on any project is the identification of potential hazards in the construction and operation of the facility based on a review of available preliminary documents. These typically will include the process flow diagram and the plot plan. This listing of hazards will be used during later stages of the project design in the HAZOP Reviews and should be as complete as possible. However, any items observed later may be added as soon as they are identified.

At this stage of the project we must not mandate that money be spent foolishly in the name of safety. Some alternatives can result in a safer operation while costing less money than conventional solutions. For example, increased vessel strength may provide adequate safety at lower cost than utilizing relief valves with all their attendant costs and problems. The engineer or designer in responsible charge of the design has a continual obligation to look for more cost effective ways to ensure plant safety.

As construction, operations and, maintenance expertise is called upon during the conceptual phase to optimize costs, likewise the knowledge of the safety expert should be made available to those working on the conceptual design. This role is not only to assure safety of the facility but also to assure that safety is achieved in the most cost effective manner.

B. Safety Design Criteria

The project design criteria should be understood with respect to the federal, state, and local regulations. Applicable industry codes and standards should be identified. The philosophy of equipment design with respect to safety considerations should be outlined in sufficient detail at the early stages of the project. References should be given to particular use of materials of construction, and applicable information regarding material to be processed and the resulting products considered. The use of prevention, mitigation and protection should all be a part of safety assurance during the conceptual phase.

Management is often insistent on increasing production and reducing operating costs. Where this potentially compromises safety, the process safety specialist must raise a red flag and advise management where this would be detrimental.

Civil and structural considerations related to safety include the necessary compliance with all building codes, both national and local as well as applicable industry standards. Special attention should also be given to blast-proof designation for specific areas such as the process control building.

C. Equipment Design—Preliminary Considerations

A checklist of some of the equipment installations where safety should be reviewed in preparing the safety plan for the design includes:

Relief systems—relief valves, headers and flare networks
Piping systems—including flanges, expansion joints, strainers, gasket materials, and valves
Electrical equipment—power and static electricity
Rotating equipment
Mechanical conveying equipment
Storage tanks
Explosive mixtures absorbed in insulation

D. Risk Management

Optimum control of the safety costs on a construction project requires that the risks be assigned appropriately. This most frequently means that the party best able to control the risk assumes the risk. Risk allocation may be accomplished by providing for deterrence incentives before the accident occurs and compensation as a result of an accident. This is known as the tort system.

Risk may also be allocated by using contract terms that attempt to avoid reliance on the *tort* system. Risk shifting may also be accomplished by risk spreading through some form of insurance. A fourth method is that of risk containment or limit of liability which is common when dealing with firms that have limited assets or capital resources.

Early in the design phase of the project, the insurance company which will ultimately carry the plant insurance should be called in to review the preliminary design efforts, especially the plot plan, as well as the specifications. The insurance carrier will generally make suggestions for risk reductions. Some of the modifications may be mandatory if the plant is to be insured. For example, equipment spacing is normally of concern to the insurance carrier.

E. Special Considerations for Pilot Plants

Pilot plant safety is a specific instance of safety consideration in the conceptual phase. In a bench-scale or pilot plant, shortcuts are sometimes taken because of budgetary, space or time constraints that compromise the safety of the operation.

A pilot plant also normally will have a number of changes to the design, many of which are accomplished almost "on line." This practice adds to a potentially unsafe condition.

III. SAFETY CONSIDERATIONS IN THE ENGINEERING PHASE

It is very important that safety problems be removed early in the design. Unnecessary costs are added when additional equipment or design changes have to be made later in the project. For this reason, checks and controls of the identified safety issues must be utilized during the design of the project.

Even though safety specialists are to be on call and should review the engineering documents, one should not assume that they have the responsibility for a safe design. Discipline engineers and designers are those who are responsible for a safe design.

An important element of the cost of safety to be considered in the design effort and for which money must be provided in the budget is the effect of legislation and regulation on the design.

A. Occupational Safety and Health Administration

The Occupational Safety and Health Act (OSHA) of 1970 became effective in April of 1971. Its basic purpose is to assure all workers a safe and healthful job environment. It requires all employers to:

1. Eliminate all recognized hazards in the workplace
2. Comply with an ever-increasing number of detailed OSHA standards
3. Submit to inspections by OSHA safety and health inspectors

4. Comply with record keeping and reporting requirements as set forth by OSHA

Initially OSHA concentrated on accident safety in the work place, but a shift in emphasis toward long-term health hazards ensued starting in the mid-1970s.

Typical of this emphasis are OSHA's process safety regulations that impose legal requirements for chemical processes covered by regulations. OSHA's list of highly hazardous and toxic chemicals is continuously growing and currently includes over 130 substances.

These requirements include the employer's obligation to:

1. Perform a *Process Hazard Analysis*
2. Maintain and communicate *process safety information* to employees
3. Maintain written documentation of *operating procedures*
4. Provide *training* for new employees and retrain current employees
5. Conduct *pre–start-up safety reviews*
6. Implement written *procedures to manage changes* in all aspects of the processing facility
7. Investigate and *report on every incident* resulting in actual or potential injury within 48 hours of occurrence

Each of these requirements implies an additional cost to any owner or contractor involved in a project or in-plant operation where any of these chemicals is involved as a feed stock, a catalyst, an intermediate product, a byproduct or a final product.

OSHA identifies six methods of analyzing the risks involved in a chemical manufacturing process for the purpose of the safety analysis. These six are:

1. What-if
2. Checklist
3. What-if and Checklist
4. Hazard and Operability Study (HAZOP)
5. Failure Mode and Effects Analysis (FMEA)
6. Fault Tree Analysis

The initial review during the engineering phase is commonly called a *what-if review* and should be based upon piping and instrument flow diagrams and plot plans. This review identifies potential accidents and determines the sequences of related events.

B. The HAZOP Review

The most comprehensive, expensive, and labor-intensive safety check on a project during the engineering phase is the HAZOP (Hazard and Operability)

Analysis or Review. This is a method of identifying hazards and problems that prevent efficient, safe operation. The technique is in common and required use for many chemical projects, but the philosophy and methodology behind it is applicable to a wide variety of project types.

The HAZOP review starts when available documentation includes the piping and instrument flow diagrams or mechanical flow diagrams, the plot plans, process control diagrams or logic, and 3–D models or orthographic plans. These are studied in detail by the HAZOP team to identify specific nodes for access, operability, and the possible hazards stemming from the process and utility systems. The study will also identify actions that should be taken by operators and/or others in cases of plant disruption or other emergencies.

A significant part of the formal HAZOP review is the preparation of the formal supporting documentation in the proper format and with the proper approvals noted. This is required for OSHA compliance and should be performed when the design is substantially complete. Immediately afterward the piping drawings can be issued as *approved for construction*. Obviously any major revisions to the documents at this stage will jeopardize the budget and schedule.

The primary effects that the HAZOP review can have upon the costs are twofold. First, if there are significant modifications required to the design effort at this late stage, there will be costs for all of the rework. Second, the project schedule may be severely impacted by these late changes. Contracts may have already been issued and field forces mobilized. Continuous consideration of the impending HAZOP Review should be given throughout the design to minimize the unfavorable cost impact when the formal HAZOP Review is done. The project Safety Management Plan should provide a basis for determining the number and type of people who will be involved in the HAZOP Reviews and how much time will be required.

Firms and their estimators must not only consider the costs of complying with the OSHA regulations, but also the cost of noncompliance. Fines may be imposed, particularly in the case of willful violations, and these can be up to $70,000. A criminal violation can be assessed against individuals up to $250,000 and up to $500,000 for a corporation. Jail terms may also be imposed in these cases.

Safety-related items that add to the operation of the facility are: pressure-relief systems, control room design, safety-related process control software, safety shutdown and interlock systems, flame arrestors, explosion isolation systems, and secondary containment systems.

A warning about the adverse cost effect of designing systems with excessive contingency or safety factors is appropriate. An uneconomic and cancelled project can be the result. The estimator should not be held accountable for engineering designers who persist in adding repetitive safety margins. It is important that the final safety factor bear a relationship to reality.

Simulation studies may be used to improve the facility design with respect to fire, storm, spill, explosion, flood, earthquake, structural failure, sabotage or terrorist attack. As human error has been suggested as the cause of up to 40 percent of all plant disasters, efforts should be directed toward making the operation as foolproof as economically feasible. Some of these would include improving the design or more rigorous checking to eliminate human errors in operations, improvement or simplification of maintenance, providing additional safety training, and elimination of faulty procedures. More training would also reduce the stress caused by an impending or existing emergency which in itself increases the likelihood of human error.

C. Safety Equipment to be Provided for in the Design

The plant design and cost estimate must consider elements provided strictly for safety including:

1. Those things that physically restrain plant personnel from injuring themselves such as warning signage, color coding, emergency and warning lights, and handrails and cages for ladders
2. Those items that assist an injured person such as personal protective equipment and emergency eyewash and shower facilities
3. All equipment included in the fire protection systems such as smoke detectors, the alarm system, sprinklers, fire extinguishers of various types, monitors, hose reels and shelters, foam and inert gas systems, fire walls and doors, emergency exits, and the fire water system itself

IV. SAFETY CONSIDERATIONS IN THE PROCUREMENT PHASE

The primary responsibility for safety during the procurement phase is to ensure that all of the safety-related requirements stipulated by the specifications and purchase orders have been fulfilled by the manufacturer, vendor, or supplier. The responsibility for this generally falls upon the equipment inspector who customarily conditionally accepts the merchandise prior to shipment.

Similarly, there have been cases where relatively simple items such as valves and gaskets have been purchased from low bidders with a minimum of inspection at the supplier's plant or on delivery. Later, after the facility has been placed in operation, discovery shows that non-spec materials have been substituted. This can certainly lead to an unsafe situation where these valves and gaskets are used in critical process lines.

A. Special Considerations—Used Equipment and Materials

A special case where procurement safety may be involved is that situation in which used plants or individual equipment items are bought for installation at another site. These purchases are normally made on an "*as is, where is*" basis. The responsibility for safety may not be adequately defined or understood. The new installation may not conform exactly to the old and it is important that rigorous checks be made to verify the suitability of the new design. Removal insurance is generally a good idea and will most likely be required by the seller. This insurance offers protection for the seller, for the buyer, and for any contractors involved in the removal and their employees. The seller's property or remaining facilities are also covered. An alternative method of purchasing used equipment is buying freight on board (FOB). Usually the price is higher, but the seller has full responsibility for dismantling and packing and loading. Both of these alternatives should be evaluated to determine which is the most cost effective.

B. Heavy Loads

The transport of heavy items of equipment, pre-assembled units and modules can also be dangerous. Provisions must be made to avoid accidents to the involved personnel and to the public during this operation. In general, transport of equipment and materials in third world countries may involve risk because of the lack of local modern heavy-lift equipment.

C. Transport of Hazardous Materials

On many projects the procurement organization is responsible for making arrangements for transport of materials and equipment to the jobsite. Of special note is when hazardous chemicals or other substances including corrosive, radioactive, and flammable materials as well as some catalysts are required. Transport of these is obviously more expensive than conventional shipping.

V. SAFETY CONSIDERATIONS IN THE CONSTRUCTION AND TESTING PHASE

Safety at the jobsite may be initiated by reviewing the provisions in the contract. These will outline the expectations over and above those legal and regulatory provisions that the contractor must comply with regarding safety. The Construction Industry Institute in their publication *Managing Subcontractor Safety* (CII Safety Task Force, 1991) advocates including a requirement for a Safety Plan "including such information as safety inspections, enforcement, safety staffing, permits required, pre-employment testing, substance abuse testing, safety meetings, personal protective equipment required, orientation training, documentation of critical craft skills, basic safety training, record keeping, accident investigation procedures, and monthly reporting of statistics to the contract manager."

For work done at an operating plant, the Safety Rules and Procedures are usually made a part of the contract. These should be reviewed carefully prior to making an estimate or a bid to determine the effect they will have on the labor productivity. For some constructors the Safety Procedures for a given plant may be extremely onerous. If they have not been adequately evaluated prior to making the bid, the results could be very unpleasant.

The contract therefore is a good source of information for action items that must be costed out in making either an owner's estimate for the cost of the contracted work or the estimate for the contractor's bid.

It is obvious that the construction industry involves danger and it continues to have one of the worst safety records of any industry. Safety programs do work though, and some firms have been able to achieve injury rates of only 10% of the construction injury averages.

Safety can pay out and it is in the construction phase that this may be most graphically illustrated. Insurance rates, for example, can vary from a low of about 4% of all direct labor costs to 15% or more. These costs alone are substantial. The lower rates are indicative of an excellent record in maintaining a safe jobsite.

Safety and security are related and frequently considered together in estimating a project. As defined by McGuire (1989)

> *Safety* is concerned with the protection of personnel from physical hazards and environmental hazards that may exist on the site.
> *Security* (or Loss Control Management) is concerned with prevention of loss from theft and protection of property from vandalism—or in some areas terrorist activities.

A poor safety record on a single jobsite can have far reaching effects on a firm for many years in the future. As McGuire rightfully points out, safety is a public relations issue. A less than desirable public image, increased costs of insurance, and potential for legal actions combine to make an aggressive and results-oriented safety program well worth the cost.

Safety can be demonstrated to be a priority item on a jobsite provided it is given the proper attention by senior management. This would include putting safety on the agenda for all of the jobsite meetings. There should be a visible presence of safety expertise always available as a resource. Safety goals should be set and all personnel made aware of them. Selected contractors and subcontractors should be chosen from those most qualified and with the best price, but from a list containing only those with superior safety records.

The Construction Industry Institute concludes in their publication *Managing Subcontractor Safety* that general contractors have a significant influence on their subcontractors with regard to safety performance. They find that owners have an influence on both their contractors and subcontractors. The long-term impact of providing a job environment that improves overall job safety is that construction costs will decline. The improved safety records of all parties involved will directly increase job profits.

Most fatal accidents on a jobsite are the result of falls, accidents involving pieces of equipment, electrocution, accidents involving underground pipes and cables, and cave-ins around excavations. Accident reduction will result in cost savings, so these areas should be targeted for special attention during the work. Site history will frequently indicate where repetitive accidents have occurred and the Safety Plan should contemplate money to be provided for accident prevention.

Fire precautions must be included in the plan. These should not only be concerned with fire prevention, but should also include the development of evacuation plans for the personnel as well as protection of critical documents from fire damage by providing fireproof file cabinets.

McGuire (1989) also lists several items that have proven successful in helping to assure a good safety performance in the field. These include:

1. Site induction courses with heavy emphasis on safety
2. Site audits (site inspections) are highly successful when visible, and when senior site management participates. Success can be helped also if a dialogue with workers (encouraging good performance and counseling poor performance) is a part of the audit
3. Use of permit-to-work systems (excavation permits, electrical lockout procedures, etc.)
4. Programs to maintain safety awareness (publicity, incentives, continuous training, accident investigations, weekly toolbox meetings, etc.)

These items will be among those considered for inclusion in the Site Safety Plan and money provided in the estimate for their costs.

A. Zero Injuries

One of the most important developments in improving the safety record in construction has been the work done in the field of "Zero Injury." In recognizing that elimination of injuries is vital to the efficient execution of construction projects, the Construction Industry Institute set up a task force to continue research in this area of worker safety. Their report *Zero Injury*

Techniques, Publication 32–1 published in 1993 documents important factors that impact the cost of construction. Some of these factors are:

1. Construction accounts for about 10% of the gross domestic product with an annual dollar volume of about $450 billion
2. Construction employs about 5% of the U.S. workforce but suffers 20% of the traumatic occupational fatalities and 12% percent of the total number of disabling injuries
3. Workers compensation insurance costs doubled during the period from 1980 to 1987
4. In some states, companies are paying up to 30% of their direct labor costs for premiums. This amount will often exceed the profit margin. Companies with a poor safety record may pay twice the premium costs as compared to those with excellent safety records

This same document identifies the five high-impact Zero Injury Safety Techniques as being:

1. Safety Pre-Project/Pre-Task Planning
2. Safety Orientation and Training
3. Written Safety Incentive Program
4. Alcohol and Substance Abuse Program
5. Accidents/Incidents Investigations

Using these techniques in conjunction with a broad base of others suggested by the study, zero injury is being obtained on all types of construction jobs by large and small contractors on projects up to and including several million work-hours, as well as on union, nonunion, and merit shop jobs. The study also emphasizes that use of the techniques alone will not guarantee zero injuries, but it is more likely to occur on jobs where they have been implemented.

Incorporating this concept into the Safety Plan can only be done at a cost, but based on reviews of actual projects by the CII it is apparent that these costs usually are completely recovered due to the safer work environment.

One of the most effective methods of promoting safety at the jobsite is the control of new employees including a mandatory physical examination, drug screening and a reference check including a check on workers compensation claims from previous jobs. Preferably only workers with experience should be hired, as accident statistics show that the most vulnerable are the youths and those working outside their own craft lines. When it is necessary to use workers without experience, additional orientation must be provided and the level of safety communications increased. Some companies have adopted the "buddy" system pairing an inexperienced with an experienced person. Others have issued a different colored hard hat to the inexperienced workers to identify them so that others can help them work safely. All of these have an initial cost and there will always be pressure to try shortcuts to save money. The cost estimator must ascertain that sufficient money has been allowed so that the job can be done right.

B. Testing

A particularly vulnerable time during the construction phase is when the testing of systems and equipment is underway. Procedures and additional supervision are critical during the testing period.

C. Insurance

Insurance represents a major element of the cost of most engineering/construction projects. There are many opportunities to save money by careful design of the insurance programs. It is almost imperative that experts in the field be involved in the selection of the types of policies as well in choosing the carriers. Unfortunately, it appears that much more expertise is involved in developing specifications for a complicated piece of mechanical equipment in a facility than is usual for specifying the insurance coverage. The important types of insurance coverage available are briefly described below together with comments about the cost savings possible for each. It is not intended that these descriptions be detailed and in each case insurance requirements should be discussed with the appropriate specialists.

D. Workers Compensation

Each of the fifty states has a workers compensation program and there are only three states in which insurance coverage is not mandatory at present. Although the states may differ in details of the programs, the intent is to remove employment-related injuries from the court system. All that needs to be established is that the injury is work-related. The workers compensation programs make the employers responsible for all medical costs, some reimbursement of lost wages, rehabilitation costs, and death benefits. In return, the employee relinquishes the right to resort to the court system.

Workers compensation coverage represents a significant cost, but the risk of having insufficient insurance can be devastating. It is extremely important to have an agent that understands the nature of your business and the risk exposure as well as the subtleties of the policies offered by the different carriers. Policies will have many different options. On most there is a substantial benefit given to those companies with good safety records as indicated by your *modifier*. The lower the modifier, the lower the premium. This translates to substantial savings in the coverage.

E. Other Insurance

It is important that both owners and contractors have *Commercial General Liability* coverage. These policies cover all exposures of commercial liability except those specifically excluded which are generally automobile liability, professional liability, and workers compensation.

Builders Risk insurance covers direct property risks during the construction phase of a project, specifically equipment losses, materials to be installed, and partially completed work. These losses may be the result of fire, wind, flood, faulty workmanship, or design error.

Excess Liability and *Umbrella Insurance* policies are written to cover losses in excess of those covered by primary policy or policies. The proper amount of insurance is determined by a cost/comfort evaluation; but, at some level, almost all firms accept that they must be self-insured for the greatest catastrophic losses.

Owners and contractors should investigate the advantages of coordinating some insurance coverage as doing so is frequently beneficial to both parties. Generally, the owner must take responsibility for initiating this action.

Wrap-Up Insurance is a program where one party, generally the owner, obtains a single policy that covers several of the parties involved in constructing a facility. The policy is written for the same exposure. This type of policy is more common for very large projects. Lower rates are possible, but the administration of this program is sometimes complex and always must be carefully managed to obtain maximum benefit. The Wrap-up insurance policy uses a single experience modifier. One caution for the contractor is that wrap-up insurance does not usually cover the contractor's construction equipment. Although not universally the same, the Wrap-up policy may contain coverage for workers compensation, general liability, builder's risk and sometimes umbrella liability.

A similar type of insurance is the *Owner Controlled Insurance Program* in which the owner does the purchasing of the policy but the individual policies are written for and paid for by the specific firms. Separate experience modifiers are used by each of the companies for their respective policies.

Ocean Marine Cargo Insurance is special marine property insurance designed to insure against physical loss or damage to any goods which are subject to ocean or air shipment. This type of insurance covers all risk conditions including war and strikes and should be written on a warehouse-to-warehouse basis. This insurance should be considered primary insurance for the prime contractor and owner but excess to any insurance carried by the ocean/air shipping company.

F. Security

Loss Prevention Management during the construction phase of the project includes all aspects of prevention of losses through theft and vandalism whether from employees, criminals, terrorists, or natural disaster. Among those items to be considered are:

1. The physical security of the site including temporary fencing with controlled gates or other access for vehicle, rail and pedestrian entry with adequate sight distance or monitoring system along fence
2. Passes or badges for entrance
3. Administrative security programs
4. Properly equipped and competent security force
5. Restricted areas such as the material warehouse
6. Adequate site lighting
7. Communication systems to provide support for normal and emergency systems

From a cost standpoint, additional security should always be provided during a period of economic downturn, or at times when the facility is to be constructed in an impoverished region or a politically sensitive country.

VI. SAFETY CONSIDERATIONS IN THE START-UP PHASE

Operating procedures are an essential element in a plant start up. In particular, the operating manuals contain safety and health precautions that need to be observed. Experienced start up personnel will realize that this is a particularly dangerous period in the life cycle of the facility. The operating procedures should be developed with the collaboration of a safety expert to assure that all bases have been covered and that the manual is clear on how to carry out the start up duties safely. The manual will contain instructions on what to do when the different alarms are activated during an upset.

The manual needs to be kept current and must be immediately available to operations personnel involved in the start up. The individual in charge of the start up needs to ascertain additions, modifications or deletions which are made apparent during the start up and subsequent operation of the facility. When changes are made by the maintenance crews, these should be communicated immediately to the operating crews and these must be reflected in an updated version of the material. Where some of the control room staff are not fluent in English, the instructions and procedures should be prepared in the language understood.

Pre–start-up safety reviews are an important part of the safety plan for a project. This review goes right along with the appropriate training of each employee involved in operating the facility.

The process control system can either be a tremendous help or a barrier to a safe plant start-up dependent upon how it is designed and how it is used during the start up.

Simulators are a possible asset to be used in training plant operators and their use should be considered in making the start-up plan and in developing the estimate.

A. Safety Considerations for Plant Modifications/Revamps

One of the most frequent plant modifications is the installation of a new process control system or a plant instrument upgrade program.

Many times the existing plant documentation has not been kept current. This adds to difficulties in defining the exact scope of the work and is a frequent root cause of underestimating costs.

Personnel should be kept current with the changes, particularly with those that introduce modifications in plant operation and that may be likely to create a hazardous condition.

Small changes or minor revamps may lead to unsafe operating conditions in the plant because they may not have been as carefully analyzed as a major revamp and there is more likelihood that the changes may not be communicated to everyone that may be involved in plant operation.

Plant utility systems may create a dangerous condition during or after a revamp or modification project. Of special note might be the temporary changeover of a system to accommodate the revamp work and then failure to return the system to its normal condition.

Estimating the costs of a revamp project is difficult, particularly one in which the facility continues operation during most of the modification work. Where equipment scheduled to continue in service has not been inspected prior to the start of work, there is stress introduced when major repairs or modifications are necessary. This is exactly the situation where safety often takes a back seat. Estimators should assure that the funds are adequate to eliminate the pressure for cutting corners in safety provisions.

VII. OPERATION AND MAINTENANCE OF A FACILITY: OVERVIEW

Many of the safety and cost considerations reviewed earlier are also applicable to the operation and maintenance activities. They are mitigated somewhat because there is a more stable workforce and training can be spread over a longer time with increased emphasis being given by repetition. In the case of safety, however, familiarity with the operation can engender a form of "contempt" for the danger involved. In this sense, there are both positives and negatives in dealing with the more "permanent" part of the facility's life cycle.

A. The Safety Management Plan

In order to examine the cost of operational safety, we may start off by acknowledging that we must have a firm plan of how safety will be managed at this facility. It is not usually the estimators responsibility to develop the plan, but the estimator can rightfully expect to have a safety management plan on which to base the estimated cost of operation. Here, plant management must take the lead in safety, but this will happen only if the corporate management is supportive.

Today the basis for a safety management plan is a thorough understanding of the OSHA regulations and a merging of this plan with the normal and abnormal plant operating procedures. At this time an in-depth review of the process conditions as well as the physical condition of the plant is in order. The development of the plan is not enough though. It must be communicated and understood by the employees at the plant and plant management must have a very visible commitment if the safety program is to succeed. In some plants this is going to require a definite change in the corporate culture. Only by changing behavior can we improve safety performance.

A very valid statement attributed to Peter Drucker says that "what gets measured gets done" and this is the approach that we have to take to improve our safety records. No one can offer a guarantee of a safe workplace, but we need to have "zero injuries" as a goal.

Foremost among the elements that should be part of any Safety Management Program is the visible support of plant management and a continual effort to avoid worker apathy to safety. Other steps include:

1. Collect all safety information relating to the facility including all *toxic and hazardous materials* involved.
2. Conduct an *evaluation of dangers* involved in the operation particularly with regard to system failure and the most dangerous aspects of the operation such as start up, upsets, shutdowns, modifications, and emergencies.
3. Maintain specific *standard operating procedures.*
4. Provide comprehensive *safety training programs* for the supervisors and operating personnel based upon an analysis of their capabilities and needs.

5. Develop a site-specific procedure for conducting periodic *safety audits* including a check of mechanical integrity.
6. Write a *procedure for introducing changes* by operating or maintenance personnel into the existing plant configuration. This procedure should include repeated checks for any novel departures from the existing configuration.
7. Write a *procedure for investigation* into incidents including the corresponding assignment of responsibility.
8. Maintain an updated listing of all mandated and/or recommended *safe working practices*. New information must be added as it becomes apparent.
9. Formalize an *emergency plan* that assigns responsibilities for emergency management (planning, control, and response) and outlines specific steps that are to be taken when an unforeseen incident occurs.

B. Estimates and Cost Control

Preparation of an estimate for the cost of implementing and maintaining a Safety Management Program for the operation of a facility does not differ materially from what has been discussed on the previous pages. For a new facility, it is a matter of costing out the plan and making sure that all aspects have been covered. This requires no additional information, experience, or intelligence than that for developing an estimate of any other sort. Here though, it is important to verify that all of the components of the plan have been estimated. One of the common failings of such an estimate is that assumptions are made that "someone else" has included those costs in their budget.

In the case of an existing facility where a new emphasis is being given to safety, it is a matter of determining what each of the new elements are and adding them to the costs of the existing program.

VIII. CONCLUSIONS

Safety programs have an initial cost that creates a temptation to take a risk. Good safety practices do pay off, but very much in the sense of preventing the occurrence of unpleasant and costly incidents. In this sense, the savings are difficult to quantify. Some money is undoubtedly spent needlessly in the name of safety. Many safety practices are now mandated, and the penalties for failing to observe them are sizeable. Safety is not only cost-effective in the long run, it is also the right thing to do.

Estimating the cost of safety-related items is simple once they have been defined. In this chapter we have described some of the critical elements of safety programs, and their associated costs.

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Controlling the Costs of Shipping

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I. INTRODUCTION

An understanding of terminology, contractural obligations, and liabilities is essential in planning, budgeting, monitoring, and controlling shipping costs.

The cost of procuring equipment and commodities for project installation includes the cost and logistics of transportation, whether by land, sea, or air. Modes of transportation for inland movement of goods could be by rail, contract carrier, common carrier, air, or waterways. Overseas cargo shipments are by barge, ship, or air and will normally include additional, associated costs of export preparation, packing, insurances, and freight forwarding documentation. For overseas shipments, three elements of travel are involved: getting the products from the point of manufacture or supply distribution to the port of de-embarkation, to the port of entry, and, to the site location. Once on site, costs associated with receiving, inventorying, storage, retrieval, and handling become matters of construction and/or traffic management, indirect elements of estimating, and cost control.

Each country has its own regulatory requirements concerning duties, taxes, and tariffs, both in the rate and exemptions, to protect their national market interests. Costs associated with duties, taxes, and tariffs should be analyzed on a case-by-case basis.

Timing of shipments is an important factor, more so for locations outside the realm of domestic confines, from the continental U.S. to Artic Regions, for example. Windows of opportunity for ocean shipments to the North Slope are dependent upon periods when there is access to shipping lanes free from ice; overland shipments to the northern provinces of Canada are prohibited during road bans, that time of year when thaws occur; similarly, the speed at which trains are allowed to travel over tundra will be restricted.

National observances of religious and historic holidays will need to be considered, more so in some countries than others. (This will usually only affect a customs clearance or perhaps delivery date.)

Hauling associated with the disposal of hazardous materials is a specialized activity and the necessary precautions and costs are not addressed here. For a definition of regulations, fees, and surcharges applicable to waste disposal, reference is made to: Cressman and Martin (1993), Decisions in the Marketplace, in: *Hazardous Waste Cost Control* (R. A. Selg, ed.), Marcel Dekker, Inc., New York.

II. GUIDELINES FOR FREIGHT CALCULATIONS

A builder or contractor will normally require that a manufacturer, fabricator, or supplier provide the cost of freight in their price, or as an adder to their price. This places much of the burden for sourcing, coordination, and liability upon the one furnishing the materials or goods.

Regardless of who is responsible for determining freight costs, the guidelines for calculation remain the same. Schedule requirements, distances, dimensions and weights, invoice value, and commodity definition are all factors to be considered. International shipments require further considerations such as: freight forwarding documentation, duties, taxes, tariffs, and additional transportation/handling costs. Dependent upon how the shipment is executed, the extent of liability will vary between the shipper, the forwarding carrier, and the receiver. It is important, therefore, to specify needs and expectations. The tables presented herein will identify those important aspects for costing and control.

The seller's risk, as defined by the International Chamber of Commerce, extract referenced, is determined by the availability or goods to the receiver. "FOB Works with Freight Allowed to Jobsite," for example, represents the seller arranging for the mode of transit, loading the cargo aboard the carrier, and prepaying the transportation cost. Liability, however, becomes the responsibility of the purchaser, once goods are loaded and secured.

The erection requirements will sometimes dictate the mode of transportation. Dependent upon size, weight, and travel distance, rail transport may be more economical, whereas truck transport may be more advantageous under other circumstances. Both modes should be investigated, except in cases of the obvious. A destination that does not have siding or railhead access, for example, would likely be a poor choice for rail shipments.

The Estimate of Freight, example shown, is prepared like any other component of cost. The description is noted, dimensions and weights listed, liability, mode, class, and mileage recorded, and the appropriate rate applied (either to weight or mileage, as applicable).

Oversize or overweight shipments require special consideration. If by rail, additional cars may be required; if by truck, permits or escorts may be required. The routing may also have limiting factors such as bridge capacity, overhead restrictions, hours of transportation, and the like. Maximum permissable loads and routing restrictions need to be investigated. Examples are shown.

The subheadings, following, elaborate on definitions. Some associations, such as the American Institute of Steel Construction (AISC), have a "Code of Standard Practices" for their industry. This is a minimum acceptable standard, when not otherwise specified by the purchaser. Buyers often issue a "Procurement Specification" as an attachment to their purchase order stipulating the terms, conditions, and responsibilities to which the seller of goods or provider of services must adhere. Two examples are provided.

Consult with local carrier representatives and regulatory agencies for specific application, pertaining to your shipments.

The following tables provide information necessary to control shipping costs:

1	Cost and Schedule Considerations
2	Weights
3	Other Shipping Considerations
4	Maximum Permissable Loads
5	Other Shipping Methods
6	Air Cargo
7	Determining Freight Classification
8	Examples of Trailers for Equipment Hauling
9	International Commerce Terms
10	Tariffs
11	Agencies and Associations
12	Sample Estimate of Freight Costs
Appendix A	Code of Standard Practices (Typical)
Appendix B	Procurement Specifications (Example)
Appendix C	Freight Forwarding Services (Example)

(text continues on p. 689)

Table 1 Cost and Schedule Considerations

Shipper	Shipments for export	Receiver
Compliance with procurement specifications	Export preparation	Unloading
Compliance with standard practices	Export forwarding documentation	Inspection for damage, shortages, etc.
Preparation for shipment	Brokerage fees	Overages, shortages, and damaged freight (OS&D)
Tagging, marking	Dock fees	
Flange protectors	Insurances	
Spider-bracing	Import duties/tariffs	
Cribbing	Licensing	
Crating	Agents fees	
Banding		
Dunnage		
Packing		
Blocking		
Stuffing		
Loading		

Table 2 Weights

When calculating shipping weights for components, such as piping and fabricated steel, consideration should be given for allowances to be added or deducted from theoretical mill weights for such things as:

Credits for bolt holes, coped webs, blocked or stripped flanges of steel members

Additional 0.5% to compensate for Painted members,

Additional 3.5% to compensate for Galvanized members.

In many cases, Scale Tickets will be required to verify freight invoices billed on unit weights and/or to ensure that loads are within allowable regulations.

Table 3 Other Shipping Considerations

Demmurage charges

A demurrage charge is compensation paid, as damages, for the delaying of a ship, freight car, or motor carrier as by the failure to load, unload, or sail within a specified period of time, as defined by the carrier line.

Unloading requirements

Shippers of bulk granular materials (sand, gravel, grains, fertilizers, and the like) should coordinate with the receiver to determine the type of carrier preferred (bottom dump or end dump, for trucks; bottom dump or rotary dump, for rail cars).

Shippers of bulk liquid materials should determine whether or not carriers are required to be equipped with discharge pumps.

Availability of a specified carrier may impact delivery schedules.

Table 4 Maximum Permissable Loads

	Dimensions	
Truck: 40 ft standard trailer		
Width	8 ft - 0 in.	
Length	40 ft - 0 in.	
Height (above road surface)	13 ft - 6 in.	
Weight, normal max., loaded	42,000–44,000 lbs	
Permits may be required if load limitations exceed State/Local permit requirements and fees may vary. Escort Services may also be required.		
Rail		
Clearances for cars with dimensions of:		
Length, inside	50 ft - 6 in.	
Length, couples	54 ft - 8 1/2 in.	
Length, truck c/c	41 ft - 3 in.	
Car floor	4 ft - 2 in.	(above top of rail)
Height	10 ft - 11 in.	(above floor of open car)
Height	10 ft - 1 in.	(at center of enclosed car)
Height	9 ft - 7 in.	(at side of enclosed car)
Width	10 ft - 8 in.	(open car)
Width	10 ft - 0 in.	(enclosed car)
Weight	100,000 lb	(can vary with type of car)

An item, such as an Absorber Tower, may exceed the allowable length of a car and require reserving a lead car and a trailing car. If the length is such that supporting the load on a single car is not recommended, then swivel bolsters will be required to allow the load mobility to execute curves in the rail line.

Source: Association of American Railroads

Table 5 Other Shipping Methods

Truck/Rail Cargo
One method of shipment for containers is the practice of loading goods in an enclosed common carrier van or on a trailer and loading aboard a flatbed rail car for cross-country transport. Upon arrival near the destination, the van or trailer is off-loaded and a tractor transports over-the-road to the final destination. The term "piggy-back" is often used to describe this technique.

Fabricated-In-Transit
Fabricators and manufacturers can often obtain raw materials from a mill source via rail transport, perform their production operation, and continue the shipment aboard the same rail line at a lesser rate than two individual shipping schedules.

Cooperative Rail Usage
One enterprising mining company entered into a long-term agreement with a utility company and the rail line that serviced their respective needs to ship unit trains of ore from the Great Lakes region to the intermountain west for smelting and then load the rail cars with coal for the return trip. The distance which cars traveled empty was greatly minimized, thereby achieving attactive rates for both the mining company and the utility company.

"Hot-Shot" Deliveries
There are occassions when items may be required on an emergency, or out-of-sequence, need. These nonscheduled occurences are handled on a case-by-case basis, usually determined by the urgency, the distance, and the size/weight of the item or items.

This concept is similar to that of a courier service. The advantage is that of quick service and dedicated delivery; the disadvantage is that of cost. Charges are usually based on a rate/mile with a guaranteed minimum. The minimum is usually based on a compensation for the round-trip elapsed time for the driver and transportation equipment; i.e., to and from the point of dispatch, not from the shipper to the receiver.

Table 6 Air Cargo

1. Air Cargo shipped via commercial passenger carrier has the following limitations:

Max. Length	60 in.
Max. Width	40 in.
Max. Height	30 in.
Load bearing weight cannot exceed	150 lb/ft^2

2. Air Cargo shipped via charter carrier:
   Consult with local carrier representative.
3. Air Cargo shipped via UPS/DHL/etc.:
   Consult with local carrier representative.
4. Conditions under which transportation and construction lifts might require the use of helicopters include:
   - Mountainous terrain
   - Jungle interiors devoid of ground routes or inland waterways
   - Remote tundra sites devoid of ground routes
   - Height of lifts that exceed conventional crane capabilities and/or the use of tower cranes is impractical.

Table 7 Freight Classification

Modes
Air
Cargo
Charter
Land, truck
Common carrier, LTL (less than truck load)
FCL (full container load)
Contract carrier
Land, rail
LCL (less than container load)
FCL (full container load)
Box car
Flat bed
Gondola
Water
Barge
Ship

Examples (assume 1000 miles; > 5000 lb)

Item	Mode	Freight class		Rate* ($/Cwt)
Generator set	LTL	70		17.54
	Truck	45	(24,000 lb min.)	9.29
	Rail	45	(30,000 lb min.)	14.68
Pumps	LTL	85		21.06
	Truck	45	(24,000 lb min.)	9.29
	Rail	45	(24,000 lb min.)	14.68
Pressure vessels	LTL	85		21.06
	Truck	40	(30,000 lb min.)	9.29
	Rail	40	(45,000 lb min.)	13.03

Shipper's should be aware that discounts from Motor Carrier published rate tables can vary dependent upon the "attractiveness" of their tonnage.
* These rates are based upon a point of origin to a point of destination, exclusive of loading and unloading costs.
Source: Richardson Engineering Services, Inc., Mesa, Arizona.

Table 8 Examples of Trailers for Equipment Hauling (Low Range to High Range Capacity)

Type	No. axles	No. tires	Deck type	Deck length (ft)	Capacity (ton)
Fixed gooseneck	2		Drop	23–25	25
	2		Drop	17	50
	3		Drop	17	35
	3		Drop	20	75
	4		Drop	17	50
	4		Drop	20	120
	2		Flush	14–18	22
	2		Flush	17	50
	3		Flush	17	35
	3		Flush	20	75
	4		Flush	17	50
	4		Flush	20	120
Folding gooseneck	2	8	Drop		25
	2	8	Drop		50
	3	12	Drop		35
	3	12	Drop		75
	4	16	Drop		50
	4	16	Drop		120
	2	8	Flush		25
	2	8	Flush		40
	3	12	Flush		35
	3	12	Flush		60
	4	16	Flush		50
	4	16	Flush		60
Hydraulic gooseneck	2	8			25
	2	8			50
	3	12			35
	3	12			100
Float	2	8		32	40
	2	8		40	40

Specially designed low-boy trailers, with multiple axles, are available for heavy loads, which also provide additional height clearance. An investigation should be made to insure that loads will clear roadway conditions; such as, railroad crossings. In all cases, a routing check should verify clearances for:

	Weight	Width	Height	Length
Roadways	X	X	X	X
Bridges	X	X	X	
Overpasses/tunnels		X	X	
Transmission lines			X	
Congested areas		X		X

Source: Rental Rate Blue Book for Construction Equipment, Section 19, "Trailers," Section 20, "Tractors," DataQuest, Inc., San Jose, CA

Table 9 International Commerce Terms

Term	Definition	Seller's Cost/Risk
EXW	Ex works	The seller minimizes his risk by only making the goods available at his own premises.
FCA	Free carrier	The seller arranges and pays for precarriage in the country of export.
FAS	Free alongside ship	The seller arranges and pays for precarriage in the country of export.
FOB	Free on board	The seller arranges and pays for precarriage in the country of export.
CFR	Cost and freight	The seller arranges and pays for the main carriage, but without assuming the risk of the main carriage.
CIF	Cost, insurance, and freight	The seller arranges and pays for the main carriage, but without assuming the risk of the main carriage.
CPT	Carriage paid to	The seller arranges and pays for the main carriage, but without assuming the risk of the main carriage.
CIP	Carriage and insurance paid to	The seller arranges and pays for the main carriage, but without assuming the risk of the main carriage.
DAF	Delivered at frontier	The seller's cost/risk is maximized due to making the goods available upon arrival at the agreed destination.
DES	Delivered ex ship	The seller's cost/risk is maximized due to making the goods available upon arrival at the agreed destination.
DEQ	Delivered ex quay	The seller's cost/risk is maximized due to making the goods available upon arrival at the agreed destination.
DDU	Delivered duty unpaid	The seller's cost/risk is maximized due to making the goods available upon arrival at the agreed destination.
DDP	Delivered duty paid	The seller's cost/risk is maximized due to making the goods available upon arrival at the agreed destination.

Note: A "rule-of-thumb" for budget estimates is that freight forwarding costs will be 15–18% of material costs. This includes the cost for, "Insurance Premium for Marine Transit," 0.1563% of material cost.
Source: "Guide to Incoterms," Jan Ramberg, ed., ICC Publishing S.A., 1991, ICC Publication No. 461/90, International Chamber of Commerce, Paris, France

Table 10 Tariffs

Each Country of Entry has its own statutes and regulations governing items which can be imported, and duty tariffs applicable to each item. The rate will also be determined by the Country of Origin.

Commodity	Most favored nation	General preferential	Least developed	U.S.
Boilers, steam generating	12.5%	8.0%		Free
Instruments				
Monitoring	10.3%	6.5%		5.1%
Electrical panel indicating	10.3%	6.5%		Free
With strip recorders	Free	Free		Free
Designed for use with data processing	3.9%	Free		1.9%
Pumps				
Concrete	9.3%	2.5%		Free
Rotary positive displacement	9.3%	2.5%		Free
Centrifugal	9.3%	2.5%		Free
Reactors, nuclear	12.5%	8.0%		Free

Source: Revenue Canada, Customs, Excise and Taxation, January, 1993.

Table 11 Agencies/Associations

Department of Transportation (U.S.), 400 Seventh Street, SW, Washington, D.C. 20590
Federal Highway Administration, (202) 366-0630
Federal Railroad Administration, (202) 366-0881
Federal Information Center, (800) 735-8004
Federal Maritime Commission, Suite 110, 14950 Heathrow Forest Pkwy., Houston, TX 77032-3842, (713) 229-2841
Interstate Commerce Commission, 12th & Constitution Avenue, NW, Washington, D.C. 20423, (202) 927-7119
National Air Transportation Association
U.S. Customs Service

Contact "Blue Pages" for local listings.

Table 12 Sample Estimate of Freight Costs

Project: Estimate of freight
Date: Destination: Houston

Item description	Size	Weight	FOB	Mode	Class	Mileage	Rate ($/cwt)	Estimated freight ($)
Generator set	313 in. L × 96 in. W × 131 in. H	74,970	Dallas	Rail	45	243	8.09	6,065.07
Fan, industrial		6,975	Kansas City	LTL	85	710	17.90	1,248.53
Pumps		2,160	Denver	LTL	85	1019	26.68	576.29
Structural steel, fabr.		92,000	Houston			50	3.48	3,201.60
Piping spools, fabr.		54,000	Houston			30	3.48	1,879.20
Total								12,970.69

III. APPENDIX

A. Code of Standard Practices

6.6 Marking and Shipping of Materials

6.6.1 Erection marks are applied to the structural steel members by painting or other suitable means, unless otherwise specified in the contract documents.

6.6.2 Rivets and bolts are commonly shipped in separate containers according to length and diameter; loose nuts and washers are shipped in separate containers according to sizes. Pins and other small parts, and packages of rivets, bolts, nuts and washers are usually shipped in boxes, crates, kegs, or barrels. A list and description of the material usually appears on the outside of each closed container. Bar coding is presently being sought out.

6.7 Delivery of Materials

6.7.1 Fabricated structural steel is delivered in such sequence as will permit the most efficient and economical performance of shop fabrication and erection. If the owner wishes to prescribe or control the sequence of delivery of materials, he reserves the right and defines the requirements in the contract documents. If the owner contracts separately for delivery and erection, he must coordinate planning between contractors (and suppliers).

6.7.2 Anchor bolts, washers, and other anchorage or grillage materials to be built into masonry should be shipped so that they will be on hand when needed. The owner must give the fabricator sufficient time to fabricate and ship such materials before they are needed.

6.7.3 The quantities of material shown by the shipping statement are customarily accepted by the owner, fabricator, or erector as correct. If any shortage (or misfabrication) is claimed, the owner or erector should immediately notify the carrier and the fabricator in order that the claim may be investigated.

6.7.4 The size and weight of structural steel asemblies may be limited by shop capabilities, the permissible weight and clearance dimensions of available transportation, and the job site conditions. The fabricator limits the number of field splices to those consistent with minimum project cost.

6.7.5 If material arrives at its destination in damaged condition, it is the responsibility of the receiving party to promptly notify the fabricator and carrier prior to unloading the material, or immediately upon discovery.

Source: American Institute of Steel Construction, Inc., Chicago, Illinois.

B. Procurement Specifications (Example)

8.0 Shipment of Equipment and Materials

All equipment and materials shall be shipped to the jobsite in accordance with these requirements.

8.1 Protection

The Supplier shall provide protection for equipment and materials in the period between completion of manufacture and delivery to the site. Protection shall include, but not be limited to, the following provisions:

Special handling instructions visibly displayed on the shipment. This shall include storage requirements for any equipment that cannot be stored outdoors.

Adequate preparation to facilitate rigging and handling, including lifting lugs where appropriate.

Adequate crating, blocking, and anchoring, as required to prevent damage and loss during transit and storage.

Proper loading of plate, tubular products, formed shapes, and sheet metal work, and other equipment and material, so as to prevent permanent deformation or crimps in material during transit or unloading.

Affix durable metal, plastic, or wood covers to openings to keep pipe, tubing, conduit, vessels, and machinery closed after final shop inspection.

Provide covers, enclosures, and other means to minimize corrosion, moisture damage, mechanical injury, and accumulation of dirt in equipment and machinery.

Protect surfaces subject to harmful damage from oxidation, staining, or other attack caused by dust, dirt, or atmospheric elements.

Provide rust-preventive compound for outdoor storage on exposed machined surfaces.

Provide suitable compound or similar means for protection of cosmetic finishes. Damaged surfaces shall be repaired.

Provide grease packing or oil lubrication in all bearings and similar items.

Clean and coat with rust-preventative compound all external gasket faces, flange faces, couplings, rotating element shafts, bearings, and like items. Protect with suitable wood, metal, or other substantial type coverings.

Provide enclosure and/or moisture absorbing compound to protect equipment subject to harmful internal moisture deterioration in a saturated or high-moisture atmosphere.

Protect equipment where damage can result from entry of dust or other foreign matter.

Block, bolt, or otherwise restrain movement of internal parts where dam- age could result from normal handling during transit, unloading and erection. Returnable containers and special shipping devices shall be returned by the Supplier's field representative at the Supplier's expense.

Pack separately all spare parts, start-up parts, special tools, and Instruction Books.

Protect stainless steel and alloy surfaces from carbon steel and other contaminations.

8.2 Marking

Identification of equipment and materials shall include, but not be limited to, the following provisions:

Each item of equipment and material shall be tagged or marked as identified in the delivery schedule or on Compliance Submittals and complete standardized packing lists and bills of material shall be included with each shipment.

Identify containers, crates, etc., containing spare parts, tools, or Instruction Books.

Affix adequate labels on equipment shipped with bags of desiccant inside, and to indicate existence of dog bolts or other restraints against movement of internal parts.

Include packing lists in duplicate in each crate, package, or bundle shipped.

8.3 Shipment

Shipment of equipment and materials shall be in accordance with the following requirements:

Shipment shall be suitably anchored to avoid damage from severe movements resulting from bumping, sudden turns, etc.

All electronic prefabricated assemblies, including control panels and computer cabinets, shall be shipped by through-truck freight in padded furniture vans when required by the manufacturer.

Where specified, the Supplier shall mount and ship impact recorders on each railcar transporting the equipment. The impact recorders shall be mounted at the factory to provide a permanent record of the magnitude of axial, transverse, and vertical forces to which the equipment will be subjected while in transit. The custody of the impact recorders upon arrival at the plant site shall be the responsibility of the Supplier's field representative. The recorder impact charts shall be delivered to the Contractor and shall become part of the furnished equipment.

8.4 Transportation

Transportation of equipment and materials shall be in accordance with the following minimum requirements:

All equipment and materials shall be delivered by truck or by railroad to the plant site.

All factory-assembled components that can be transported by highway carriers shall be delivered to the plant site by truck from the Supplier's shipping point or railhead of Contractor's choice.

Supplier shall be responsible for routing and obtaining all necessary permits for highway and railway clearance and load restrictions. Routing of shipments shall be acceptable to the Contractor.

8.5 Preshipment Inspection

The Contractor reserves the right to inspect the equipment prior to shipment.

The Supplier shall notify the Contractor of all shipments not less than 10 days prior to the date of shipment to allow the Contractor to inspect the equipment, if so desired.

8.6 Shipments

Shipments to the plant site shall be consigned to the following locations:

Rail Shipments (will advise)
Truck Shipments (will advise)

8.7 Shipping Notice

The Supplier shall submit to the Contractor two copies of shipping notices describing each shipment of material or equipment. The shipping notices shall be mailed to arrive approximately 3 days prior to the estimated shipment arrival. The addreses for each shipping notice will be determined later.

8.8 Materials List

The Supplier shall prepare and submit, with the first shipping notice, two copies of an itemized materials list covering all equipment and material furnished under these specifications. The materials list shall be in sufficient detail to permit an accurate determination of the completion of the shipment.

8.9 Hazardous Materials

All shipments of hazardous materials shall be identified on the materials list. A copy of the hazardous materials documentation required shall be included with the shipping papers attached to the shipment. This shall include Material Safety Data Sheets covering any hazardous materials as required under Federal Hazardous Communications Standards and certain state and local laws. If Material Safety Data Sheets are not required by law, the Supplier or Subcontractor shall provide copies of a document certifying that no such data sheets are required under any federal, state, or local law, regulation, statute, or ordinance in effect at the jobsite.

15.0 Packaging and Identification of Spare Parts and Start-up Parts

Spare parts and start-up parts shall be shipped in appropriate containers. The containers shall be designed as permanent storage enclosures. Separate containers shall be used for the spare parts and for the start-up parts for each major piece of equipment. Where applicable, containers shall be designed and constructed for return shipment of damaged or worn components for repair.

Spare parts and start-up parts shall be protected from damage due to moisture and dirt accumulation during an extended storage period by use of special coatings, airtight membranes, bags of desiccant, or other means acceptable to the Contractor.

Each container for spare parts shall be marked with the large painted legend, as follows:

Project Name
Unit
Spare Parts for (Name of Equipment)
DO NOT OPEN EXCEPT WITH OWNER'S PERMISSION

Each container for start-up parts shall be marked with the large painted legend, as follows:

Project Name
Unit
Startup Parts for (Name of Equipment)
DO NOT OPEN EXCEPT WITH OWNER'S PERMISSION

A weatherproofed itemized list or standardized packing list of the contents shall be attached to the outside of each container. A similar list shall also be inside each container.

C. Freight Forwarding Services (Example)

1A.1 General

This section covers the general description, scope of services, and supplementary requirements for equipment, materials, and services under these specifications.

1A.2 Work Included Under These Specifications

The work under these specifications shall include furnishing Freight Forwarding Services, and providing miscellaneous materials and services complete as specified herein and in accordance with the contract documents defined in the article entitled Contract Documents of the General Conditions.

1A.3 General Services

Freight Forwarder shall provide general freight forwarding services including, but not limited to, the following:

Analyzing transport routings to determine best possible routings in interest of Engineer. Factors analyzed should include, but not be limited to, economic, transit times, dependability, traceability, and other factors essential to transport depending on freight terms, CIF or prepaid basis of the goods.

Arranging, expediting, and prepaying inland transportation to seaport or airport.

Arranging, expediting, and paying for seaborne transportation.

Arranging, expediting, and paying for airborne transportation.

Arranging container drop-off at Supplier's facilities and return to container owner when empty at project site.

Arranging for freight consolidation services and warehousing as required.

Providing all documentation required to affect delivery of the goods.

Providing inventories of shipments to permit verification of shipments at Project site.

Provide tracking and expediting services for goods while in transit, including a single contact point for Engineer to obtain status of shipments, including status by telephone. Service is required to be available on a 24-hour basis.

Preparation of transportation insurance claims and assistance in pursuing such claims.

Providing status reports of goods in transit, preferable by direct computer linkage between Engineer and Forwarder.

Provide adequate export packaging to facilitate safe travel to Project site.

Providing shipping requirements including obtaining Statutory Waivers which include:

Proposed vessel and registry.

Commodity.

Weight and dimensions.

Value of shipment.

Port of export.

Estimated loading date.

Discharge port.

Information regarding previously contacted U.S. flagged carriers and personnel including responses are required to legitimize the unavailability of qualified U.S. transportation.

Provide all required shipping documents including, but not limited to, shipper's export declaration, commercial invoice, certificates of origin, hazardous materials declarations, packing lists, bills of lading, airway bills (if applicable), all prepared in letter quality to ensure legibility. Freight Forwarder shall prepare and submit documents in accordance with import requirements.

Billing Engineer for services rendered, including reimbursement of freight charges paid by Forwarder and other unit cost services specified herein.

General Contract administration.

1A.4 Analysis of FOB Point

1A.5 Unloading at Site

All goods shall be delivered Ex-Hook at unloading facilities dock. Vessels must have the ability and gear to self-unload or allow the onsite Construction Agent the opportunity to move off the dock or out of the landing craft at the site.

1A.6 Large Item Transport

It will be necessary for the Forwarder to arrange transport of certain large heavy shipments of equipment which must be shipped fully or partially assembled on shipping vessels having heavy lifting capability.

1A.7 Containers

For container shipments, Forwarder shall provide containers of the size, type, and quantity required by the Supplier at his facility on a schedule as determined by the Supplier. Forwarder shall consult with the Supplier as required to assure that containers are available as required. Forwarder is responsible for all demurrage or storage charges incurred by use of the containers in excess of the time allowed by Contractor elsewhere in this document. Forwarder shall visit Supplier's facility to advise on packaging for shipment and inspection of packaging prior to acceptance for delivery.

1A.8 Consolidation

It is anticipated that some shipments by Suppliers may be LCL quantities. Forwarder shall be responsible for consolidation of such shipments into container loads when feasible. Consolidation with LCL lots not connected with the Project will be permitted only with the specific authorization by the Engineer.

It may be necessary due to schedule constraints that certain LCL quantities shipped without consolidation will be required as directed by the Engineer. In no instance shall Forwarder hold equipment and materials for consolidation and shipment in excess of 30 days.

Forwarder shall arrange for warehouse storage of goods as required. The costs of warehousing goods awaiting consolidation shall be included in the price for consolidation services. Should the Engineer require temporary warehousing due to unforseen circumstances, Forwarder will be reimbursed for the costs incurred.

The Forwarder's lump sum proposal shall include the following information:

Provide designated U.S. Port(s) of Export

Provide required delivery date to U.S. Port of Export to coincide with U.S. flagged vessel debarkation date and required Project on-site delivery requirements.

Provide detailed shipping instructions (wharf number, warehouse location, facilities) including contact at U.S. Port of Export for all consolidations. This information will be provided to all potential Suppliers and all equipment shipped FOB (U.S. Port of Export location).

Provide procedures to implement successful security, warehousing, and damage control to ensure successful consolidtion.

1A.9 Miscellaneous Materials and Services

Miscellaneous materials and services not otherwise specifically called for shall be furnished by the Contractor in accordance with the following:

All temporary nuts, bolts, gaskets, special fasteners, shipping materials, protective materials, etc., required to furnish the services specified herein.

XYZ three-way impact recorders are to be provided and mounted on the auxiliary and generator transformers.

1A.10 Work Not Included Under These Specifications

The following items of work will be furnished by the Engineer:

Receiving, storing, and field erection of all equipment

Any shipments originating outside the United States

1A.11 Services to be Provided

It is the intent of this Agreement that the Forwarder provide complete freight forwarding services including consolidation considerations as a lump sum price as detailed in Article A.8 for the entire scope of materials defined in Section A2.

1A.12 Project Schedule

Appendix A1, Project Summary Schedule, attached hereto is based on Owner's Notice to Proceed occurring (to be defined). The schedule is provided solely for Forwarder's general information as the information given herein is subject to change; no warranty, expressed or implied, is given by the Engineer as to the relationship of the information given to actual events. Current project CPM schedules will be provided as available.

1A.13 Estimated Shipping Requirements

Appendix A2 to Attachment A, Estimated Shipping Volumes and Weights, attached hereto, is provided for the Forwarder's general information is assessing the magnitude of shipments anticipated. A portion or all of the goods listed will be shipped by the Supplier FOB Project site or FOB Port of Export as indicated in Appendix A1 to Attachment A. The information given is an estimate only; there is no warranty given, expressed or implied, as to its accuracy or relevancy to actual shipments. Upon Contractor's Notice to Proceed, Forwarder is allowed accessibility to Engineer's facilities to examine current drawings for appropriate weights and measurements.

1A.14 Transit Insurance

Insurance covering physical loss or damage to the goods will be provided by the Owner. If loss or damage occurs to the goods following FOB receipt at Supplier's facility and prior to receipt at the Project site, the Forwarder shall assist the Engineer in determining the extent of loss and preparing claims to the insurer.

1A.15 Forwarder's Facilities

As part of Forwarder's proposal, a complete listing of, and information on, Forwarder's local or correspondent firm's offices and consolidation facilities at locations within the United States and at the Country of Entry shall be provided.

Forwarder shall also provide as part of the proposal, designation of, and information on, those transportation firms intended to be utilized if awarded this Agreement. Utilization of other transportation firms during the course of this Agreement shall be made only with concurrence of the Engineer.

1A.16 Forwarder Shipping Preparation Requirements

1A.16.1 Preparation for Shipment

The Contractor shall prepare and package all goods, equipment, and materials, except as specifically noted in Section A2, for moist tropical ocean shipment in such a manner as to protect them from damage in transit, and also from damage without other means of protections, either during storage at the site or while en route to the site. Spare parts shall be packed for prolonged storage under tropical conditions. Where necessary, heavy parts shall be mounted on skids so that cable slings for handling can be readily attached. Where it is unsafe to aply external slings to a package, attached slings shall be provided so that attachment can readily be made.

All equipment and materials shall be suitably coated, wrapped, or covered and boxed or crated for export shipment and to prevent damage during handling and storage at the site. All electrical equipment including panels shall be completely covered with high quality waterproof material. All pilferable items shall require adequate packaging to prevent loss.

All accessory items shall be shipped with the equipment. Boxes and crates containing accessory items shall be marked so that they are identified with the main equipment. The contents of each box and crate shall be identified with markings on the exterior.

1A.16.2 Packing and Marking Instructions

Each individual package of each shipment shall be plainly tagged or marked for identification, as follows:

CONSIGNED TO:
PROJECT:
LOCATION:
SUPPLIER:
PLANT EQUIPMENT:
CONTRACT NO.:
CASE NO.:
GROSS WEIGHT, KG:
NET WEIGHT, KG:
DIMENSION, CMS:

All boxes, crates, cases, bundles, loose pieces, etc., shall be marked consecutively from No. 1 upward throughout all shipments from a given port to completion of the order without repeating the same number.

The following additional instructions shall be observed:

For supply of steel structures, the Contractor must indicate each member of steel structures in a manner that will allow correct sequence of storage and retrieval for ease and cost effectiveness with erection requirements.

The Contractor shall prepare the bill of materials or supply list or materials list to the Engineer.

Shipment of each category of spare parts shall be packed in separate cases.

The Contractor must indicate specification section number of each main equipment in the packing lists and mark on the package.

The attached label on each item or group of identical items in a package shall indicate the specificationm section number and item description.

Umbrella marks shall be put on every package containing nonweatherproof equipment.

Each box containing spare parts, special tools, or rental tools shall be marked with a large painted legend as follows:

CONSIGNED TO:
PROJECT:
SUPPLIER:
SPARE PARTS FOR: (Name of Equipment)
DO NOT OPEN EXCEPT WITH ENGINEER'S PERMISSION

Each packing list shall indicate whether shipment is partial or complete, and shall incorporate the following information on each container, etc., according to its individual shipping number:

Export case markings.
Case number.
Gross weight and net weight in kilograms.
Dimensions in centimeters.
Complete description of materials with identification of all parts to the respective drawings, catalogs, and instruction manuals. The identification of the part shall be contained on an identification tag fastened to the respective part.
Specification file number.
Item numbers used for the packing list should correlate to item numbers used for bill of materials or supply list or material list.

One copy of packing list shall be enclosed inside each case and one other copy securely fastened to the outside of the case in a weatherproof tin or lightweight sheet metal envelope or pocket.

The Engineer retains the right to check and inspect the following:

The adequacy of the packing for the required shipment to the site.
Conformity with the marking requirements.
Checking and comparison of packing lists in conformity with specifications and contents of boxes.
Detailed specifications of packing methods to be used for various shipments, submitted not later than 2 months prior to first shipment.

1A.16.3 Shipping Documentation

The Contractor shall supply shipping documentation strictly in accordance with the following:

Packing list which must indicate whether shipment is partial or complete and which shall incorporate the following information on each container, etc., according to its individual shipping number:

Export case markings.
Case number.

Gross weight and net weight in kilograms (not to include the weight of any ocean container and/or considered packaging.
Dimensions in centimeters.
Item numbers used for the packing list should correlate to item numbers used for bill of materials or supply list or material list.

Invoice which must indicate, in addition to other regular statements, the following delaration:

Country from which goods were purchased and consigning country as well as country of origin.
Markings and numbers as well as gross weight.
Details of goods, spare parts, i.e., names, model, types, case number, qualities, quantities, size, diameter, serial number, part number, power rating, net weight weights, and other particulars as available for each type including trademarks or symbols of such goods. If there are no trademarks or other symbols, the invoice shall indicate "no trademarks" or "no symbols" as the case may be.
Selling price or value of goods per unit expressed in U.S. Dollars.
In case shipment of a complete unit of main equipment is made in a nonassembled form, the invoice should show such equipment as one complete set or one complete unit, rather than show its components and accessories item by item.
Catalog reference number (if necessary). This requirement is for small shipment and also for shipment of the repair or replacement.
The material used.
The physical dimension of spare parts.
Other expenses:
Packing charges (if any)
Insurance premiums (if insured)
Freight
Others (if any)

Shipping documentation must be as required by the following:

Banking requirements
Customs in the Country of Entry
Agencies who will inspect shipments for the Country of Entry at the Contractor's point of shipment or at the port of origin

GC.15 Delayed Shipment

The Engineer reserves the right to order the delay of equipment and materials herein contracted. In the event such a delay is ordered by the Engineer in writing, the Engineer has the obligation to pay reasonable and proper charges incurred as a result of the delay. Such extra charges shall include storage charges, handling charges, insurance, interest on investment, and transportation charges to the storage facility.

GC.31 Engineer's Responsibility

The following specific items are listed in addition to implied Engineer cooperation:

Copy of all CPM Schedules and updates

Customs clearance

Site delivery

All transportation insurance, excluding value of shipments in excess of $30MM for any one voyage

45-day prior access to all shipments

Harbor maintenance fees on FOB U.S. Port values paid in excess of $100MM.

Demurrage charges of $12/day per container for use over 45 days after arrival on site.

GC.32 Forwarder's Responsibility

In addition to the responsibilities provided herein, additional classifications and responsibilities are listed below:

45-day free demurrage at site.

10-day free demurrage at factory.

Provide all necessary site inspections at Supplier's facilities.

On-line 24-hour tracking capabilities.

Coordinate and deliver to Engineer all documents required for submittal to Banking institutions.

Initiate all appropriate waivers on Enginer's behalf.

If ocean vessel custom clearance is required at Port of Entry, Forwarder is responsible for any charges.

Issue through Bills of Lading from FOB factory to site.

Customs agent at site to assist in document presentation and clearance.

Premiums for insurances not covered by the Owner.

24

Avoiding Claims

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Timothy C. McManus Project Management Associates, Inc., Boston, Massachusetts

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John R. Knoke Project Management Associates, Inc., Portland, Oregon

I. INTRODUCTION

It is not uncommon for projects with highly technical design or construction such as hazardous waste remediation, environmental control, airports and other infrastructure, or major plant renovations built by large contractors to experience significant disputes or claims. If these projects experience typical numbers of disagreements, roughly 15–25% of the contract value, then literally billions of dollars of annual construction investment are *at risk* due to claims and disputes. This does not even reflect the millions of additional dollars worth of human capital expended by architects, engineers, contractors, sureties and owners in preparing their positions in these disputes and claims. Clearly, there is a strong incentive to avoid claims and disputes in construction projects.

This chapter examines common issues that can evolve into claims and disputes, and discusses innovative ways for owners, architects, engineers, and contractors to avoid or reduce the associated costs. Part One presents recent theory and concepts to explain the origins and factors underlying changes, claims, and disputes. Part Two applies the theories developed in Part One to outline specific activities which can be used to avoid or mitigate the potential impact of changes, claims, and disputes on major construction projects.

PART ONE: CHANGES, CLAIMS, AND DISPUTES THEORY

II. WHY CHANGES, CLAIMS, AND DISPUTES EXIST

Before presenting means for avoiding changes, claims, and disputes, it is prudent to define these terms and to try to understand why they exist. In the contract management arena, the term changes generally refers to the modification of the contract to (1) add, delete, or revise the scope of work, (2) accelerate the work, and (3) correspondingly adjust the contract price and contract time. The term claims generally refers to the first level of disagreement concerning contract interpretations, a determination rendered by the owner's representative and the pricing of changes or delays. The term disputes generally refers to the "formalization" of a claim. Having said this, the terms claims and disputes are often used interchangeably, and we will do so in this chapter.

Contractor claims usually represent a situation where the contractor has given written notice that a condition exists that requires a change in the work and/or an adjustment in the contract time and/or contract price and the owner has failed to recognize or agree to an adjustment by initiating a corresponding change order or modification. Claims can also be initiated by the owner in response to a perceived failure on the part of the contractor to perform the work as specified in the contract. Construction contract literature identifies several types of common changes, disputes, and claims.

Clough (1960, 1969, 1979) lists eight different types of changes: additions to or deletions from the contract; modifications to the work; changes in the methods or manner of work performance; changes in owner-provided materials or facilities; changes in contract time requirements; corrections in the drawings and specifications; change in owner requirements; and changed conditions (also known as *differing site conditions*).

Civitello (1985) cites ten reasons for change orders: design errors; changes in market conditions; change in owner's requirements; uncovering of undisclosed existing conditions; uncovering of unknown existing (latent) conditions; suggestions to initiate better, faster or more economical construction; change in designer preference; discrepancies in contract documents that describe situations contradicting the intent of the project; change in external requirements; and final coordination with not-in-contract (NIC) equipment.

Driscoll (1971) cites eight types of contractor claims: scope changes; constructive change orders; errors and omissions; accelerating and expediting; suspension of work and work stoppage; access or availability of site; interferences, disruptions, and delays by other contractors (at the site); and delays

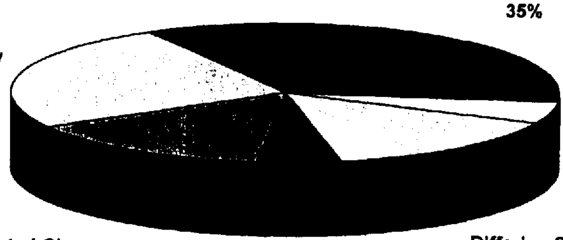

Figure 1 Profile of claims on public projects: percentage of claimed sums.

caused by strikes and acts of God. Driscoll also identifies five owner-based claims: failure of contractor to complete on time; liquidated damages and penalties; materials not to specification; defective work and damages; and property damages.

Clough (1979) further asserts that claims and disputes arise from a variety of origins: interpretation of the contract; what constitutes extra work relative to the contract, payment for changes, extensions of time; damages for owner-directed acceleration, costs occasioned by owner caused delay, defective drawings or specifications, changed conditions, etc.

In most construction projects, any of the various kinds of changes, claims, and disputes listed above can occur. The most common, however, appear to be related to design errors (errors, omissions, and discrepancies) and differing site conditions, coupled with delay (late completion and impact). In reviewing trends on recent public projects, Ponce de Leon (1990) observed that the distribution of causes for major claims is generally as shown in Figure 1. This pie chart shows that schedule extensions and productivity impact claims contribute to more than 50% of the volume of major claims.

III. CHANGES, CLAIMS, AND DISPUTES (CCD) MODEL

The lists of various causes enumerated above seem to indicate that claims, changes, and disputes are derived from a complex and sometimes confusing contract environment. However, with some global or macro-oriented thinking, a simple model can be used to understand why claims, changes, and disputes exist. This model, shown in Figure 2, is called the Changes, Claims, and Disputes (CCD) Model.

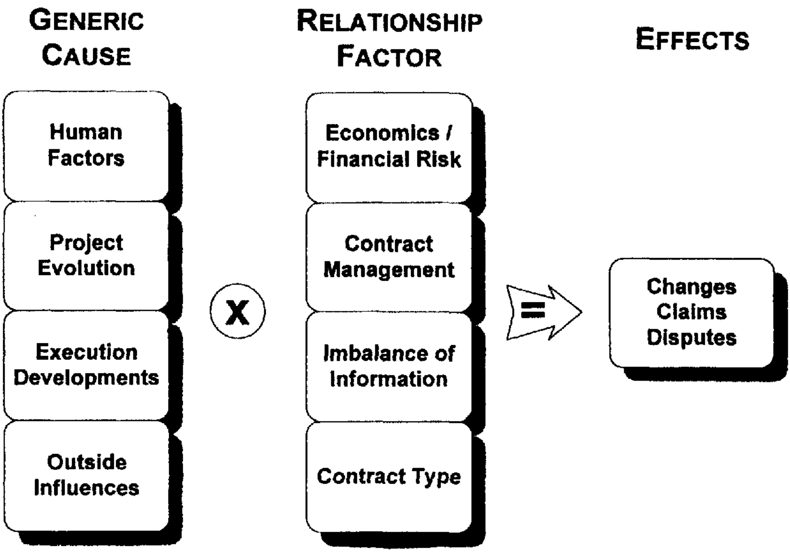

Figure 2 Changes, claims, and disputes model.

This simple, conceptual model represents claims, changes, and disputes as a result or *effect* of a multi-dimensional process. This process can be further subdivided into *generic causes* and *relationship factors*. Generic causes, just as the term infers, classify, in a general sense, the main causes for changes, claims, and disputes that might occur on any construction project. The relationship factors are circumstances in the project management process that can either mitigate or accentuate the severity of a change, claim, or dispute.

In Figure 2, generic causes and relationship factors are shown as elements of a theoretical equation resulting in changes, claims, and disputes. A discussion of the nature and potential impact each of the generic causes and relationship factors follows.

A. Generic Causes

The model states that there are four separate generic causes: (1) human factors, (2) project evolution, (3) execution developments, and (4) outside influences.

Human Factors

Although projects tend to use the latest technologies in design, construction, and controls, the daily decisions and communications still depend on people.

Following the adage, "To err is human," many of the occurrences of changes, claims, and disputes can be explained by the human factors influencing a project. Types of changes related to human factors include:

Design errors and ambiguities, including contradictions, discrepancies, inconsistencies, and flaws in design documents
Discrepancies in the contract documents that describe situations contradicting the intent of the project

The most obvious remedy for this generic cause is to utilize an aggressive, more timely, quality control program to weed out more of the errors, ambiguities, etc. As discussed later in this chapter, this is the essence of and the objective for claims avoidance reviews of design, bid, and contract documents.

Project Evolution

Construction projects, by their very nature, are dynamic: new technologies continuously evolve. The owner wants the best facilities for the funds available. Market conditions play havoc with availability of specified equipment. The second generic cause, called *project evolution,* explains the following changes, claims, and disputes:

Changes in owner's requirements can result in the addition or deletion of scope.
New technologies or market conditions can result in changes to intended facilities: specified materials may be unavailable, new and better alternatives may be found for specified materials, or new products may become available.

The best remedy for this generic cause are anticipation and quick response. Specifically, solicit user/operator involvement early in the review process and react to dynamic developments as soon as reasonably possible as the project unfolds. For example, a request to add a second train of clarifiers in a water treatment facility has its minimum effect at the early stages of design rather than at the bidding or construction phase of the project.

Execution Developments

Some changes, claims, and disputes arise from events or decisions experienced during execution of a project rather than from specific differences in the specified facilities caused by human error, extended scope, or technological developments. Examples of changes, claims, and disputes resulting from execution developments include:

All types of differing site conditions (also known as changed conditions) whether these conditions were known or unknown at time of contract award
More economical means, methods, techniques, or sequences of construction

Problems inherent in *fast tracking* or overlapping related design and construction activities

There are selective cures which can eliminate claims resulting from execution developments. For example, additional investigations (such as soil borings, material testing, etc.) can be used to resolve uncertainties regarding existing site conditions. More frequent quality reviews may be necessary for projects that are on a fast track. Constructability reviews in association with or with the cooperation of the contractor at the early stages of the contract can identify more economical construction techniques before they can evolve into an issue.

Outside Influences

The previous three generic causes discuss interactions between the three classic participants in the project (i.e., owner, designer, and contractor). The fourth generic cause, outside influences, captures events or decisions by outside parties which affect the project. Examples of claims, changes, and disputes resulting from outside influences include:

Effects of legal or statutory changes on the project (revisions to applicable codes, new clean air/water acts)
Instances of *force majure*: acts of God, floods, abnormal weather, wars, strikes, etc.
Delays to materials and equipment not procured by the contractor

As suggested earlier for the evolutionary nature of the project, the best cures for outside influences are anticipation and early response. Frequent expediting and visits to vendor shops by owner and/or design personnel often prevent unexpected slippage in delivery dates for materials and equipment. If new legislation is anticipated, contingent pricing may be used to allow for its effects.

B. Relationship Factors

In comparing similar contracts, why is it that similar changes can have markedly different effects? Why do some events or changes to a project escalate into a dispute or a claim while others do not? To help explain these questions, the CCD Model asserts that there are *relationship factors* that positively or negatively influence the impact caused by an event resulting from one or more of the generic causes. Currently, the model identifies four relationship factors: economics or financial risk, contract management, imbalance of information, and contract type. Each factor is discussed in further detail below.

Economics or Financial Risk

When changes, claims, and disputes appear, inevitably the potential for loss or gain to at least one party becomes predominant. The *economics* or *financial risk* relationship factor recognizes the cost and schedule implications of changes, claims, and disputes. This factor considers economic and financial status from a number of viewpoints:

Participant financial position: Among the owner, designer, and contractor, who is most financially strong or weak? Clearly, for example, a \$100,000 disputed change places less at stake for a \$100 million-a-year contractor than for a \$10 million contractor.

Project financial position: What is the status of the project from each participant's view? Who is operating in a loss position versus a gain position? Who "left money on the table" at contract award and how much was left in relation to pending or anticipated changes, claims, or disputes?

Geographic macro-economic position: Is the project being executed in a recessionary time or a period of growth? What are the outlooks for future project relationships between various the participants? Is there more to lose (or gain) than just the value of the claim?

Cost magnitude: How does the value of the change, claim, or dispute relate to the value of the contract or the value of current control budgets?

Schedule implications: What is the financial risk or reward to each of the participants in completing the contract on time?

The underlying premise for the economics or financial risk factor is that the larger the potential for financial loss or risk, the higher the probability that the weaker party will try to aggressively resolve the contract issue (such as a change, claim, or dispute) in their own favor.

Contract Management

The second relationship factor, *contract management*, acknowledges the quality of the inter-relationships and interactions among the parties to the contract during the life of the contract. Key considerations include:

Significance of adversarial versus teamwork approach in day-to-day activities
Ability of all parties to communicate and to "seek first to understand"
Strength of the contract language and understanding of the contract by each of the parties
Quality of planning and scheduling
Perception of fair and equitable treatment of previous contract issues
Quality of change/claim administration

The underlying premise of the contract management factor is that the better all parties work together the higher the probability that a contract issue (such as a change, claim, or dispute) will be resolved equitably, quickly and efficiently.

Imbalance of Information

The third relationship factor, *the imbalance of information*, recognizes that information is crucial in making decisions. With an imbalance of information, it may be difficult to make equitable and fair decisions. In a claims or changes situation, the types of information which should be in balance would include: change order pricing or actual cost data, schedule analysis of delay impacts, facts demonstrating entitlement of the change, interpretation of contract language, etc. Often one party has more information regarding the issue than the other (or at least believes so). When this imbalance occurs, whether real or perceived, it can pose a significant obstacle in effective resolution of the change or claim.

From a conceptual standpoint, the underlying premise of the imbalance of information factor is that the closer the parties in the contract have to balanced information, preferably by cooperation or sharing, the higher the probability that a contract issue will be resolved equitably, quickly and efficiently.

Contract Type

The fourth relationship factor relates the *contract type* (reimbursable cost, unit price, or lump sum) to the likelihood of claims and disputes. Each contract type carries a different level of risk. Hence, it is understandable that reimbursable cost contracts will typically generate the least claims, unit price contracts will yield claims when actual quantities significantly deviate from the bidding basis, and lump sum contracts can generate a substantial number of contract issues, claims, and disputes.

The contract type relationship factor does not advocate the exclusive use of reimbursable cost contracts, but rather recognizes that, given the same contract issue (for example, a differing site condition due to unexpected boulders in an area to be excavated), the likelihood of amicable resolution of that issue will be greater in a project where a reimbursable cost contract is in place rather than a unit price or lump sum contract.

IV. USING THE CCD MODEL TO IDENTIFY CLAIMS AVOIDANCE ACTIVITIES

The Changes, Claims, and Dispute (CCD) Model maintains that a claim, change, or dispute is the result of one or more of the generic causes and its severity is influenced by the interaction of one or more of the relationship factors. In terms of effort versus benefit for the application of a formal claims and changes avoidance program, priorities follow the CCD Model: (1) to eliminate or reduce the amount of changes, attack the generic causes of changes; (2) to mitigate changes or claims, influence the positive aspects of the relationship factors; and (3) to understand that, given the ground rules for a given project, some elements of the CCD Model cannot be influenced.

A. Attacking the Generic Causes

Of the four generic causes, the human factor nature of the project can be the most influenced by an innovative claims avoidance program. Through specific quality assurance activities, avoidable human errors can be minimized or eliminated. Reviews for constructability, biddability, claims avoidance, claims exposure, and design effectiveness accomplish the same objective: to improve the quality and clarity of the design and contract documents for construction by flushing out ambiguities, errors and omissions, and unclear or interpretative requirements. This is where the highest return on effort invested to avoid claims can be achieved.

Changes arising from the other three generic causes are more difficult to eliminate. To address these causes emphasis should be placed on recognition, anticipation, and early implementation (which are attributes of good contract management—a relationship factor in this model). In some projects, effects resulting from the evolution of the project can be minimized by strong project control leadership by owner personnel or their agents.

B. Influencing the Relationship Factors

In contrast to attacking the generic causes, each relationship factor can be positively influenced to help mitigate the impacts of changes, claims, and disputes:

In understanding the effects of economic or financial risk, owner or engineer estimates can identify areas of financial risk in contractor bids. Prequalification of bidders based on financial capacity and similar completed contracts is practiced by many owners. Reviews of financial status during the prequalification of prospective bidders can eliminate possible insolvent bidders.

The contract management factor can be improved through team building programs such as "partnering"; balanced contract language that reflects reasonable consensus among the stakeholders; and recognition, anticipation, and early response to situations that lead to claims and disputes.

The imbalance of information relationship factor can be improved by good organization and sharing of project documents by all parties, regular analysis of payment requests and schedule submittals, and maintenance of appropriate daily records and logs. This generally requires that the contract documents establish the expectations for the production of such information by the contractor, as there will be a cost associated with this effort.

Early recognition of possible changes, contingent prices, or requests for bid prices for alternative designs can be used to improve the contract type intensity factor.

PART TWO: SPECIFIC METHODS TO AVOID OR MITIGATE CHANGES, CLAIMS, AND DISPUTES

As presented in the introduction, Part Two is based on the CCD Model developed in Part One and outlines specific activities, procedures, or reviews which can be used during the design and construction process to avoid or mitigate common causes of changes, claims, and disputes. Figure 3 illustrates the processes of *eliminating causes* of and *reducing intensity* first described in Part One as they relate to an overall claims avoidance plan.

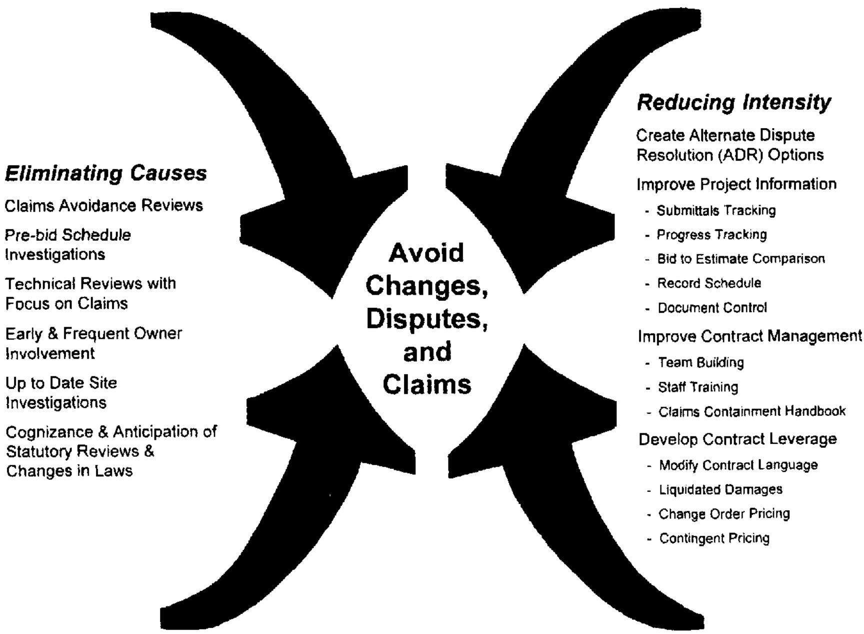

Figure 3 Outline of a claims and disputes avoidance plan.

V. CLAIMS AVOIDANCE REVIEWS

Claims avoidance reviews are systematic reviews of design and contract documents focused to identify areas susceptible to changes, claims, and disputes. These reviews form an integral component of a total quality management (TQM) program designed to eliminate human errors in these documents. Claims avoidance reviews should critique *constructability* and *biddability* and may also examine the selection of optimal designs, equipment, and construction methods and phasing.

For typical medium to large construction projects, there should be *at least* three separate claims avoidance reviews:

Review of design documents
Review of bidding documents
Post-award review in cooperation with the contractor awarded the contract

Figure 4 illustrates the timing of these reviews with respect to a schedule for a typical construction project. Optimally the claim avoidance reviews for

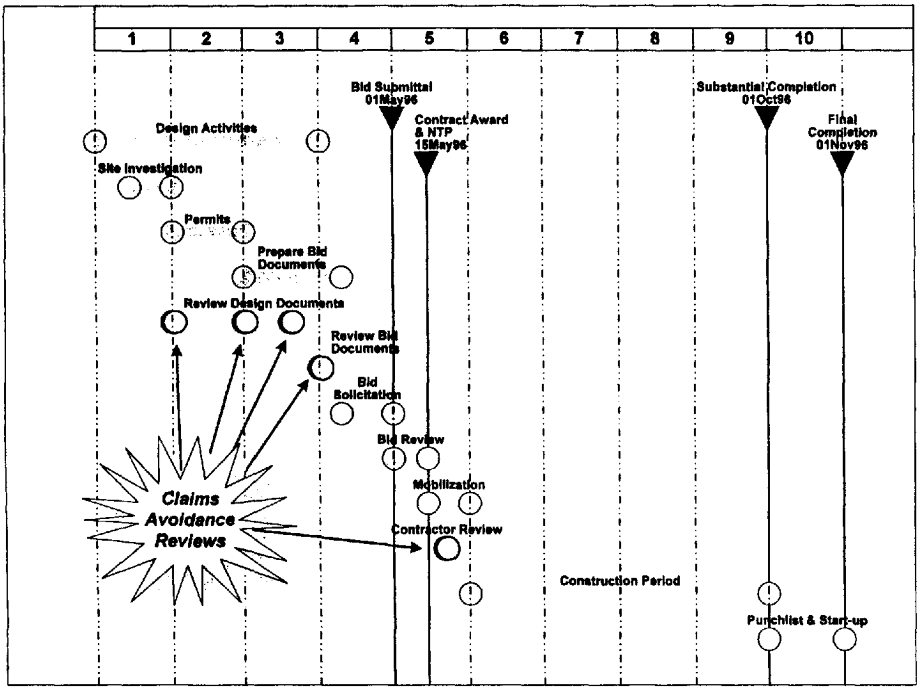

Figure 4 Typical integrated design and construction schedule showing timing of claims and dispute reviews.

design and bidding documents should be performed when sufficient information has been generated to perform an effective review, but early enough to allow time to revisit designs and bid documents without causing a delay to the overall project schedule. Ideally, claims avoidance reviews of design documents should occur near the 50% and again near the 90% design milestones. The reviews of bid documents should occur immediately after the completion of design documents and/or several weeks before solicitation of bids. The objective of performing reviews at each of these milestones is to allow a reasonable amount of time to incorporate the results before the corresponding documents are required for their intended purpose. The post-award review with the successful bidder (i.e., the contractor awarded the contract) should occur as soon as possible after contract award, preferably within ninety days after award. This timing takes advantage of the so-called "honeymoon period" that usually occurs just after contract award and before substantial work is performed at the project site.

A. Avoidance Review of Design Documents

Claim avoidance reviews of design documents examine content as well as the implied instructions given to the contractor. Some examples of review emphasis are discussed below:

Investigate the availability of specified equipment or key materials as well as an outlook for obsolescence. For instance, in process and treatment plant facilities, identify pumps and drivers associated with unique capacity and flow requirements, components of exotic materials, proprietary designs, and unique design features. With machinery specialists on the design team, ascertain the number of vendors who can realistically meet these requirements. Determine the necessary delivery/lead times, and verify that they will support the anticipated schedule.

Audit plans, specifications, and design bases with respect to recent track record for requests for interpretation, claims, changes, and disputes. Generally, evaluating the corresponding files of the design professional on one or two recently completed projects can be worthwhile. The objective of this review is to avoid repeating past mistakes.

Assess the possibility that a competent contractor can meet the specified performance requirements, sequences of work, etc. For example, investigate the ability of local contractors to meet the compaction requirements for hazardous waste landfill liner materials (from a material as well as construction equipment availability). Also, tie-ins of new to existing water treatment facilities often require coordination with low flow operations; inquire as to how is this addressed in the design.

Review the relevance of site investigations data to issues of constructability. Consider whether this data has become obsolete due to time delays or disturbances caused by other projects at the site. For instance, relate the location and frequency of soil borings to the location of new facilities or underground work (such as tunnels, culverts, conduits, etc.). Also, for work in existing buildings, inquire whether tests for ACBMs (asbestos-containing building materials) have been performed and what procedures are in place for removing ACBMs.

Compare cross references in plans, specifications, and between plans and specifications to identify potential errors, conflicts or inconsistencies. Spot check or trace references to code requirements to determine whether the references are current.

Perform selected dimensional accessibility checks; for example, verify that overall dimensions are consistent with the sum of included dimensions, that stair riser dimensions and tread count are consistent with corresponding differences in elevation, or that remote valve operators are easily accessible.

B. Avoidance Review of Bid Documents

Claim avoidance reviews of bid documents primarily examine and critique the contract language and special instructions of the bid documents. In the situation where a claims avoidance review of the design documents has not occurred, this review could also cover the design documents (using the above guidelines for Review of Design Documents). Some areas of review emphasis include:

Include appropriate disclaimers regarding subsurface conditions indicated by soils reports to avoid unreasonable reliance on those reports by bidders. Examples of generally acceptable disclaimer provisions can be found in the EJCDC and FORMSPEC™ model specifications.

Consider provisions stipulating that available float in the contract schedule must be consumed before a claim for a time extension can be considered.

Review the contract language regarding variations in estimated quantities. For example, investigate how the contract would address an additional 3 ft of depth in excavation.

Include a dispute clause which requires formal submittal of a claim to a claims review board as a prerequisite to filing a lawsuit. Also, venue should be restricted to local courts.

Review material or equipment substitution provisions, and disallow "or equal" and substitutions for selected specifications, as the design professional may recommend. Equipment substitutions that do not improve the life cycle cost of named or specified equipment should be disallowed. Additionally, ensure that acceptable substitutions consider all secondary effects, such as delays, and specify under what conditions the owner will share any resulting savings with the contractor.

Incorporate bid dispute provisions aimed at clarifying procedures related to bid withdrawal, objections to award of a contract, and conditions which may warrant disqualification of a bidder.

Review the clarity of language used to determine the order of precedence in the contract documents when there are conflicts or inconsistencies.

Evaluate the need for a CPM-based progress schedule specification.

Review provisions to address defective work, particularly where a variance is acceptable but the language is not clear about recovery for the delay.

For projects involving the handling, storage, or removal of hazardous, toxic, or asbestos containing materials, add language covering prequalification and/or formal certification of the contractor or subcontractors with appropriate governmental agencies as a requirement of the bid.

C. Post-Award Review with Contractor Awarded the Contract

A substantial number of potential claims can be avoided through quality control and constructability reviews of the contract documents during the *contract start-up* phase by key owner, designer, and contractor personnel (including cognizant subcontractors and suppliers). During these reviews, the majority of significant errors, omissions, ambiguities or inconsistencies in the plans and specifications should become apparent. Reviews should culminate with lists of (1) issues requiring interpretation or clarification by the owner and designer, (2) specific recommendations for changes needed to overcome problems discovered, and (3) possible "value engineered" changes that might be desirable depending on the impact on contract price and contract time.

To execute these reviews effectively and to avoid an inordinate load on staff, the reviews can be approached with a trade or discipline orientation. Coordination meetings to share information can be planned in a sequential basis starting with site preparation and earthwork and continuing through concrete, tunneling, steel work and superstructures, piping and mechanical, and so on.

D. Recommended Staffing for Claims Avoidance Reviews

Each claim avoidance review should be represented by: (1) technical personnel who are knowledgeable in the type of work described by the contract, and (2) a project/contract management specialist who understands contract administration and the potential effects of changes, claims, and disputes. In addition, where practical, it is useful to have key owner's staff available to facilitate understanding of project coordination issues with the owner. The optimal number of individuals involved in a claim avoidance review is dependent on the size of the project, complexity of the technology used in the project, and the amount of time available to perform the review. Ideally, the reviews can be completed in two or three days, spanning consecutive weeks.

E. Considerations for "Aged" or "Rushed" Projects

Aged projects are those for which, for one reason or another, the normal progression of project development (e.g. as shown in Figure 4), has been interrupted or postponed. A common example of an aged project occurs when design and bid documents become dormant as the project awaits governmental approval or funding. In contrast to aged projects, *rushed* projects are those for which the progression of project development is accelerated. Examples of rushed projects include those which are on a "fast track," i.e., there is an overlap in design and construction activities.

Aged or rushed projects expose a higher susceptibility for changes, claims, and disputes. The following additional review activities can be used to avoid some of the problems inherent with these types of projects:

Investigate how the current location and scope of facilities relate to assumptions used in the original design. If project facilities have been relocated, check the relevance of soil borings or other site investigations against the new location. Also, visit the site to ascertain whether any refuse, spoils, or other unexpected materials, particularly hazardous wastes, may exist at the new site.

For aged projects, check the validity of as-built conditions to avoid changes caused by the deterioration of existing facilities, improvements, or construction of new facilities adjacent to the project site. Also, check commercial and regulatory sections of contract documents to identify obsolete insertions and replace with the latest updates.

In rushed designs where upgrading of equipment items occurs, verify that recommended sequences of construction, specified temporary scope of work, and existing facility connections are still relevant or have been modified according to the needs of the new design.

VI. TECHNICAL REVIEWS WITH A CLAIMS EXPOSURE FOCUS

To complement separate claims avoidance reviews and convey a "claims avoidance attitude," normal technical reviews of design and contract documents should also contain a claim exposure focus. Many changes and claims can be eliminated by making the correct decisions and obtaining the owner's preferences at the early stages of the project. Some suggestions for developing a claim exposure focus in technical reviews include:

Play "devil's advocate" and challenge the pros and cons of design decisions from a constructability perspective. This technique is most often successful when executed by design and construction professionals who have not been intimately involved in the daily decision making process.

Schedule meetings with owner representatives at key milestones in the design process. Encourage operations and maintenance personnel, as well as project executives, to review the status of the design. Discuss the owner's plan for handover of the facilities. Many owner preference change orders can be eliminated by effective and timely design reviews.

Compile a "Handbook of Avoidable Changes" from recent relevant projects and compare the proposed design against the handbook. This handbook can be developed by codifying repetitive changes into a manual which encourages the designer to avoid repeating the same mistakes, and to affect the design so that neither a request for interpretation nor a change is required.

VII. PRE-BID SCHEDULE INVESTIGATIONS

Another frequent review process that looks at the constructability issues of the project is a Prebid Schedule Investigation. This review examines the design or bid documents and determines: (1) a recommended overall contract duration and level of liquidated damages, (2) milestones for contract award dates and other significant project events, (3) recommended or required sequence of work restraints, (4) durations for owner and designer activities to be performed during construction, and (5) requirements for a CPM-based scheduling specification that will correlate the general conditions and requirements of the contract.

In addition to these five general goals of a prebid schedule investigation, there are number of other specific areas that should be reviewed during this investigation:

Review the site conditions from a construction logistics standpoint. For example, for an expansion of an existing wastewater treatment plant, consider accessibility of the site by construction and delivery vehicles, determine the largest loads that can safely be brought in and out of the site, look at the availability of laydown areas and temporary parking, and inquire about restrictions in traffic flow affecting the construction site as well as the local community.

Consider the effect of weather conditions on the project. For example, must the structure be watertight before certain work activities can continue within the building enclosure? What are the expected regional variations for seasonal disruptions such as hurricanes or harsh winter weather which might result in restrictions to concrete, masonry, roofing, planting, or painting activities?

Review the definitions of substantial completion and final completion for the project. Investigate whether there is a requirement for a "phased" or "staged" release of portions of the project to the owner. Identify activities that can occur between the contract milestones of substantial and final completion (such as punch list inspections, landscaping, final instrumentation checks, etc.).

Review the responsibilities for maintenance of facilities turned over prior to final completion in the event that a phased or staged handover is required.

Identify and review the interactions between contracts for projects that will use multiple prime contractors. Inquire about specific interface coordination between the contracts. Verify that the schedule properly recognizes the significance of these interfaces. For example, if one contractor will be constructing an outfall for a water treatment plant while another will be building the expanded facilities, examine the coordination and scheduling requirements for the outfall connection. Similarly, if a mechanical contractor is placing floor penetrations and an electrical contractor is placing conduit within a concrete pour, investigate the scheduling and coordination of these activities.

The previous activities in a claims avoidance plan identified ways to eliminate causes of changes, claims, and disputes. The next section will discuss activities that can reduce the severity of changes, claims, and disputes on a project. There are four major themes: (1) creating Alternate Dispute Resolution (ADR) options, (2) improving project information processes, (3) improving the contract management processes, and (4) developing contract leverage.

VIII. ALTERNATE DISPUTE RESOLUTION (ADR) OPTIONS

Many owners, designers, and contractors agree that litigation is a costly process that raises havoc with normal operations and deteriorates business relationships. *Alternate dispute resolution* has emerged as a popular option to resolve contract issues on construction projects. ADR can be chosen at the time of the dispute or mandated as part of the contract. Muller (1990) lists nine different types of ADR method or techniques: negotiation, mini-trial, contract dispute review boards, "rent-a-judge," mediation, court-appointed masters, expert resolution, binding arbitration variations, and nonbinding arbitration variations. Ponce de Leon discusses the merits and various aspects and applications of dispute review boards as they relate to mitigating the impacts of claims on large infrastructure projects (1994).

Each type of ADR has its own merits. There is likely to be an option that will best suit the parties in the dispute. In considering an option to be exercised as part of a claims avoidance plan, the following criteria should be considered: possibility that an unfamiliar contractor may not be interested in repeat business, precedent from case law in the locality; availability of staff, experts, or arbiters for mediation teams or dispute boards; recent ADR experiences; and protection of expert work products from discovery and freedom of information requests (should ADR fail and litigation follow).

IX. IMPROVING PROJECT INFORMATION

The CCD Model contends that information is a key factor in mitigating changes, claims, and disputes. There are two main types of information targeted for improvement: (1) basic project information and (2) change, claim, or dispute entitlement documents.

A. BASIC PROJECT INFORMATION

Basic project information includes standard project statistical data, cost and schedule records, and documentation tracking systems typically produced in the day-to-day execution of a construction contract. The following issues may be addressed to mitigate the potential impact of changes, claims, or disputes.

Bid to Estimate Comparisons

Prior to bidding, it is useful to have the owner or designer compile an estimate to compare with the contractors' bids. A suggested level of detail for each component or facility includes: bulk quantities, direct man-hours, labor costs, and material costs. When developing the portion of the estimate addressing indirect costs, consider job site office operations and labor costs, construction equipment charges, and contractor's gross margin, and allowances to cover home office overhead and profit.

As part of qualification submittals required of the apparent low bidder, include the submittal of a bid tabulation that corresponds to the estimate discussed above. In lump sum contracts, specify that the apparent low bidder provide this breakdown as a prerequisite to the owner's evaluation of whether the bidder is qualified and responsible.

A comparison of the bid to estimate will provide cost information to assist in recognition of areas of strength and weakness in the apparent low bid. This comparison may also reveal weaknesses in the bid documents, if it is clear that the bidders consistently misunderstood portions of the plans, specifications, or commercial requirements. This knowledge can also be useful in understanding the selected contractor's financial position and posture with respect to the project.

Submittals Tracking

Develop a list of all shop drawings, samples, schedules, construction documentation, and other contractor submittals to be reviewed and approved during the construction of the project. Implement a submittal tracking system that will control the flow of documents between the contractor to the reviewing party. This system will enable planning of reviews, avoid potential delays, and provide a contemporaneous record of submittal events that can be used in avoiding or contesting claims and disputes.

Progress Schedule Tracking

Schedule control is essential for any construction project to maintain an understanding of what has been completed, what remains to be completed, and when the remaining work will be completed. There are three key phases in schedule control: (1) development of control tools, (2) periodic monitoring of progress, and (3) updates or revisions to the schedule which reflect delays and/or the contractor's plan for completing the remaining work.

Requirements for project schedules are usually specified in the contract. CPM scheduling is commonly specified along with a host of reports to identify activity relationships, resource requirements, rate of progress, etc. During the first few weeks, nominally 10% of the construction duration, the contractor is typically preparing the initial detailed CPM schedule (also known as detailed work plans) and creating the specified reports. It is during this development period that working level reviews of the contractor's schedule are crucial to understanding the details of the contractor's plan to execute the work (Fredlund and King, 1992). Key areas of review would include: resource leveling; adherence to specified sequences and constraints; consideration of owner's and other external activities (including submittal reviews, agency approvals, etc.); compliance with contract times; manipulation of float; and composition of periodic reports.

Upon successful installation of a control schedule, the emphasis shifts to periodic updating of the schedule and monitoring schedule performance. Similar to the reviews for the initial progress schedule, the updated schedule should be reviewed for: changes in sequencing of construction activities; incorporation of all contract time modifications due to approved contract changes; verification of actual dates for completed or in progress activities;

revisions to curves employed to report rate of progress; and maintenance of forecasted completion dates against the contract times.

B. Changes, Claims, and/or Dispute Entitlement Documentation

Entitlement documentation is derived from essentially the same standard project statistical data, cost and schedule records, and documentation tracking reports typically produced in the day-to-day execution of a construction contract. The principal difference is that entitlement documentation is organized and packaged to present a specific issue or argument. Entitlement documentation also typically includes analyses of the packaged data prepared from the viewpoint of the presenter. The following issues may be addressed to mitigate the potential impact of changes, claims, or disputes.

Contemporaneous Documentation

As reported by Richard Long, to establish credibility, project data collected for the analysis of a claim should have been developed contemporaneously with the performance of the work, based on direct knowledge of the facts recorded, and should represent accurately the historical record of the project (Long, 1985). Documentation typically gathered for the evaluation of claims should include all relevant bid documents, contract documents, key record documents (e.g., approved submittals, interpretations, etc.), correspondence, test reports, daily records, progress payments, change order documentation, punch lists, progress schedules, and other cost and schedule data.

Document Control

Construction projects typically generate an overabundance of documents. Some prior investment in developing a computerized document control system will usually pay dividends when changes, claims, and disputes arise. Through appropriate indexing of documents, a quick assembly of facts that are pertinent to evaluating contested changes, claims, and disputes can be easily accomplished.

Video Surveys

Conduct a video survey of the site during the period between bid advertisement and bid opening. In addition, whenever there is a point of contention, record the actual conditions at the site in question. These surveys can be used as demonstrative exhibits during the resolution of the dispute.

Multimedia Project Records

The evolving capabilities of microprocessor hardware and software now make it practical to record, file, and catalog integrated video, still pictures, images, sound, and text on computer-accessible compact disks. This multimedia approach to mitigating the impact of disputes facilitates the creation of entitlement documentation that can show video and still pictures of the area under contention; present audio records of relevant meetings, inspections, or interviews; and correlate with pertinent correspondence, analyses, and printed inspection reports (Liu and Knoke, 1995).

Record or "As-Built" Schedules

Legal precedent demonstrates that delay disputes can often be resolved by analyzing critical paths in the as-planned versus the as-built schedule. Why wait until litigation? A proactive claims avoidance plan could include the collection of contemporaneous schedule information and the development of an independent record schedule that records the actual start and finish dates of each activity, the actual logic sequencing, periods of intermittence or disruptions in the planned work, and extra work related to change order negotiations (Knoke and Jentzen, 1994). An independent record schedule can be used to compare against the contractor's submittal of a record schedule as well as a request for a time extension.

Important features of a good record schedule include: clear distinctions between original, modified, and disputed work; as-built activities in the same level of detail as the contractor's schedule; identification of idle time, crew shifts, and remedial work; sequence of activities in negotiation of change orders; and correlation of data from project logs for submittal approvals and material deliveries to site or storage. In the case of multiple contracts, the interface between prime contracts (such as site access, approval of shop drawings and other submittals, and material deliveries) should be identified.

X. IMPROVING THE CONTRACT MANAGEMENT PROCESS

Another important aspect of claims avoidance is the approach used to manage the contract. The CCD Model asserts that claims and disputes can be mitigated through teamwork, claims avoidance attitude, and sound project management skills. Innovative ways to promote improvements in contract management include: team building with a focus on claims avoidance, additional training of staff, and development of a claims containment handbook.

A. Team Building with a Claims Avoidance Focus

Team building with a focus on claims avoidance has two principal thrusts: (1) to break down communication barriers and adversarial relationships between owners, designers, and contractors and (2) to create an attitude that minimizes avoidable costs associated with changes, claims, and disputes. Specific activities that can be helpful include the following:

Mission Statement

State the project's goals and objectives with regard to avoiding claims and disputes. These goals and objectives can be stated in a mission statement that can be disseminated among the project team. An example of a typical mission statement, coined the *ten canons of claims and disputes avoidance*, follows:

1. Eliminate or minimize delays of early project activities.
2. Reduce the cost and schedule impact of changes.
3. Create a "balanced risk sharing" posture with contractors.
4. Eliminate or minimize ambiguities in contract documents.
5. Manage the contract with focus on claims avoidance.
6. Be on an equal position to negotiate costs of changes and disputes.
7. Be on an equal position to negotiate schedule effects of changes and disputes.
8. Provide an effective ADR (alternative dispute resolution) procedure or process.
9. Be prepared to win in litigation, (if necessary).
10. Periodically self-audit the effectiveness of the claims avoidance program.

Periodic Changes, Claims and Disputes Meetings

For large contracts (greater than $100 million), periodic meetings between key owner, designer, and contractor personnel can be productive in resolving issues before they escalate into disputes. Discussion can center on: investigating more efficient ways to incorporate changes into the construction sequence; outlining specific actions needed to negotiate and equitably resolve cost and schedule effects of a change or claim; or defining documents necessary for entitlement of a change or claim.

B. Training of Staff

Consistent with the goals and objectives of a claims avoidance program, additional training of the staff is often needed to upgrade the dispute avoidance skills of key project personnel and senior management. The goal of the training is to develop proficiencies required to avoid, mitigate, and resolve contract issues. Specific training seminars would address:

Project goals and objectives concerning the claims avoidance program. A mission statement such as the earlier example can serve as the focus of the seminar.

Knowledge of the contract documents and language used. By identifying key contract clauses, equitable and consistent interpretations of the contract documents can be used to defuse or contain many claims and disputes. Examples of areas to review would include: contract change pricing, risk sharing provisions, differing site conditions, provisions for time extensions, alternative dispute resolution procedures, etc. Current legal precedent underlying each topic would be useful and enlightening.

Knowledge of unusual technical or commercial features of the project design. Examples of topics to cover would include: subsurface and other site investigations; definition of substantial and final completion including the contract time milestones; specified construction sequences, means, or methods; requirements for staged or phased handover; and owner/designer activities during construction.

Contract management procedures, including understanding of specified responsibilities. Topics to be reviewed would include: daily logs, progress schedule analysis, change order administration, project correspondence, shop drawing and other submittal approvals, payment certificate analysis, etc.

Procedures for handling requests for information (RFIs) and how to deal with common disputes arising from related decisions.

Management of a change, claim, or dispute. Topics to be reviewed would include relevant contract language, flow chart of responsibilities to assess and resolve the issue, schedule analysis required to determine time extensions, change order estimating, etc.

Management of alleged differing site conditions, taking into consideration the contract provisions, site investigations (such as soils reports), and handling of hazardous, toxic, or asbestos containing materials.

Improving negotiation fundamentals and communication skills, including role playing examples for mock disputes.

The value and need for team-building and professional behavior for all project personnel.

The extent of claims avoidance training for a project team member should be related to the influence that the individual has to avoid changes, claims, and disputes. However, it is important that all members of the project team be familiar with: (1) the intended design concept for the project, (2) the contract documents, (3) goals and objectives of the claims avoidance program, (4) the project schedule, and (5) norms of good practice regarding claims containment.

C. Claims Containment Handbook

For very large projects (greater than $250 million), a "Claims Containment Handbook" can serve as a supplement or byproduct of formal staff training on claims avoidance. The handbook would be a reference for all project personnel who deal with changes, claims, or disputes. The handbook would address the mitigation, processing, analysis, and settlement of disputes and claims. A Claims Containment Handbook would provide:

Explanations of claims containment contract provisions or clauses and their risk sharing features. Specific provisions in the project's contract should be highlighted and discussed.

Procedures for the administration of contractor-prepared schedule submittals. Discussion of issues such as review and approval of the schedule, compliance requirements, and float suppression should be included.

Procedures for preparing independent record or as-built schedules.

Procedures for the administration of change orders, claims, and disputes. This procedure should include: flow charts and responsibility matrices for the assessment and resolution of contract issues; guidelines for pricing changes as stated in the contract; guidelines for the determination time extensions; etc.

Procedures for handling RFIs and how to deal with common disputes arising from related decisions.

Key regulatory and project documents.

Glossary of project terms and selected documents (such as recent court decisions, judicial stipulations and final orders, agency mandated design guidelines, etc.).

XI. DEVELOP CONTRACT LEVERAGE

The contract is the most important tool in the claims avoidance tool kit. The contract describes the intent of the project, time deadlines for its completion, the agreed price, etc. Within this chapter, a key contractual concept has been implied: language within the contract can be used, modified, or added to help avoid extraneous costs due to changes, claims, and disputes. This section discusses innovative provisions that can "leverage" the contract language to avoid or mitigate these extra costs.

A. Key Modifications to Contract Language

Throughout this chapter, numerous references have been made to specific clauses, provisions, or specifications in the contract to assist the claims avoidance or containment process. A brief checklist of these references is reiterated below:

Bid dispute provisions: procedures for bid withdrawal, objections to award of a contract, and conditions which may warrant disqualification of a bidder.
CPM progress schedule specification: comprehensive progress scheduling provisions that address initial progress schedule submittal, frequency of periodic submittals (i.e., updates), content of submittals, short-term look-ahead schedules, compliance with contract times, and float suppression.
Comprehensive change order pricing provisions.
Audit clause to allow access by owner representatives to contractor's monthly job cost reports to verify costs associated with claim and dispute estimates.
Dispute provisions: outlining ADR procedures, venue for litigation (normally local courts), requirement for formal submittal of claim as a prerequisite step to filing a lawsuit.
Material or equipment substitution provisions disallowing equipment substitutions that do not improve life cycle costs and ensure that substitutions consider all secondary effects such as delays.
Quantity variation provisions for estimated quantities in unit price contracts.
Additional bid information requiring a breakdown of lump sum bid price into specific components; submittal of preliminary schedule after bid opening but before contract award.
Owner review of contractor submittals specifying durations for owner's review and timing of subsequent reviews if submittal has to be revised.
Change order notice procedure requiring consecutively numbered requests for change orders.
Daily field log specifying requirements for the contractor's daily field records.
Waiver provisions addressing reservation of rights, waiver of future claims relating to a change order, or other agreed changes.
Backcharges provisions for unanticipated owner's costs such as owner-provided inspections requiring overtime.
Specified order of precedence in contract documents when there are conflicts or inconsistencies within the documents.
Contract provisions stipulating that available float in the contract schedule must be consumed before a claim for a time extension can be considered.
Use of soils reports stipulating appropriate disclaimers to avoid unreasonable reliance on these reports by bidders.
Termination provisions to allow termination of contract when delays jeopardize the viability of the project schedule.

In addition to ensuring the application of recommended contract modifications such as those outlined above, some consideration should be given to using supplements to standard provisions or completely rewriting them. This decision is likely to hinge on the frequency of use of the documents versus the cost of rewriting. In either event, it is also advised to reduce incomprehensible legalese in contract documents.

B. Liquidated Damages

One common form of contract leverage is "liquidation of damages clauses." Liquidated damages, as they are commonly referred to, are contract provisions through which the parties agree that the owner will incur real costs (which are difficult to predict) as a result of unexcused delays which must, in turn, be reimbursed by the contractor through the payment of specified sums of money. Liquidated damages clauses must pass two tests for legitimacy: (1) the damages must be *difficult to ascertain* at the inception of the contract and (2) the specified amount must be based on a *genuine prior estimate* of the probable damages.

Liquidated damages clauses usually specify an amount of damages per calendar day that the contractor must pay if the contract is not completed by the contract time. Typically, in recent water treatment projects, there are two amounts specified in liquidated damages clause: one amount for breaches to substantial completion milestones and a second amount for breaches to final completion. In many cases, the liquidated damages for substantial completion are much higher than for final completion because more damages occur in postponing substantial completion (because the owner can often make beneficial use of the plant at substantial completion).

The liquidated damages clause is an exclusive remedy for late completion. Other clauses in the contract may allow the owner to recover damages for contract breaches such as defective work and abandonment. Although liquidated damages is not a recent concept, there are a number of innovative approaches that make the clauses more enforceable as well as more equitable (Ponce de Leon, Klanac, and Edwards, 1993):

Use probabilistic estimating techniques to assist in quantifying the amount of liquidated damages. This approach is a three-step process: (1) identify the owner's "possible" damages, (2) quantify the damages based on a range of delays, and (3) assess probabilities for the range of delays.

Items to be considered in identifying owner's "possible" damages include: extended staff costs for owner's representatives assigned to the project; excess financing costs; use of temporary facilities and operations; costs of continuation of facilities and operations to be replaced by the new project; delay damages to follow-on or succeeding contracts; and fines levied by regulatory agencies if the project is delayed.

For each selected range of delays (e.g., 0–20 days delay, 20–40 days delay, etc.), each identified component of the overall damage cost is estimated. Some damages, such as extended costs of owner's representatives or use of temporary facilities, will vary directly with the amount of delay. Other costs, such as delays to follow-on or succeeding contracts or regulatory fines, depend on their time-relationship with the project. For example, if there is 50 days float between succeeding contracts, there will be no damages or disruption costs resulting from succeeding contracts until the project has been delayed by more than 50 days.

Finally, a probability can be assessed for each range of delay selected. Ideally, this probability should be related to an empirical analysis of previous projects. For example, a statistical analysis of similar projects will yield information on the historical schedule-related performance of contractors. In reality, these probability assessments may be more subjective or judgmental due to lack of relevant data or time to carry out a statistical analysis.

Use appropriate contract language when specifying liquidated damages. The fact that the parties used the words "liquidated damages" in their agreement does not prevent a court from construing the agreement to assess a penalty. Hence, avoid the words "penalty" or "forfeit" in these clauses.

In federally funded projects where liquidated damages schedules are available from procurement regulations, use the schedule or an independent assessment but not both. Often courts will rule that the addition of estimated actual damages to the statutory schedule effectively doubles the estimated loss.

Be specific in choosing milestones and defining liquidated damages to be assessed to the milestones. Most contracts use the substantial completion milestone as the key date to trigger liquidated damages because the owner generally can make beneficial use of the project at that time and damages assessed thereafter begin to appear to be a penalty rather than compensation for losses. Also, if more than one milestone is addressed in liquidated damages clauses, use clear language to specify the effect of each liquidated damage upon breach of each milestone. For example, if the liquidated damages are to be exclusive and/or additive, specify this clearly.

Some recent projects, such as a recently constructed water treatment and pumping station in Lake County, Illinois, are adding bonus/penalty provisions in addition to liquidated damages to provide appropriate incentives for schedule performance.

C. Change Order Pricing

Many projects' contract documents do not provide specific guidelines for pricing changes. Consequently, the parties are left to negotiate the best deal they can get, using previous experience as a guide. This arbitrary and sometimes haphazard negotiation process can be circumvented by specifying a comprehensive method for pricing changes as part of the contract or agreeing to a method at the onset of construction (i.e., during the honeymoon period between contract award and start of substantial work at the site).

Specific pricing data should address:

Labor costs: Prevailing wage rates, labor burden factors (i.e., payroll taxes, fringes, etc.), typical craft mixes per discipline, and man-hour unit rates can be derived from standard estimating guides from such sources as R. S. Means or Richardson's. Adjustments may be needed when the contractor's cost basis is not the same as that assumed in the standard estimating guide (e.g., foremen as direct labor or field staff).

Material and/or equipment costs: Address requirements or guidelines for treating transportation and storage costs, trade discounts/rebates/refunds, number of supplier quotations, etc.

Construction equipment: Discuss appropriate pricing methods for contractor-owned vs. rented equipment. Also specify the methods for application of pricing standards such as the *Blue Book* and correct pricing of rental equipment (e.g., monthly hire rate when equipment is on site for a month, weekly hire rate when equipment is on site for less than a month but greater than five days, etc.).

Small tools: Specify minimum purchase cost of construction equipment versus a small tool (normally $500 to $1,000). Specify the pricing scheme for small tools as a percentage or on a directly reimbursable basis.

Site office and general conditions costs: In case of compensable time extensions, specify treatment of nonvariable costs (i.e., fixed costs such as building purchases) versus variable costs; only variable costs should be compensable.

D. Contingent Unit Prices

If the contract documents do not provide unit prices or if alternate prices are required due to agreed changes in the design intent, the contractor can be requested to provide selected unit prices to address uncertainty in the scope of work. For instance, on an expansion to a water treatment plant, unit prices could be negotiated or requested for a variety of activities such as:

Additional cubic yards of over-excavation when unsuitable material is encountered below grade elevations

Supplemental cubic yard rates for disposal of different types of contaminated excavation materials (i.e., ignitable, corrosive, reactive, or toxic)

Standard increments for longer or shorter lengths of structural piling, for leaving sheet piling in place, or for removing electrical wiring and installing and testing replacement wiring.

XII. CONCLUSION

Most major projects and many influential public and private owners today are developing some form of claims avoidance plan. The theory and specific practical advice outlined in this chapter can be used to further enhance and develop these plans. The next logical step in the claims avoidance arena is to develop yardsticks for measuring the effectiveness of a comprehensive dispute avoidance program. There are several parameters from which performance can be measured:

The quantity of RFIs or clarifications to the design documents. If the claims avoidance program is working, the quantity of requests for information or clarifications received over time will be significantly reduced.

The value of changes, claims, and disputes as a percent of contract value. In the introduction, a rate of 15–25% was cited as the current range of construction costs currently impacted. A project with a successful claims avoidance program should experience a much lower percentage. As the industry applies the principles outlined in this chapter, these percentages should continue to fall.

The ratio of estimated savings due to a reduction of changes, claims, and disputes versus the investment in staff, training, and other activities in the claim avoidance program. If the costs of implementing and administering a claims avoidance program falls, and the resulting savings stay the same, or continue to fall, then it may be assumed that some or all of the principals and practices have been embraced and are working effectively.

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