S&K

SKILLS & KNOWLEDGE OF COST ENGINEERING

6th Edition

AACE INTERNATIONAL

Skills and Knowledge of Cost Engineering

Sixth Edition

Dr. Makarand Hastak, PE CCP, Editor

2015

1265 Suncrest Towne Centre Drive, Morgantown, WV 26505-1876, USA
Phone: +1.304.2968444 | Fax: +1.304.2915728 | E-mail: education@aacei.org | Web: web.aacei.org

A Publication of

AACE INTERNATIONAL

Skills and Knowledge of Cost Engineering

Sixth Edition

Dr. Makarand Hastak, PE CCP, Editor

A continuing project of the AACE International Education Board

2015/2016 Education Board Members:
Peter W. Griesmyer, FAACE (Chair)
Dr. Nadia Al-Aubaidy
Dr. Baabak Ashuri, CCP DRMP
Michael Bensussen
Chris A. Boyd, CCP CEP
Dr. John O. Evans III, PSP
Dr. Makarand Hastak, PE CCP
Marina G. Sominsky, PSP
James G. Zack Jr., CFCC, FAACE AACE Hon. Life, VP – Education Board

Contributing Members:
Nelson E. Bonilla, CCP FAACE
Mark T. Chen, PE CCP FAACE AACE Hon. Life
Clive D. Francis, CCP FAACE AACE Hon. Life
John Jeffrey Hannon, CEP
Katherine Hull
Marlene M. Hyde, CCP EVP FAACE
Donald F. McDonald Jr., PE CCP PSP FAACE
Ekaterina Pujanova
Neil D. Opfer, CCP CEP PSP FAACE
Sunu M. Pillai, Esq. CCP EVP PSP
Stephen O. Revay, CCP CFCC FAACE

AACE International Publications Staff:
Formatting and Layout: Marvin Gelhausen, Managing Editor
Cover Design: Noah Kinderknecht, Noah Kinderknecht Design
Cassandra LoPiccolo, Business Development Coordinator

Editorial Team:

Editor:
Dr. Makarand Hastak, PE CCP

Associate Editors:
Chris A. Boyd, CCP CEP
Mark T. Chen, PE CCP FAACE AACE Hon. Life
Dr. John O. Evans III, PSP
Clive D. Francis, CCP FAACE AACE Hon. Life
Peter W. Griesmyer, FAACE
Sean T. Regan, CCP CEP FAACE
Rohit Singh, PE CCP
James G. Zack, Jr., CFCC FAACE AACE Hon. Life

Table of Contents

INTRODUCTION

Cost Engineers: Who Are They and What Do They Do?

Scott Amos, Ph.D., PE[1]

What is cost engineering and who are the people we call cost engineers? The first place to seek an answer is the *AACE International Constitution and Bylaws* which states:

> **Article I-Section 2**—The Association is dedicated to the tenets of furthering the concepts of total cost management and cost engineering. Total Cost Management (TCM) is the effective application of professional and technical expertise to plan and control resources, costs, profitability and risk. Simply stated, it is a systematic approach to managing cost throughout the life cycle of any enterprise, program, facility, project, product or service. This is accomplished through the application of cost engineering and cost management principles, proven methodologies and the latest technology in support of the management process.
>
> **Article I-Section 3**—Total cost management is that area of engineering practice where engineering judgment and experience are used in the application of scientific principles and techniques to problems of business and program planning; cost estimating; economic and financial analysis; cost engineering; program and project management; planning and scheduling; and cost and schedule performance measurement and change control.

The full AACE International Constitution and Bylaws is available at: web.aacei.org/aboutUs/governments/constitution

What this says is that the list of practice areas in Article I-Section 3 are collectively called *cost engineering*; while the "process" through which these practices are applied is called *total cost management* or TCM. Let's elaborate a bit more.

TCM and its sub-processes (strategic asset management and project control) can be summarized as management processes focused on coming up with ideas for strategic assets, analyzing and deciding upon the best idea, and finally planning and creating the selected projects in a controlled way (i.e., project control). While this is the process, who performs it?

Many people would say that "engineers" and "engineering" are most often responsible for creating functional projects or strategic assets; they are correct. However, there are multiple elements to engineering projects, e.g., a bridge project. Most look at engineering and see the element of physical design and the calculation and analysis tasks that are done to support the design of a bridge; again, they are correct. However, many people do not see that beyond the physical dimension of the design of the bridge structure, there are also dimensions of money, time, and other resources that are invested in the creation of the asset. These investments are collectively referred to as costs. Someone needs to estimate what the bridge might cost, determine the activities needed to design and build the bridge, estimate how long these activities will take, etc. Furthermore, someone needs to continually monitor and assess the progress of the bridge design and construction to ensure that the completed bridge meets the owner's objectives. This is a significant amount of work that requires special skills and knowledge.

The cost dimension requires calculation, analysis, planning, and control. No bridge has ever been built without dealing with both the physical and cost dimensions. However, the engineering skills and knowledge required to deal with costs are quite different from those required to deal with the physical design. From that difference, the field of cost engineering was born. Cost engineers work alongside other engineers or software analysts, play producers, architects, and other creative disciplines to handle the cost dimension. Returning to the AACE Constitution and Bylaws definition stated earlier, the skills and knowledge needed by the cost dimension are: business and program planning; cost estimating; economic and financial analysis; cost engineering; program and project management; planning and scheduling; and cost and schedule performance measurement and change control. All these functions are performed as part of the TCM process.

Cost engineers often specialize in one functional aspect of the project process. They may have titles such as cost estimator, parametric analyst, strategic planner, scheduler, cost/schedule engineer, project manager, or project control leader. They may work for the business that owns and operates the asset or they may work for the contractor that executes the projects. No matter what their job title or business environment, a general knowledge of, and skills in, all areas of cost engineering are required to perform their job effectively. This edition of the Skills and Knowledge of Cost Engineering provides a comprehensive overview of many TCM subject areas.

---

[1] Scott J. Amos, PhD PE, is a Professor of Construction Engineering and Management in the Department of Civil and Environmental Engineering at the South Dakota School of Mines and Technology in Rapid City, SD. This article appeared in Skills and Knowledge of Cost Engineering, 5th Edition (S&K5) as part of the preface and has been edited for inclusion in this publication.

SECTION 2 – COST ESTIMATING

Chapter 9—Cost Estimating

Larry R. Dysert, CCP CEP DRMP FAACE AACE Hon. Life

Abstract
Cost estimating is of integral importance to the quality of the cost and scheduling program on any project. Of paramount importance to the success of a project is the integrity of the cost estimate; and this is ensured using the appropriate cost estimating methodology. The cost estimate becomes the basis for setting up the cost budget, resources and the ensuing progress and schedule monitoring processes during project execution. To achieve this, a cost estimating basis/framework is necessary.

The cost estimating framework that is developed in this chapter includes:

- A system for the classification of cost estimating
- The methodologies used in the preparation of cost estimates
- Establishing estimating accuracy as it relates to the scope definition
- The application of risk analysis to contingency

This chapter presents functional examples for the different cost estimating methodologies inclusive of:

- Conceptual Estimating
- Ratio or Factored Estimating
- Parametric Estimating
- Detailed or Deterministic Estimating

This cost estimating chapter also establishes the relevance of the Work Breakdown Structure (WBS) and Resource Breakdown Structure (RBS) to the structure of the estimate and the ensuing budget and schedule. Finally, good estimating practices are stressed such as; the inclusion of the Basis of the Estimate (BOE) documents as a pre-requisite in presenting the final estimate.

In conclusion, this chapter provides a solid background in estimating, and establishes that estimates are a vital component to project success to establish project budgets and to provide accurate information to support scheduling, cost monitoring, and progress measurement of a project during execution.

Keywords
Basis of Estimate (BOE), Budget, Classification of Cost Estimates, Conceptual, Contingency, Cost Monitoring, Estimate Accuracy, Estimating Methodologies, Parametric and Deterministic Estimating, Ratio or Factored, Resource Breakdown Structure (RBS), Scheduling, and Work Breakdown Structure (WBS).

INTRODUCTION
Cost estimating is the predictive process used to quantify, cost, and price the resources required by the scope of an investment option, activity, or project. The output of the estimating process, the cost estimate, may be used for many purposes such as:

- Determining the economic feasibility of a project
- Evaluating between project alternatives
- Establishing the project budget
- Providing a basis for project cost and schedule control

Cost estimating may be used to quantify, cost and price any investment activity, such as building an office building or process power plant, developing a software program, or producing a stage play. The basic estimating steps are the same: Understand the scope of the activity to quantify the resources required, apply costs to the resources, apply pricing adjustments, and organize the output in a structured way that supports decision-making. Additional steps involve the assessment of risk associated with the estimate, and review and validation of the estimate. For the purposes of this chapter, the primary focus will be on estimating as applied to support the creation of capital assets (a building, industrial facility, bridge, highway, etc.); however, the estimating processes described can be applied to any investment activity.

As potential projects are considered, there are many decision points at which to decide whether a specific project should be continued to be developed. Each subsequent decision-making point, during the project life cycle, typically requires cost estimates of increasing accuracy. Estimating is thus an iterative process that is applied in each phase of the project life cycle as the project scope is defined, modified, and refined.

The cost estimate is obviously of paramount importance to the success of a project. The capital cost of a proposed project is one of the key determinants in evaluating the financial viability and business case of the project. From an owner's perspective, if the cost estimate is not accurate, the financial return from the capital investment may not be realized; and compounding this problem is the fact that other deserving projects may not have been funded. It is obvious that estimating is critical for the economic and optimal use of an owner's limited capital budget.

From a contractor's perspective, accurate estimating is just as important. In a lump-sum bidding situation, the profit margin of the contractor is dependent on the accuracy of his or her estimate. If the project is exceptionally large, the loss from an inaccurate estimate on a lump-sum bid can potentially put a contractor out of business. For cost-plus projects, the contractor will face less direct economic risk from an inaccurate estimate, but the damage to the contractor's reputation can be severe.

The cost estimate, however, serves other purposes besides establishing the budget for a project. It also serves as a tool or resource used for both scheduling and cost control of projects. The estimate not only establishes a project budget, but plays an equally important role in providing the information required to monitor the budget during project execution. It is the relationship between estimating, scheduling, and cost control, which is typically identified by the term "cost engineering" that serves as a driver for successful and cost-effective projects. Thus, an effective estimate must not only establish a realistic budget, but must also provide accurate information to allow for scheduling, cost monitoring, and progress measurement of a project during execution.

Learning Objectives

Cost estimating is one of the cornerstones of cost engineering and total cost management. The objective of this chapter is to introduce the reader to the various classifications of cost estimates, and the estimating methodologies and procedures used to prepare cost estimates. After completing this chapter, the reader should be able to:

- Understand the classification of cost estimates
- Understand some of the common methodologies used in preparing cost estimates
- Relate estimate accuracy to the level of scope information and methodologies used in preparing cost estimates
- Understand how to apply risk analysis to determine contingency in an estimate
- Understand how to present and review estimates
- Apply the knowledge gained to specific project estimating situations

Estimate Classifications

Estimate classifications are commonly used to indicate the overall maturity and quality for the various types of estimates that may be prepared; and most organizations will use some form of classification system to identify and categorize the various types of project estimates that they may prepare during the lifecycle of a project. Unfortunately, there is often a lack of consistency and understanding of the terminology used to classify estimates, both across industries as well as within single companies or organizations.

AACE International developed Recommended Practice 17R-97, *Recommended Practice for Cost Estimate Classification*, to provide generic guidelines for the general principles of estimate classification that may be applied across a wide variety of industries [1]. This document has been developed to:

- Provide a common understanding of the concepts involved in classifying project cost estimates
- Fully define and correlate the major characteristics used in classifying cost estimates, so that different organizations may clearly determine how their particular practices compare to the AACE guidelines
- Use degree of project definition as the primary characteristic in categorizing estimate classes
- Reflect generally accepted practices in the cost engineering profession

AACE RP 17R-97 maps the phases and stages of project estimating with a maturity and quality matrix; providing a common reference point to describe and differentiate various types of cost estimates [1]. The matrix defines the specific input information (i.e., design and project deliverables) that is required to produce the desired estimating quality at each phase of the estimating process. The matrix defines the requirements for scope definition and indicates estimating methodologies appropriate for each class of estimate.

AACE identifies five classes of estimates, which it simply designates as Class 1, 2, 3, 4, and 5. A Class 5 estimate is associated with the lowest level of project definition (or project maturity), and a Class 1 estimate is associated with the highest level of project definition. For each class of estimate, five characteristics are used to distinguish one class of estimate from another. The five characteristics used in the AACE Recommended Practice are:

- Degree of project definition
- End usage of the estimate
- Estimating methodology
- Estimating accuracy
- Effort required to produce the estimate

The level of project definition is the primary (or driving) characteristic used to identify an estimate class. The other characteristics are "secondary," with their value typically determined by the level of project definition. Figure 9.1 shows the generic *AACE Cost Estimate Classification Matrix*.

	Primary Characteristic	***Secondary Characteristic***			
ESTIMATE CLASS	**MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical +/- range relative to index of 1 (i.e. Class 1 estimate) [a]	**PREPARATION EFFORT** Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Screening or feasibility	Stochastic (factors and/or models) or judgment	4 to 20	1
Class 4	1% to 15%	Concept study or feasibility	Primarily stochastic	3 to 12	2 to 4
Class 3	10% to 40%	Budget authorization or control	Mixed but primarily stochastic	2 to 6	3 to 10
Class 2	30% to 75%	Control or bid/tender	Primarily deterministic	1 to 3	5 to 20
Class 1	65% to 100%	Check estimate or bid/tender	Deterministic	1	10 to 100

Notes: [a] If the range index value of "1" represents +10/-5%, then an index value of 10 represents +100/-50%.
[b] If the cost index value of "1" represents 0.005% of project costs, then an index value of 100 represents 0.5%.

Figure 9.1—Generic Cost Estimate Classification Matrix [AACE RP 17R-97] [1]

Typically, project owners (the owner organization responsible for the investment of funds in the project) are concerned with Class 5 through Class 3 estimates. Most capital projects base their final funding decisions on estimates associated with Class 3 level of project definition, which should provide a sufficient level of estimate accuracy for the commitment of final funding for the project. Often Class 5 and Class 4 estimates may be prepared by the project owner organization itself; but may also be prepared by their engineering contractors or other 3rd parties. In general, most Class 3 estimates are not prepared by the owner organization because of the resources required for preparation of these more detailed estimates; and these will typically be prepared by their engineering or other contractors. Despite which entity prepares the estimates up to and including the final funding estimate, the owner organization needs to accept final responsibility for these estimates through a thorough review and validation process (including the identification and assessment of cost risks associated with the estimate). In the end, the owner is responsible for project funding.

Class 2 and Class 1 estimates for capital projects are typically prepared to support construction bids or project execution change control (post-authorization changes); and for capital projects. These are most often prepared by construction contractors.

In addition to the generic estimate classification system, a more specific version [AACE RP 18R-97] has been created for the process industries (see Figure 9.2) [2]. The term "process industries" is intended to include firms involved with the manufacturing and production of chemicals, petrochemicals, pulp/paper and hydrocarbon processing. The commonality among this industry (for the purpose of estimate classification) is their reliance on Process Flow Diagrams (PFD's) and Piping and Instrument Diagrams (P&ID's) as primary scope defining documents. These documents are key deliverables in determining the level of project definition, and thus the extent and maturity of estimate input information, and subsequently the estimate class for an estimate for a process industry project.

	Primary Characteristic	*Secondary Characteristic*		
ESTIMATE CLASS	**MATURITY LEVEL OF PROJECT DEFINITION DELIVERABLES** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 75%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	65% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology, availability of applicable reference cost data, and many other risks affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

Figure 9.2—Cost Estimate Classification Matrix for the Process Industries [AACE 18R-97] [2]

This Estimate Classification System for the Process Industries is meant to supplement the generic standard. Additional estimate classification recommended practices have been established for other industries as well (e.g., general construction, software development, etc.).

Included with the supplemental guideline for the process industries [AACE RP 18R-97] is a chart which maps the maturity of estimate input information (project definition deliverables) against the classes of estimates (see Figure 9.3) [2].

ESTIMATE CLASSIFICATION					
General Project Data:	**CLASS 5**	**CLASS 4**	**CLASS 3**	**CLASS 2**	**CLASS 1**
Project Scope Description	General	Preliminary	Defined	Defined	Defined
Plant Production/Facility Capacity	Assumed	Preliminary	Defined	Defined	Defined
Plant Location	General	Approximate	Specific	Specific	Specific
Soils and Hydrology	None	Preliminary	Defined	Defined	Defined
Integrated Project Plan	None	Preliminary	Defined	Defined	Defined
Project Master Schedule	None	Preliminary	Defined	Defined	Defined
Escalation Strategy	None	Preliminary	Defined	Defined	Defined
Work Breakdown Structure	None	Preliminary	Defined	Defined	Defined
Project Code of Accounts	None	Preliminary	Defined	Defined	Defined
Contracting Strategy	Assumed	Assumed	Preliminary	Defined	Defined
Engineering Deliverables:					
Block Flow Diagrams	S/P	P/C	C	C	C
Plot Plans		S	P/C	C	C
Process Flow Diagrams (PFDs)		S/P	P/C	C	C
Utility Flow Diagrams (UFDs)		S/P	P/C	C	C
Piping & Instrument Diagrams (P&IDs)		S	P/C	C	C
Heat & Material Balances		S	P/C	C	C
Process Equipment List		S/P	P/C	C	C
Utility Equipment List		S/P	P/C	C	C
Electric One-Line Drawings		S/P	P/C	C	C
Specifications & Datasheets		S	P/C	C	C
General Equipment Arrangement Drawings		S	P/C	C	C
Spare Parts Listings			S/P	P	C
Mechanical Discipline Drawings			S	P	P/C
Electric Discipline Drawings			S	P	P/C
Instrumentation/Control System Discipline Drawings			S	P	P/C
Civil/Structural/Site Discipline Drawings			S	P	P/C

Figure 9.3—Estimate Input Checklist and Maturity Matrix for the Process Industries

This is a checklist of basic deliverables found typically in common practice in the process industries. The maturity level is an approximation of the degree of completion of the deliverable. The degree of deliverable is indicated by the following letters:

- None (blank): Development of the deliverable has not yet begun
- Started (S): Work on the deliverable has begun. Development is typically limited to sketches, rough outlines, or similar levels of early completion
- Preliminary (P): Work on the deliverable is advanced. Interim cross-functional reviews have usually been conducted Development may be near completion except for final reviews and approvals
- Complete (C): The deliverable has been reviewed and approved as appropriate

Note: It is only the level of project definition that defines the class of the estimate. Although typically the other characteristics associated with the estimate classification matrices are correlated with the level of project definition, this is not always the case and the other characteristics do not define the class of estimate. As an example, it is possible to prepare a Class 5 (conceptual) estimate on a very repetitive project for which the scope may be well understood (although not defined by technical deliverables), and for which very good reference cost data exists that may have a higher level of estimate accuracy than a Class 3 estimate for a project involving new technology in a new geographical location for which adequate reference cost information is not available.

Estimating Methodologies

In general, estimating methodologies commonly fall into two broad categories: conceptual and deterministic. As can be seen from the Cost Estimate Classification Matrices (see Figures 9.1 and 9.2), as the level of project definition increases, the estimating methodology tends to progress from conceptual (stochastic or factored) methods to deterministic methods.

With conceptual estimating methods, the independent variables used in the estimating algorithm are generally something other than a direct measure of the units of the item being measured. They usually involve simple or complex modeling (or factoring), based on inferred or statistical relationships between costs and other, typically design related, parameters. Often, the cost estimating relationships used in conceptual estimating methods are at least somewhat subject to conjecture.

For deterministic estimating methods, the independent variables used in the estimating algorithm are more or less a direct measure of the item being estimated, such as straightforward counts or measures of items multiplied by known unit costs. Deterministic estimating methods require a high degree of precision in the determination of quantities, pricing, and the completeness of scope definition. Of course, any particular estimate may involve a combination of conceptual and deterministic methods.

There is another key difference between conceptual and deterministic estimating methods. Conceptual estimating methods require significant effort in data-gathering and methods development before estimate preparation ever begins. There is a significant effort in historical cost analysis to develop accurate factors and estimating algorithms to support conceptual estimating. Preparing the conceptual estimate itself takes relatively little time, sometimes less than an hour.

In contrast, a deterministic (or detailed) estimate requires a large effort during the actual preparation of the estimate. The evaluation and quantification of the project scope can take a substantial amount of time, sometimes weeks or even months for extremely large projects. Research and application of accurate detailed pricing information, and application of specific estimating adjustments to the quantified scope can also take considerable time.

The estimating method used for any particular estimate will depend on many factors: the end use of the estimate, the amount of time and money that is available to prepare the estimate, the estimating tools and data available, and of course the level of project definition and design information on hand.

Conceptual Estimating Methodologies

Conceptual estimating methods are typically used for Class 5 and Class 4 (and sometimes for Class 3) estimates. They are often referred to as "Order-of-Magnitude" (OOM) estimates in reference to their typically wide range of estimate accuracy (as previously defined in the estimate classification matrices). They provide a relatively quick method of determining the approximate probable cost of a project without the benefit of detailed scope definition. As indicated in the estimate classification matrices, these estimates may be used for:

- Establishing an early screening estimate for a proposed project or program
- Evaluating the general feasibility of a project
- Screening project alternatives (such as different locations, technologies, capacities, etc.)
- Evaluating the cost impacts of design alternatives
- Establishing a preliminary budget for control purposes during the design phase of a project

Conceptual estimates are generally based on little project definition (i.e., engineering deliverables), thus typically subjecting them to a wide range of estimate accuracy. Their accuracy can depend on several factors—including the level of project definition, the quality of the past historical cost data used in development of the factors and algorithms, as well as the judgment and experience of the estimator. These limitations should, of course, be recognized in using conceptual estimating methods. Nonetheless, there are many cases where conceptual estimates can be very reliable, especially in estimating repetitive projects. Generally, the emphasis with conceptual estimating is not on detailed accuracy, but on obtaining a reasonable cost estimate of sufficient accuracy to insure that the results are meaningful for management to make the decision at hand. Early, conceptual estimates (Class 5 or Class 4 estimates) are typically used to determine whether the project may meet project financial thresholds, and thus support investment in additional design and engineering development to support an estimate that can be used to establish final project funding (typically a Class 3 estimate).

There are a wide variety of conceptual or OOM estimating methodologies. Several of the more commonly used methods are: end-product units, physical dimensions, capacity factor, various ratio or factor methods, and parametric modeling. Most conceptual estimating methods rely on relationships of one form or another.

End-Product Units Method

This conceptual estimating method is used when the estimator has enough historical data available from similar projects to relate the end-product units (capacity units) of a project to its construction costs. This allows an estimate to be prepared relatively quickly, knowing only the end-product unit capacity of the proposed project. Examples of the relationship between construction costs and end-product units are:

- The construction cost of an electric generating plant and the plant's capacity in kilowatts
- The construction cost of a hotel and the number of guest rooms
- The construction cost of a hospital and the number of patient beds
- The construction cost of a parking garage and the number of available parking spaces

To illustrate, consider a client that is contemplating building a 1,500 luxury hotel in a resort area. The client needs an approximate cost estimate for the proposed hotel as part of the feasibility study. Assume that a similar luxury hotel has been recently completed at a nearby resort and the following information is available.

The hotel just completed included 1000 guest rooms, as well as a lobby, restaurants, meeting rooms, parking garage, swimming pool, and nightclub. The total construction cost for the 1,000 room hotel was $67,500,000. The resulting cost per room is thus calculated as $67,500,000/1,000 = $67,500 per room.

Therefore, we can use this information to determine the cost of the 1500 room hotel, of comparable design and a nearby location, as $101,250,000 ($67,500/Room X 1500 Rooms). While this cost estimate may serve to meet the needs of the feasibility study, it has ignored several factors that may impact costs.

For example, it has ignored any economies of scale that may be generated from constructing a larger hotel; and has assumed that the cost of the common facilities (lobby, restaurants, pool, etc.) vary directly with the increase in the number of rooms. It is important to identify and assess the cost impact of these differences, and make the appropriate adjustments to the initial cost estimate. Similarly, if the location or timing of the proposed hotel had differed significantly from the known cost data point, then cost indices can be used to adjust for these differences.

Physical Dimensions Method

Somewhat similar to the end-products units method is the physical dimensions estimating methodology. The method uses the physical dimensions (length, area, volume, etc.) of the item being estimated as the driving factor. For example, a building estimate may be based on square feet/meters or cubic volume of the building; whereas pipelines, roadways, or railroads may be based on a linear basis.

As with the end-product units method, this estimating methodology also depends on historical information from comparable facilities. Consider the need to estimate the cost of a 3,600 SM warehouse. A recently completed warehouse of 2,900 SM in a nearby location was recently completed for $623,500, thus costing $215/SM. The completed warehouse used a 4.25M wall height, thus containing 12,325 CM, and resulting in a cost of $50.59/CM on a volume basis ($623,500/12,325 CM).

In determining the cost for the new warehouse, we can estimate the new 3,600 SM warehouse using the SM basis at $774,000 ($215/SM X 3,600SM). However, the new warehouse will differ from the one just completed by having 5.5M high walls; so we may decide that estimating on a volume basis may provide a better indication of costs. The volume of the new warehouse will be 19,800 CM (3,600 SM X 5.5M), and the new estimate will be $1,002,000 (rounded to the nearest $1000).

Again, we have ignored the cost impact of economies of scale in developing the estimate, and any other differences in quality between the two warehouses. If additional information is available to identify and assess these differences, then further adjustments should be made to the cost estimate. If location or timing differences had existed, we would also account for those cost impacts by using cost indices or other adjustments.

Capacity Factor Method

A capacity factored estimate is one in which the cost of a new facility is derived from the cost of a similar facility of a known (but usually different) capacity. It relies on the (typical) non-linear relationship between capacity and cost. In other words, the ratio of costs between two similar facilities of different capacities equals the ratio of the capacities multiplied by an exponent:

$\$B/\$A = (Cap_B/Cap_A)^e$

Where: $A and $B are the costs of the two similar facilities; and Cap_A and Cap_B are the capacities of the two facilities. This is shown in Figure 9.4.

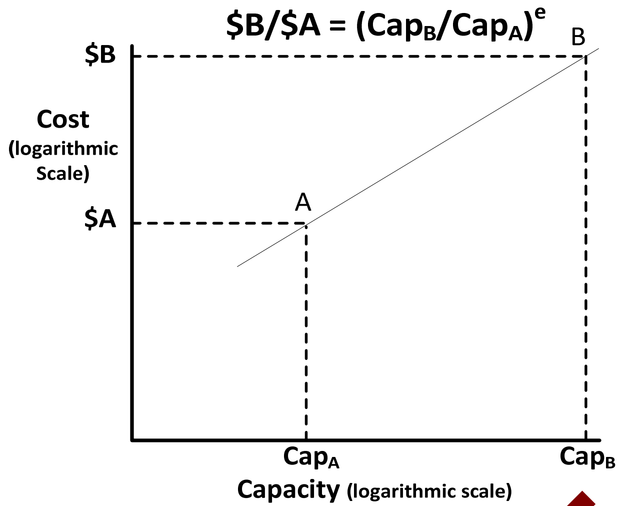

Figure 9.4—Capacity Factor Relationship

If we rewrite this equation to use as an estimating algorithm, it becomes:

$\$B = (\$A)(Cap_B/Cap_A)^e$

Where: \$B is the cost of the facility being estimated, \$A is the known cost of a similar facility, Cap_B is the capacity of the facility being estimated, Cap_A is the capacity of the similar facility, and "e" is the exponent or proration factor.

The exponent "e" typically lies between 0.5 and 0.85 depending on the type of facility, and must be analyzed carefully for its applicability to each estimating situation. The exponent "e" used in the capacity factor equation is actually the slope of the curve that has been drawn to reflect the change in the cost of a facility, as it is made larger or smaller (see Figure 9.4). These curves are typically drawn from the data points of the known costs of completed facilities. The slope will usually appear as a straight line when drawn on log-log paper. With an exponent value less than 1, scales of economy are achieved such that as facility capacity increases by a percentage (say, 20 percent), the costs to build the larger facility increase by less than 20 percent.

The methodology of using capacity factors is sometimes referred to as the "scale of operations" method, or the "six tenth's factor" method, because of the common reliance on an exponent value of 0.6 if no other information is available. With an exponent of .6, doubling the capacity of a facility increases costs by approximately 50 percent, and tripling the capacity of a facility increases costs by approximately 100 percent.

It is also important to realize that although the data, when plotted on a log-log graph, will usually appear as a straight line over a small range of capacity values; it is probably not constant over the entire range of possible capacities or facility sizes. In reality, as facility capacities increase, the exponent tends to increase as illustrated in Figure 9.5. As an example, between the capacities A and B (in Figure 9.5), the capacity factor exponent may have a value of 0.6; however between the capacities B and C, the exponent has a value of 0.65. Between the capacities C and D, the value of the exponent may have risen to 0.72. Eventually, as the facility capacity increases to the limits of existing technology, the exponent tends toward a value of 1. At this point, it becomes more economical to build two facilities of a smaller size than one large facility. In other words, cost becomes a linear function of capacity, and scales of economy are no longer obtained.

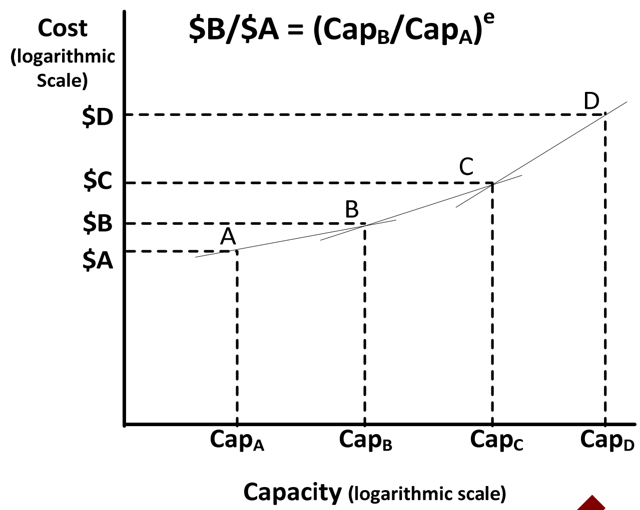

Figure 9.5—Capacity Factor Exponents are not Constant Across all Capacity Ranges

Capacity factored estimating can be quite accurate. If the capacity factor used in the estimating algorithm is relatively close to the actual value, and if the facility being estimated is relatively close in size to the similar facility of known cost, then the potential error from capacity factoring is quite small, and is certainly well within the level of accuracy that would be expected from such a conceptual estimating method. For example, if the new facility is triple the size of an existing facility, and the actual capacity factor is 0.80, instead of an assumed 0.70, you will have underestimated the cost of the new facility by only 10 percent, calculated as $(3^{.8} – 3^{.7})/3^{.8}$. Similarly, for the same threefold scale-up in facility size, but the actual capacity factor would be 0.60 instead of an assumed 0.70, you will have overestimated the facility cost by only 12 percent, calculated as $(3^{.7} – 3^{.6})/3^{.6}$.

Thus, if the facility size being estimated is reasonably close to the size of the known facility, and a realistic capacity factor exponent is used, error from the capacity factoring algorithm is small. However, this error can be compounded by other assumptions we must make in an actual estimating situation. Typically, we must also adjust for differences in physical scope, location and time between the estimated facility and the known facility. Each of these adjustments can also add to the level of error in the overall estimate.

Let's examine a typical situation where we need to estimate the costs of a 100,000 BBL/Day Hydrogen Peroxide unit, to be built in Philadelphia and completed in 2004. We have recently completed a 150,000 BBL/Day plant in Malaysia, with a final cost of $50 million in 2002. Our recent history shows a capacity factor of 0.75 is appropriate. The simple approach is to just use our capacity factor algorithm:

$\$B = (\$A)(Cap_B/Cap_A)^e$
$\$B = \$50M \times (100/150)^{.75} = \$36.9M$

This would be fine for as far as it goes, but as we have noted in our earlier discussions of estimating methodologies, we have thus far ignored differences in quality (or scope), location, and time.

For this example, let's adjust for the differences in scope, location, and time. The plant in Malaysia included piling, tankage, and owner costs that will not need to be included in the proposed plant for Philadelphia. Construction in Philadelphia is expected to cost 1.25 times the construction costs in Malaysia (location adjustment). Escalation will be included as a 1.06 multiplier from 2002 to 2004 (an obviously simple approach). There are costs for additional pollution requirements in Philadelphia that were not included in the cost of the Malaysian plant. Taking these into account, the estimate now appears like this:

150,000 BBL/Day Plant in Malaysia	$50M
Deduct Piling, Tankage, Owner Costs	***- $10M***
Adjusted Cost for Scope	**= $40M**
Malaysia to Philadelphia Adjustment (X 1.25)	= $50M
Escalate to 2002 (X 1.06)	= $53M
Factor = $53M X $(100/150)^{.75}$	= $39M
Add Pollution Requirements (+$5M)	= $44M

The key steps in preparing a capacity factor estimate are:

- Deduct costs from the known base case that are not applicable in the new plant being estimated
- Apply location and escalation adjustments to normalize costs. This now determines what the adjusted scope for the base case will cost in the new location and time frame
- Apply the capacity factor algorithm to adjust for plant size
- Add any additional costs which are required for the new plant but which were not included in the known plant

The capacity factor estimating method provides a relatively quick and sufficiently accurate means to prepare early estimates during the concept screening stage of a project. The method requires historical cost and capacity data for similar plants and processes. Although published data on capacity factors exists, the best data would be from your own organization and requires a level of commitment to collect, normalize, and maintain this information. When using this method, the new and existing known plant should be near duplicates, and reasonably close in size. You must account for differences in scope, location, and time. Each of the adjustments that you make adds additional uncertainty and potential error to the estimate. Despite this, capacity factor estimates can be quite accurate, and are often used to support decision-making at the pre-design stage of a project.

Ratio or Factor Methods

Ratio or factored estimating methods are used in situations where the total cost of an item or facility can be reliably estimated from the cost of a primary component. For example, this method is commonly used in estimating the cost of process and chemical plants where the cost of the specialized process equipment makes up a significant portion of the total project cost. This is often referred to as "Equipment Factor" estimating.

Equipment factored estimates are used to develop costs for process and utility units for which the behavior of the costs of the direct labor and bulk materials used to construct the facilities is correlated with the costs (or the design parameters) of the major equipment. Typically, this estimating methodology relies on the principle that a ratio or factor exists between the cost of an equipment item and costs for the associated non-equipment items (foundations, piping, electrical, etc.) needed to complete the installation.

An equipment factored estimate can typically be generated when project definition (engineering complete) is approximately one to 15 percent complete (Class 4). A sufficiently accurate equipment list should be available at this point in the project. This estimate is often a feasibility estimate used to determine whether there is a sufficient business case to pursue the project. If so, then this estimate may be used to justify the funding required to complete the engineering and design required to produce a funding or budget estimate (Class 3).

Depending on the particular factoring techniques and data used, the factors may estimate Total Installed Costs (TIC) or Direct Field Cost (DFC) for the facility. Usually, the factors generate costs only for the Inside Battery Limits (ISBL) facilities, and require the Outside Battery Limit Facilities (OSBL) costs to be estimated separately; however, sometimes appropriate factors are used to estimate the costs of the complete facilities. Therefore, it is extremely important to understand the basis of the particular factors being used in an equipment factored estimate.

In 1947, Hans Lang first published an article in *Chemical Engineering* introducing the concept of using the total cost of equipment to factor the total estimated cost of a plant [3]:

Total Plant $ = Total Equipment $ X Equipment Factor

Lang proposed three separate factors based on the type of process plant (see Table 9.1). Lang's factors were meant to cover all the costs associated with the total installed cost of a plant including the Battery Limits Process Units (ISBL Costs) and all Offsite Units (OSBL Costs).

Table 9.1—Lang Factors

Type of Plant	Factor
Solid Process Plant	3.10
Solid-Fluid Process Plant	3.63
Fluid Process Plant	4.74

An example of a Lang Factor estimate for a fluid process plant:

Total Estimated Equipment Cost	= $1.5M
Total Plant Cost	= $1.5M X 4.74
Total Plant Cost	= $7.11M

Lang's approach was rather simple, using a factor that varied only by the type of process. Since that first publication, many different methods of equipment factoring have been proposed, and some methods have become very sophisticated. The term "Lang Factor," however, is often used generically to refer to all the different types of equipment factors.

In 1958, W.E. Hand elaborated on Lang's work by proposing different factors for each type of equipment (columns, vessels, heat exchangers, etc.) rather than process type [4]. Hand's factors estimated direct field cost, excluding instrumentation. Hand's published equipment factors ranged from 2.0 to 3.5 (which might correlate to approximately 2.4 to 4.3 including instrumentation). Hand's factors excluded Indirect Field Costs (IFC), Home Office Costs (HOC), and the costs for Offsite or Outside Battery Limit (OSBL) facilities. These costs would need to be estimated separately.

An example of an estimate prepared for a fluid processing plant using Hand's equipment factoring techniques appears in Figure 9.6. In this example, the total cost of all equipment items for each type of equipment was multiplied by a factor for that specific type of equipment to derive the DFC for that equipment type. For instance, the total cost of all vertical vessels ($540K) was multiplied by an equipment factor of 3.2 to obtain an installed DFC of $1,728K. The DFC costs for all equipment types totals $7,753K. Direct Field Labor (DFL) was estimated at 25 percent of DFC or $1,938K. The Indirect Field Costs (IFC) were then estimated at 115 percent of the DFL costs, totaling $2,229K. The sum of the DFC and IFC costs comprise the Total Field Costs (TFC) of $9,982K. Home Office Costs (HOC) are factored as 30 percent of DFC, which totals $2,326K. For this estimate, the Project Commissioning Costs were factored as three percent of DFC, and Contingency was factored as 15 percent. The Total Installed Cost (TIC) for this estimate totals $14,422K.

Acct No.	Item Description	Adj. Factor	Cost: Labor $	Eqmt $	Eqmt Factor	Total	Eqmt Mult	% Total
51	Columns			650,000	2.1	1,365,000		
52	Vertical vessels			540,000	[illegible]	1,728,000		
53	Horizontal Vessels			110,000	2.[illegible]	264,000		
54	Shell & Tube Heat Exchangers			[illegible]0,000	2.5	1,575,000		
55	Plate Heat Exchangers			11[illegible]00	2.[illegible]	220,000		
56	Pumps, Motor Driven			765,[illegible]	[illegible].4	2,601,000		
				[illegible]05,000				
	DIRECT FIELD COSTS	**25% of DFC**	**1,93[illegible]00**			**7,753,000**	**2.8**	**53.8%**
10	Temporary Construction Facilities							
11	Construction Services/Supplies/Consumables							
12	Field Staff/Subsistence/Expense							
13	Payroll Burdens/Benefits/Insurance							
14	Construction Equipment/Tools							
15	International Expense							
	INDIRECT FIELD COSTS	**[illegible]% of DFL**				**2,229,000**		**15.5%**
	TOTAL FIELD [illegible]					**9,982,000**	**3.6**	**69.2%**
20	Project Management							
21	Project Controls/Estima[illegible]ng							
22	Project Procurement							
23	Project Cosntruction Management							
24	Engineering/Design							
25	Home Office Expenses							
	HOME OFFICE COSTS	**30%of DFC**				**2,326,000**		**16.1%**
	TOTAL FIELD and HOME OFFICE COSTS					**12,308,000**	**4.4**	**85.3%**
30	Owner's Costs							
31	Project Commissioning Costs	**3%**	**Of DFC**			233,000		
32	Escalation							
33	Other Non-Assignable Costs							
34	Contingency	**15%**	**Of Above**			1,881,000		
35	Fee							
	OTHER PROJECT COSTS					**2,114,000**		**14.7%**
	TOTAL PROJECT COSTS					**$14,422,000**	**5.1**	**100.0%**

Figure 9.6—Equipment Factored Estimate Example

Note the various equipment factors displayed in this example. Total equipment cost to DFC is a factor of 2.8 (a typical range would be 2.4 to 3.5). Total equipment cost to TFC is a factor of 3.6 (with a typical range being 3.0 to 4.2). Total equipment cost to total project cost, including contingency, is a factor of 5.1 (a typical range would be 4.2 to 5.5). This correlates closely with Lang's original overall equipment factor of 4.74 for fluid plants.

Arthur Miller proposed another enhancement to the concept of equipment factors in 1965 [5]. Miller recognized the impact of three specific variables that affect the equipment material cost to a greater degree than they affect the cost of the associated bulk materials and installation. These three factors are: the size of the major equipment, the materials of construction (metallurgy) of the equipment, and the operating pressure. Miller noted that as the size of a piece of major equipment gets larger, the amount of corresponding bulk materials (foundation, support steel, piping, instruments, etc.) required for installation does not increase at the same rate. Thus, as the equipment increases in size, the value of the equipment factor decreases.

A similar tendency exists for metallurgy and operating pressure. If the equipment is made from more expensive materials (stainless steel, titanium, monel, etc.), the equipment factor will become smaller. If the operating pressure increases, the equipment factor gets smaller. Again, as the equipment becomes more costly because of expensive materials of construction or higher operating pressures, the costs for the associated bulk materials required for installation increase at a lower proportion or rate, and the resulting equipment factor becomes smaller.

Miller suggested that these three variables could be summarized into a single attribute known as the "average unit cost" of equipment. The "average unit cost" of equipment is:

Total Cost of Process Equipment/Number of Equipment Items

If the "average unit cost" of equipment increases, then the equipment factor is scaled smaller. The correlation between increasing average unit cost of equipment and decreasing equipment factors was statistically validated by subsequent studies by Roland Rodl [6] and M. Nushimura [7].

Thus far, the equipment factors we have discussed have been used to generate all-in DFC or TIC costs. Another method of using equipment factors is to generate separate costs for each of the disciplines associated with the installation of equipment. Using this methodology, each type of equipment is associated with several discipline specific equipment factors. For example, one discipline equipment factor will generate costs for concrete, another factor will generate costs for support structural steel, another generates the cost for piping, etc. An advantage to this approach is that it provides the estimator with the capability to adjust the costs for the individual disciplines based on specific knowledge of the project conditions, and improves the accuracy of the equipment factoring method. It also allows the costs for each specific discipline to be summed, and compared to other similar projects. Miller, and later K.M. Guthrie, described this methodology [8].

An example of using discipline specific equipment factors is shown in Figure 9.7. The example shows discipline equipment factors for a 316SS Shell & Tube Heat Exchanger with a size range of 350 – 700 SM. In this example, the equipment cost of $10,000 is multiplied by each of the indicated factors to generate the DFC costs for that discipline. For example, the equipment installation labor is factored as $10,000 X 0.05 = $500; piping material and labor is factored as $10,000 X 1.18 = $11,800; etc. The total DFC costs for installation of this heat exchanger totals $28,600 (including the equipment purchase cost of $10,000). This equates to an overall DFC equipment factor of 2.86. These costs do not include IFC, HO, or OSBL costs.

Exchanger, Shell & Tube, 316 Stainless Steel, 350-700 SM										
	Eqmt. Cost	Eqmt. Install Labor	Concrete	Structural Steel	Piping	Electrical	Instruments	Painting	Insulation	Total DFC Costs
Factor		0.05	0.11	0.11	1.18	0.05	0.24	0.01	0.11	2.86
Cost	$10,000	$500	$1,100	$1,100	$11,800	$500	$2,400	$100	$1,100	$28,600

Figure 9.7—Discipline Equipment Factor Example

Development of the actual equipment factors to be used in preparing process plant estimates is a tedious and time-consuming affair. Although some published data exists on equipment factors (see the articles included in the references), much of this data is old, and some of the assumptions in normalizing the data for time, location, and scope are incomplete or unavailable. A clear explanation of what is or what is not covered by the factors is sometimes missing. Lacking anything better, the published data provides a starting point for your database of equipment factors; however, the best information will be data that comes from your own organization's project history and cost databases, and which matches your engineering and construction techniques.

Overall equipment factors from total equipment cost to DFC/TIC (true "Lang" factors) are the easiest to generate. Historical data from completed projects should be normalized to a common time and location/labor productivity baseline. The total equipment costs, direct field costs, and total installed costs should be very easy to derive from the historical data. The results can then be analyzed, plotted, and tested to establish overall equipment "Lang" factors.

Developing individual equipment factors that vary based on the type of equipment, or separate factors for each discipline is much more complicated. Generally, it is difficult to derive the required data from the actual cost histories for completed projects. Project accounting and cost coding typically does not collect actual cost data in the necessary format. Instead, these types of equipment factors are typically developed by generating detailed estimates for a matrix of equipment types, size ranges, metallurgies, operating pressures, etc. The estimates are then carefully analyzed to develop individual equipment and adjustment factors, so that equipment size, metallurgy, and operating pressure can be accounted for.

The factors developed in this manner can then be tested and calibrated against actual project histories. The proposed equipment factors (and adjustment factors, if necessary) are applied to the actual equipment costs for completed projects, and the results from the factoring exercise are compared to the actual project costs to determine if a reasonable degree of accuracy has been obtained. If the factoring results vary widely from the actual costs, or are consistently low or consistently high, then an analysis to determine the reasons will need to be performed, and development of the factors will continue until sufficient accuracy can be obtained.

When preparing an equipment-factored estimate, the first step, of course, is to estimate the cost for each piece of process equipment. The list of equipment needs to be examined carefully for completeness and compared against the Process Flow Diagrams (PFD's) and/or the Piping and Instrument Diagrams (P&ID's). When an equipment factored estimate is prepared, the equipment list is often still in a preliminary stage. Although the major equipment is identified, it may be necessary to assume a percentage for auxiliary equipment that has not yet been defined. Equipment sizing should also be verified. At this preliminary stage of engineering, a common problem is that equipment is often sized at 100 percent of normal, operating duty. However, typically by the time the purchase orders have been issued, some percentage of oversizing has been added to the design specifications. The percentage of oversizing that occurs varies by the type of equipment, and an individual organization's procedures and guidelines. It is prudent to check with the process engineers and determine if an allowance for oversizing the equipment, as listed on the preliminary equipment list, should be added before pricing the equipment.

The purchase cost of the equipment may be obtained by several methods: purchase orders or cost information from recent equipment purchases, published equipment cost data, preliminary vendor quotations, or firm vendor quotations. Since the material cost of equipment can represent 20 to 40 percent of the total project costs for process plants, it is extremely important to always estimate the equipment costs as accurately as possible. When using equipment factoring methods to develop the project estimate, this becomes even more important. If historical purchase information is used, you must ensure that the costs are escalated appropriately, and adjusted for location and/or market conditions as required.

Once the equipment cost is established, the appropriate equipment factors need to be established and applied. Ensure that adjustments for equipment size, metallurgy, and operating conditions are included if necessary. Also, any specific project or process conditions need to be evaluated to determine if additional scope-based adjustments to the factored costs are required. For example, the particular plot layout of the project being estimated may require much closer equipment placement than is typical. Therefore, you may want to make some adjustment to account for the shorter piping, conduit, and wiring runs than the factors would normally account for. Locating a project in an active seismic zone may require adjustments to foundations, support steel, etc.

Once the equipment factored costs have been developed, you must account for the remainder of the project costs that are not covered by the equipment factors. Depending on the particular type of equipment factors used, this may require developing the costs for indirect field costs, home office (project administration and engineering/design) costs, outside battery limit costs, etc.

Equipment factored estimates are typically prepared during the feasibility stage of a project. They can be quite precise if the equipment factors are appropriate, the correct adjustments have been applied, and the list of process equipment is complete and accurate. They have an advantage over capacity factored estimates in that they are based upon the specific process design for the project. It is extremely important to understand the basis behind the equipment factors being used, and to account for all costs that are not covered by the factors themselves.

Ratio or factored methods may often be used in other situations, such as estimating the cost for Outside Battery Limit Facilities (OSBL) from the cost of Inside Battery Limit Facilities (ISBL); or estimating the costs of indirect construction cost from the direct construction costs. Derivation of the appropriate multiplying factors from accurate historical cost information is critical to the resulting accuracy from this estimating methodology.

Parametric Method

A Parametric Cost Model is an extremely useful tool for preparing early conceptual estimates when there is little technical data or engineering deliverables to provide a basis for using more detailed estimating methods. A parametric model is a mathematical representation of cost relationships that provide a logical and predictable correlation between the physical or functional characteristics of a plant (or process system) and its resultant cost [9]. A parametric estimate is comprised of cost estimating relationships and other parametric estimating functions that provide logical and repeatable relationships between independent variables, such as design parameters or physical characteristics and the dependent variable, cost.

Capacity factor and equipment factors estimates are simple examples of parametric estimates; however, sophisticated parametric models typically involve several independent variables or cost drivers. Yet, similar to those estimating methods, parametric estimating is reliant on the collection and analysis of previous project cost data in order to develop the Cost Estimating Relationships (CER's).

The development of a parametric estimating model can appear to be a daunting task; however, the use of modern computer technology (including popular spreadsheet programs) can make the process tolerable, and much easier than it would have been years ago. The process of developing a parametric model should generally involve the following steps [10, 11]:

- Cost Model Scope Determination
- Data Collection
- Data Normalization
- Data Analysis
- Data Application
- Testing
- Documentation

The first step in developing a parametric model is to establish its scope. This includes defining the end use of the model, the physical characteristics of the model, the cost basis of the model, and the critical components and cost drivers. The end use of the model is typically to prepare conceptual estimates for a process plant or system. The type of process to be covered by the model, the type of costs to be estimated by the model (TIC, TFC, etc.), the intended accuracy range of the model, etc. should all be determined as part of the end use definition. The model should be based on actual costs from complete projects and reflect your organization's engineering practices and technology. The model should generate current year costs or have the ability to escalate to current year costs. The model should be based on key design parameters that can be defined with reasonable accuracy early in the project scope development, and provide the capability for the estimator to easily adjust the derived costs for specific complexity or other factors affecting a particular project.

Data collection and development for a parametric estimating model requires a significant effort. The quality of the resulting model can be no better than the quality of the data it is based upon. Both cost and scope information must be identified and collected. The level at which the cost data is collected will affect the level at which the model can generate costs, and may affect the derivation of the CER's. It is best to collect cost data at a fairly low level of detail [12]. The cost data can always be summarized later if an aggregate level of cost information provides a better model. It is obviously important to include the year for the cost data, in order to normalize costs later. The scope information should include all proposed design parameters or key cost drivers for the model, as well as any other information that may affect costs. The type of data to be collected is usually decided upon in cooperation with the engineering and project control communities. It is usually best to create a formal data collection form that can be consistently used, and revised if necessary.

After the data has been collected, the next step in the process of developing a parametric model is to normalize the data before the data analysis stage. Normalizing the data refers to making adjustments to the data to account for the differences between the actual basis of the data for each project, and a desired standard basis of data to be used for the parametric model. Typically, data normalization implies making adjustments for escalation, location, site conditions, system specifications, and cost scope.

Data analysis is the next step in the development of a parametric model. There are many diverse methods and techniques that can be employed in data analysis, and are too complex to delve into in this article. Typically, data analysis consists or performing regression analysis of costs versus selected design parameters to determine the key drivers for the model. Most spreadsheet applications now provide regression analysis and simulation functions that are reasonably simple to use. The more advanced statistical and regression programs have goal seeking capabilities, which can also make the process easier.

Generally, a series of regression analysis cases (linear and non-linear) will be run against the data to determine the best algorithms that will eventually comprise the parametric model. The algorithms will usually take one of the following forms:

Linear Relationship: $\$ = a + bV_1 + cV_2 + \ldots$

Non-Linear Relationship: $\$ = a + bV_1^x + cV_2^y + \ldots$

Where: V_1 and V_2 are input variables; a, b, and c are constants derived from regression; and x and y are exponents derived from regression.

The various relationships (cost versus design parameters) are first examined for "best-fit" by looking for the highest "R-Squared" value. R^2 has the technical sounding name of "coefficient of determination," and is commonly used as a measure of the goodness of fit for a regression equation. In simple terms, it is one measure of how well the equation explains the variability of the data. The resulting algorithms from the regression analysis are then applied to the input data sets to determine, on a project-by-project basis, how well the regression algorithm predicts the actual cost.

Regression analysis can be a time consuming process (especially with the simple regression tools of a spreadsheet program), as iterative experiments are made to discover the best-fit algorithms. As an algorithm is discovered that appears to provide good results, it must be tested to ensure that it properly explains the data. Advanced statistical tools can quicken the process, but can be more difficult to use. Sometimes, you will find that erratic or outlying data points will need to be removed from the input data in order to avoid distortions in the results. It's also very important to realize that many costs relationships are non-linear, and therefore one or more of the input variables will be raised to a power (as in the equation above). You will need to experiment both with the variables you are testing against, and the exponential powers used for the variables. Regression analysis tends to be a continuing trial-and-error process until the proper results are obtained that appears to explain the data. Several individual algorithms may be generated and then later combined into a complete parametric model.

The data application stage of the development process involves establishing the user interface and presentation form for the parametric cost model. Using the mathematical and statistical algorithms developed in the data analysis stage, the various inputs to the cost model are identified; and an interface is developed to provide the estimator with an easy and straightforward way in which to enter this information. Electronic spreadsheets provide an excellent mechanism to accept estimator input, calculate costs based upon algorithms, and display the resulting output.

One of the most important steps in developing a cost model is to test its accuracy and validity. As mentioned previously, one of the key indicators of how well a regression equation explains the data is the R^2 value, providing a measure of how well the algorithm predicts the calculated costs. However, a high R^2 value by itself does not imply that the relationships between the data inputs and the resulting cost are statistically significant.

Once you have performed the regression analysis, and obtained an algorithm with a reasonably high R^2 value, you still need to examine the algorithm to ensure that it makes common sense. In other words, perform a cursory examination of the model to look for the obvious relationships that you expect to see. If the relationships from the model appear to be reasonable, then you can run additional tests for statistical significance (t-test and f-test), and to verify that the model is providing results within an acceptable range of error.

One of the quick checks to run is to test the regression results directly against the input data to see the percent error for each of the inputs. This lets you quickly determine the range of error, and interpreting the results can help you to determine problems and refine the algorithms. After all of the individual algorithms have been developed and assembled into a complete parametric cost model, it is important to test the model as a whole against new data (data not used in the development of the model). You should consult statistical texts for more information about testing regression results and cost models.

Lastly, the resulting cost model and parametric estimating application must be documented thoroughly. A user manual should be prepared showing the steps involved in preparing an estimate using the cost model, and describing clearly the required inputs to the cost model. The data used to create the model should be documented, including a discussion on how the data was adjusted or normalized for use in the data analysis stage. It is usually desirable to make available the actual regression data sets and the resulting regression equations and test results. All assumptions and allowances designed into the cost model, to include exclusions, should be documented. The range of applicable input values and the limitations of the model's algorithms should also be explained.

As an example of developing a parametric estimating model, we will examine the costs and design parameters of Induced Draft Cooling Towers. These units are typically used in industrial facilities to provide a recycle cooling water loop. The units are generally prefabricated, and installed on a subcontract or turnkey basis by the vendor. Key design parameters that appear to affect the costs of cooling towers are the cooling range, approach, and flow rate. The cooling range is the difference in temperature between the hot water entering the cooling tower and the cold water leaving the tower. The approach is the difference in the cold water leaving the tower and the design wet bulb temperature of the ambient air; and the flow rate measures the desired cooling capacity of the tower.

Table 9.2 provides the actual costs and design parameters of six recently completed cooling towers. The costs have been normalized (adjusted for location and time) to a Northeast US, Year 2000 timeframe.

Table 9.2—Cost and Design Information for Recent Cooling Tower Projects

Induced Draft Cooling Tower Costs and Design Parameters			
Cooling Range (°F)	**Approach (°F)**	**Flow Rate (1000 GPM)**	**Actual Cost**
30	15	50	$1,040,200
30	15	40	$787,100
40	15	50	$1,129,550
40	20	50	$868,200
25	10	30	$926,400
35	8	35	$1,332,400

This data provides the input to the data analysis steps of running a series of regression analyses to determine a sufficiently accurate algorithm for estimating costs. After much trial and error, the following cost estimating algorithm was developed:

Cost = $86,600 + $84500(Cooling Range in °F)$^{.65}$ - $68600(Approach in °F) + $76700(Flow Rate in 1000GPM)$^{.7}$

From this equation, we can see that the cooling range and flow rates affect costs in a non-linear fashion (i.e., they are raised to an exponential power), while the approach affects costs in a linear manner. In addition, the approach is negatively correlated with costs. Increasing the approach will result in a less costly cooling tower (as it increases the efficiency of the heat transfer taking place). These appear to be reasonable assumptions. In addition, the regression analysis resulted in an R^2 value of 0.96, which indicates the equation is a "good-fit" for explaining the variability in the data; and the F-Test shows statistical significance between the input data and the resulting costs.

In Table 9.3, the design parameters are displayed as used in the model (raised to a power when needed) and shown against the actual costs and the predicted costs from the estimating algorithm. In addition, the amount of the error (the difference between the actual and predicted costs), and the error as a percent of actual costs are shown. The percentage of error varies from –4.4 percent to 7.1 percent for the data used to develop the model.

Table 9.3—Predicted Costs for Cooling Tower Parametric Estimating Example

Induced Draft Cooling Tower Predicted Costs from Parametric Estimating Algorithm						
Cooling Range (°F)$^{.65}$	Approach (°F)	Flow Rate (1000 GPM)$^{.7}$	Actual Cost	Predicted Cost	Error	%Error
9.12	15	15.46	$1,040,200	$1,014,000	-$26,000	-2.5%
9.12	15	13.23	$787,100	$843,000	$55,900	7.1%
11.00	15	15.46	$1,129,550	$1,173,000	$43,450	3.8%
11.00	20	15.46	$868,200	$830,000	-$38,200	-4.4%
8.10	10	10.81	$926,400	$914,000	-$12,400	-1.3%
10.08	8	12.05	$1,332,400	$1,314,000	-$18,400	-1.4%

Using the estimating algorithm developed from regression analysis, we can develop tables of costs versus design parameters (see Table 9.4), and plot this information on graphs (see Figure 9.8).

Table 9.4—Data for Cost Graph Based on Parametric Estimating Example

Induced Draft Cooling Tower Costs Based on Parametric Model			
Cooling Range (°F)	**Approach (°F)**	**Flow Rate (1000 GPM)**	**Predicted Cost**
30	15	25	$559,000
30	15	30	$658,000
30	15	35	$752,000
30	15	40	$843,000
30	15	45	$930,000
30	15	50	$1,014,000
30	15	55	$1,096,000
30	15	60	$1,176,000
30	15	65	$1,254,000
30	15	70	$1,329,000
30	15	75	$1,404,000
40	15	25	$717,000
40	12	30	$816,000
40	15	35	$911,000
40	15	40	$1,001,000
40	15	45	$1,089,000
40	15	50	$1,173,000
40	15	55	$1,255,000
40	15	60	$1,334,000
40	15	65	$1,412,000
40	15	70	$1,488,000
40	15	75	$1,562,000

This information can then be rapidly used to prepare estimates for future cooling towers. It would also be very easy to develop a simple spreadsheet model that will accept the design parameters as input variables, and calculate the costs based on the parametric estimating algorithm.

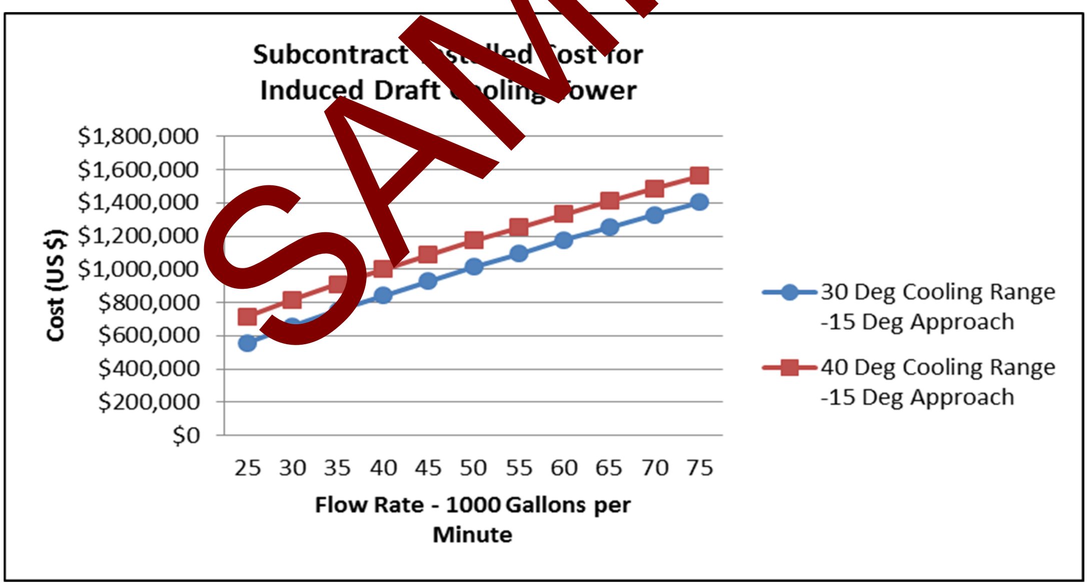

Figure 9.8—Graph of Cooling Tower Costs Based on Parametric Model

Parametric cost models can be a valuable resource in preparing early conceptual estimates. They are often used during both the concept screening and feasibility stages of a project. Parametric models can be surprisingly accurate for predicting the costs of even complex process systems. Parametric estimating models can be developed using basic skills in estimating, mathematics, statistics, and spreadsheet software. It is important to understand that the quality of results can be no better than the quality of the input data, and great care should be taken during the data collection stage to gather appropriate and accurate project scope and cost data.

Deterministic (Detailed) Estimating Methodologies

A detailed estimate is one in which each component comprising a project scope definition is quantitatively surveyed and priced using the most realistic unit prices available. Detailed estimates are typically prepared to support final budget authorization, contractor bid tenders, cost control during project execution, and change orders (Class 3 through Class 1 estimates). Detailed estimates use a deterministic estimating methodology and require a substantial amount of time and costs to prepare. It is not unusual for detailed estimates on very large projects to take several weeks, if not months, to prepare and can require thousands of engineering hours to prepare the required technical deliverables.

Detailed estimates are most often prepared by engineering or construction contractors, or other third parties, rather than the owner organization ultimately responsible for project funding. This is typically because of the large number of resources, time, and breadth and depth of detailed cost information required in the preparation of detailed estimates. In these cases, contract documents or some other form of estimate requirement documents may exist that specify how the estimate should be prepared; and these should be carefully reviewed.

The following is a description for detailed estimating activities associated with a process or industrial project, but could easily be adopted for other types of construction-related projects such as commercial construction. At a minimum, the required engineering and design data required to prepare a detailed estimate include process and utility flow drawings, piping and instrument diagrams, equipment data sheets, motor lists, electrical one-line diagrams, piping isometrics (for alloy and large diameter piping), equipment and piping layout drawings, plot plans, and engineering specifications. Pricing data should include vendor quotations, current pricing information from recent purchase orders, current labor rates, subcontract quotations, project schedule information (to determine escalation requirements), and the construction plan (to determine labor productivity and other adjustments).

In a completely detailed estimate, all costs are detailed including the direct field costs, indirect field costs, home office costs, and all other miscellaneous costs for both the ISBL and OSBL facilities. One variation of the detailed estimate is a semi-detailed estimate in which the costs for the ISBL process facilities are factored, and the costs for the OSBL facilities are detailed. Another variation is the forced-detailed estimate in which detailed estimating methods are used with incomplete design information. Typically, in a forced-detailed estimate, detailed takeoff quantities are generated from preliminary drawings and design information.

The following steps comprise the activities undertaken during preparation of a detailed estimate:

1. Prepare project estimate basis and schedule
2. Prepare Direct Field Cost (DFC) estimate
3. Prepare Indirect Field Cost (IFC) estimate
4. Prepare Home Office Cost (HOC) estimate
5. Prepare sales tax/duty estimates
6. Prepare escalation estimate
7. Prepare project fee estimate (for contractors)
8. Prepare cost risk analysis/contingency determination
9. Preview/validate estimate

The first step in preparing a detailed estimate is to begin establishing the project estimate plan and schedule. This is essentially the pre-planning phase for the estimate. As mentioned, a detailed estimate for a large industrial facility may take weeks to prepare, and involve several estimators and extensive support from engineering. The estimate plan documents the activities and course of action that will be used to prepare the estimate. The first activity is to review the organization's estimating guidelines and procedures with the estimating team. The project Work Breakdown Structure (WBS) should be reviewed with the project controls team, and agreement should be reached on the estimate format, structure, and deliverables. The detailed estimate is typically used to support cost control during execution of the project, and should be structured to accomplish that purpose. The listing of engineering and technical deliverables to be used to prepare the estimate should be reviewed, and the procedures for receiving and tracking the drawings and other design information established. The estimating team should identify the estimating resources, techniques, and data that will be used during estimate preparation. Any estimate exclusions that are known at this time should be reviewed and documented. Often, visits by the estimators to the project site are useful to understand specific site conditions.

The estimate schedule should be prepared, documenting when the various engineering deliverables are to be supplied, when each of the major sections of the estimate should be completed, and when estimate reviews will be scheduled. The estimate basis and schedule should be reviewed with the project team at an estimate kickoff meeting prior to estimate preparation. The estimate kickoff meeting provides an opportunity for the entire project team to understand the roles and responsibilities of the various participants, and to review the plans for the estimate preparation activities and estimate schedule. On very large projects, it is often beneficial to establish a few key contacts that will act as the liaisons between estimating and engineering. Any questions developed by the estimators during estimate preparation are funneled through a liaison that will then work with the responsible engineering representative to develop the answers.

Preparing the direct field cost estimate is the most intensive activity of preparing the detailed estimate. The project scope should be reviewed and understood, and all technical deliverables assembled. On large projects, the engineering drawings and technical information may be submitted to estimating over time. As each drawing or other information is received from engineering, it should be logged and kept track of. Performing the estimate takeoff (described in more detail below) should take place in accordance with the estimating department (and any special project) guidelines. This involves quantifying all the various material and labor components of the estimate. Care should be taken to ensure that all quantities are accounted for, but not double-counted. Material pricing is applied to the material quantities, using the best pricing information available. The labor worker hours are assigned to the labor activities, adjusted for labor productivity, and wage rates applied. Any estimate allowances are established. Any owner supplied materials, or other owner costs, are accounted for. The DFC estimate is then summarized and formatted. Finally, the DFC estimate should be reviewed for completeness and accuracy.

After the DFC estimate has been prepared, the Indirect Field Cost (IFC) estimate is started. The DFC estimate should be reviewed, and the total labor workhours identified. The labor workhours are typically a basis for factoring many of the of IFC costs. The indirect estimate factors should be determined, and applied. Indirect labor wage rates and staff labor rates are established and applied, and any indirect estimate allowances are accounted for. The IFC estimate is then summarized, formatted, and reviewed for completeness and accuracy. The construction manager should be specifically involved in the initial review of the IFC estimate.

The Home Office Cost (HOC) estimate is then prepared. For a detailed estimate, the various project administration and engineering disciplines should provide detailed workhour estimates for their project activities. The appropriate wage rates are then applied to the workhour estimates. Home office overhead factors are determined and applied to develop the home office overhead costs and expenses. The HOC estimate is then summarized, formatted, and reviewed.

Other miscellaneous activities and costs are then estimated. If sales tax is applicable to all (or portions) of the facility, they will need to be estimated using the appropriate local sales tax rates. If materials are to be imported, duties may be charged and will need to be estimated. Escalation costs should be estimated based on the project schedule. Depending on the project delivery method and contracting strategy, appropriate project fee estimates will need to be calculated and included. Finally, a cost risk analysis study should be performed and appropriate contingency is included in the estimate.

As with an equipment factored estimate, particular attention should be paid to pricing the process equipment for a detailed estimate as it contributes such a large share of the costs (20 to 40 percent of the total installed cost of the facility). Estimating the costs for process machinery and equipment requires many sources of input. The minimum information requirements for pricing equipment include the process flow drawings, the equipment lists, and the equipment process data sheets (usually prepared by the process engineering group). Often, the equipment process data sheets are provided to the mechanical/vessels engineering group to prepare narrative specifications and Request for Quotation (RFQ) packages.

Whenever possible, these engineering groups (perhaps in association with the procurement group) should be responsible for providing the equipment material purchase costs to the estimator for inclusion in the project estimate. Although estimating is typically responsible for pricing the material costs for bulk materials, the process and mechanical engineers are best able to accurately determine equipment material pricing and are generally in close contact with potential equipment vendors. Slight differences in equipment specifications can sometimes result in large differences in pricing, which an estimator may be unaware of. Formal vendor quotes for equipment pricing are preferred, however, sometimes time constraints in preparing the estimate do not permit solicitation of formal vendor quotes. In this case, equipment pricing may depend on informal quotes from vendors (i.e., phone discussions), in-house pricing data, recent purchase orders, capacity factored estimates from similar equipment, or from parametric pricing models.

The estimator should be responsible for checking the equipment list against the flow diagrams (or P&ID's) to ensure that all equipment items are identified and priced. The estimator must also be responsible for verifying that the costs for all equipment internals and accessories (trays, baffles, ladders, etc.) are included with the cost of the appropriate equipment. As opposed to most bulk commodity accounts (where the materials are generally available locally), freight costs for equipment can be significant and should usually be identified explicitly. Also, any vendor assistance and support costs should be identified and included with the material costs of the equipment. Major spare parts for process equipment will also need to be accounted for and included in the estimate.

Equipment installation costs are usually prepared by the estimator, with assistance from construction where required. Construction assistance is usually needed for heavy lifts, or where special installation methods may be used. The placement of large process equipment in an existing facility may also require special consideration. Installation workhours for equipment installation are usually based on weight and equipment dimensions, which are obtained from the equipment process data sheets). Using the equipment weights (or dimensions), the installation workhours are typically determined from curves based on historical data. Other forms of in-house or published data may also be used. When referencing the labor workhour data for equipment, the estimator must be careful to include all labor associated with the pieces of equipment (vessel internals, etc.). Depending on the information available, the labor hours to set and erect a heavy vessel may not include the hours to erect, takedown, and dismantle a guy derrick, gin poles, or other special lifting equipment. Special consideration may also be required to ensure costs for calibration, soil settlement procedures, special internal coatings, hydro-testing, and other testing costs are included in the estimate. Some equipment may be erected by subcontractors or the vendor, and included in the material purchase costs. Care must be taken to identify these situations.

As with the rest of the estimate, the responsibility of the estimator is to make sure that all costs are accounted for. For equipment in particular, this requires attention to detail, working closes with engineering and construction, and asking the right questions. With most process plants being so equipment-centric, the costs for purchasing and installing equipment comprise a significant portion of the total installed cost of the facility.

Detailed estimates are the most accurate of the estimating methods, but also require the most time and effort to prepare. Although detailed estimates are desirable for final budget authorization, the level of engineering progress needed and the time required for estimate preparation will sometimes preclude them from being used for this purpose. In today's economy, budgeting and investment decisions are often needed sooner than a detailed estimate would allow. Semi-detailed and forced-detailed estimates will often be employed for final budget authorizations, and a complete detailed estimate may be prepared later to support project control.

Take-Off

As mentioned above, estimating take-off is the process of quantifying the material and labor quantities associated with the project. The term take-off is also used to refer to the quantities themselves (often known as a Bill of Quantities). Take-off involves a detailed examination of the engineering drawings and deliverables to count the number of each item appearing on the drawings. The quantities of like items are then summarized according to the control structure (WBS/RBS) of the project. Once the take-off is complete, and total quantities for each like item summarized, the items can be costed (or priced), and the results added together resulting in the estimated direct field costs for the project.

Generally, the process of "take-off" for the estimate is much more efficient when standard estimating guidelines are established and followed. This provides advantage enough when a single estimator is preparing a specific estimate, but is even more important when multiple estimators are working on the same project. Guidelines for preparing an efficient take-off include:

- Use pre-printed forms for the orderly sequence of item descriptions, dimensions, quantities, pricing information, etc.
- Abbreviate (consistently) whenever possible.
- Be consistent when listing dimensions (i.e., length X width X height).
- Use printed dimensions from drawings when available.
- When possible, add up the printed dimensions for a given item.
- Measure all dimensions carefully.
- Use each set of dimensions to calculate multiple quantities where possible.
- Take advantage of design symmetry or repetition.
- List all gross dimensions that can be used again to rough check other quantities for approximate verifications.
- Convert imperial dimensions (feet/inch) to decimal equivalents.
- Do not round until the final summary of quantities.
- Multiply the large numbers first to reduce rounding errors.
- Do not convert the units until the final quantities are obtained.
- Items should be measured/converted to the same units consistently throughout the take-off.
- Mark the drawings as quantities are taken off. Use different colors to identify various types of components or items, as well as to identify items on hold, etc.
- Verify the drawings taken-off versus the approved drawing list to be used with the estimate. Check off drawings on the drawing list as take-off is complete.
- Keep similar items together, different items separate.
- Organize the take-off to match the control structure and format of the estimate.
- Identify drawing numbers, section numbers, etc. on the take-off forms to aid in future checking for completeness, and for incorporating late changes later on.
- Be alert for notes shown on drawings, changes in scale used on different drawings, drawings that are reduced from original size, discrepancies between drawings and specifications, changes in elevation that may not be obvious, etc.
- Be careful to quantify all labor operations that may not have a material component.

By keeping a uniform and consistent take-off process, the chance or error or omission is greatly reduced, and productivity is increased. Multiple estimators will find it easier to work on the same project; and if a personnel change takes place, it is much easier for a new estimator to pick up.

After the take-off is completed, the quantities can be extended, consolidated and priced. If a procurement department or other resources will be used to investigate certain pricing (major equipment, large bulk material purchases, subcontracts, etc.), a listing should be compiled and sent to the appropriate person.

With today's computerized estimating software, the process of take-off is often performed directly into the estimating software, rather than compiled manually onto forms. The software will often prompt for key dimensions and/or parameters for the specific item being quantified, and perform many of the required calculations automatically. In some cases, electronic digitizers can be used which automate the time-consuming task of measuring quantities from drawings, and can help to reduce errors. Using a digitizer, an estimator can measure the area of a concrete slab, the length of a piping run, or count a quantity of valves by tracing a boundary, touching end points, or selecting items from a paper drawing. In combination with the estimating software, the digitizer performs the required calculations required to accurately quantify the various items. The estimating software can also summarize quantities, and apply pricing.

In many construction projects, the material quantities used for estimating may be generated from the Computer-Aided Design (CAD) models developed by engineering. In such cases, the estimator must fully understand what has and has not been modeled at the time the quantities are generated by engineering to support estimate preparation. As an example, a process plant CAD model may only include the piping equal to or larger than 3” in diameter. In such a case, it is important for the estimator to account for all items (such as all piping items less than 3” in diameter) by performing a manual take-off, factoring from known relationships with other items, or by some other means. The estimator should spot check and validate that all quantities required by the scope of the project have been identified.

Take-off is performed for all of the activities and disciplines involved in the project scope. For example, for construction it may involve: site preparation and earthwork; foundations and concrete; structural steel; buildings; mechanical equipment; piping; electrical; instrumentation; and coatings. All other activities involved also need to be quantified including: project management; engineering and design; start-up and commissioning; etc. When required, activities performed by subcontractors or other third parties are identified separately from those activities being performed by the direct involvement of the party preparing the estimate.

Costing Vs. Pricing

Costing is the process of applying unit costs to the individual quantities of items associated with the estimate. For a detailed estimate, this is usually in the form of labor hours, wage rates, material costs, and perhaps subcontract costs. These costs may come from a variety of sources such as an estimating database (either in-house or commercial), vendor quotes, the procurement department, estimating experience, etc.

Pricing, on the other hand, is adjusting the costs that have been applied for specific project conditions, and commercial terms. Pricing includes adjustments to cost to allow for overhead and profit, to improve cash flow, or otherwise serve the business interests of the party preparing the estimate. Thus, the level and type of pricing adjustments depend on the particular party preparing the estimate.

For example, to a concrete contractor preparing a bid for a defined scope of foundation work, his or her costs will include the direct material and labor costs associated with pricing and installing the foundations. However, the price reflected by his bid will include not only his or her costs, but also an allowance for his or her overhead and profit; so the price reflected in his or her bid is higher than his or her cost.

Pricing also includes adjustments to costs for specific project conditions. Depending on the specific cost information used in preparing the estimate, material costs may need to be adjusted for location, materials of construction, or to account for differences between the item being installed and the item you may have an available cost for. Labor hours may require productivity adjustments for a variety of conditions such as weather, amount of overtime, interferences from production, material logistics, congestion, the experience of the labor crews, the level of contamination control, etc. Labor rates may also need to be adjusted for location, crew mix, open shop versus union issues, and specific benefit and burden requirements.

Material Costing/Pricing

The costs for material components of the project estimate may be obtained from internal estimating databases, quotations from suppliers, or from available vendor pricing catalogs. As referenced above, often accurate pricing information for the exact component may not be readily available for the required item, and the cost will need to be estimated and adjusted from the price for a closely related item. Also, pricing adjustments may be required to account for the overall quantity of items being procured (bulk purchase discounts). If pricing is obtained from internal estimating databases, constant calibration of the estimating database is required to account for changing market conditions.

Labor Costing/Pricing

The costs for labor activities depends on both the unit hours for an activity (e.g., hours to install a 10” welded valve) and the corresponding wage rates for the personnel involved with the labor activity. In construction for example, most labor activities are performed by a mixture of personnel, each of which may be compensated for at a different wage rate.

For example, a piping installation crew may involve a foreman, five pipefitter/welders, and two laborers. Thus, the unit hours for installing a 10-inch welded valve are typically accounted for as “crew” hours. If the installation of the welded valve requires eight hours, it implies that on average five hours will be required by the pipefitters/welders to set and weld the valve; two hours will be required by the laborers to obtain the valve from the warehouse and prepare it for installation; and one hour is required by the foreman for overall supervision, planning, and record keeping. The unit hours (labor hour production rates) are typically documented as crew hours per unit (such as eight hours per 10-inch welded valve). Unit hours are typically obtained from documents known as Labor Productivity Norms (Unit Labor Charts), or may be documented within an estimating database. Labor Norms (whether as stand-alone documents or contained in estimating databases) may be developed and maintained in-house by the estimating department, or may be obtained from commercially available sources.

As defined in AACE RP 73R-13, "A labor productivity norm is a value that is established as the agreed upon reference or benchmark for the number of labor hours (work effort) required to complete a defined work activity, given the specific definitions associated with that value [13]. Each labor productivity norm is an agreed upon typical or average number of labor hours required by a worker or group of workers (i.e., crew) associated with the work activity performed under the stated qualifications. For simplicity, we define a labor productivity norm as a number of hours for an activity per unit of measurement (sometimes called unit hours)."

"Labor productivity norms should be an all-inclusive value for one item of work. Labor norms should include a preamble for the relevant disciplines where the scope of each individual labor norm is defined. A preamble in the context of a labor norm is a narrative to precisely describe the content (inclusion and exclusions), the labor normal conditions, the unit of measurement and method of measurement of an activity and its applicable labor norm. It should be clear from the definitions in the preamble when circumstances or working conditions will require adjustment factors to be applied to the labor productivity norm."

"The labor productivity norm establishes the baseline labor hours for a work activity (typically treated as the 1.0 baseline, to which further adjustments may be applied based on specific project conditions)." Applying labor norms (unit hours) within an estimate requires the application of labor productivity adjustment factors to account for the differences between the basis on which the labor norms were developed (and documented) and the specific project conditions, such as:

- Weather
- Work-week schedule and overtime
- Overall scale of project activity
- Interference from production operations (in an existing facility)
- Hazardous conditions
- Material logistics
- Workspace congestion
- Experience of the labor crews

Labor rates can also be a tricky issue. Labor rates may reflect varying combinations of the following:

- Underlying base wages (the wage rate earned by the individual worker)
- Benefits and burdens (fringe benefits, taxes, and insurances paid by the worker's employer on behalf of the worker)
- Crew make-up
- Work-week schedule and overtime shift differentials
- Overhead, profit, and risk premiums
- Labor indirects of many kinds

When the labor hours assigned to an activity in the estimate reflect unit crew hours, the corresponding labor rate should be a "crew labor rate." As described above, crew may involve several types of workers with each type earning a different base wage rate (and possibly different benefits and burdens). Complicating the matter further is that there may be multiple skill levels within each worker type. For example, in the piping crew described above, four of the five pipefitter/welders may be journeyman, while one is an apprentice.

A composite crew rate for the piping crew can be calculated as shown in the following example:

Table 9.5—Composite Wage Rate Calculation

	Percent	Base Wage Rate	Benefits				Subtotal Rate with Benefits	Statutory Burdens		Total Wage Rate with B&B
			Vacation 10%	Health & Welfare	Pension	Other		Employer Insurance 3.60%	Worker's Comp 1.95%	
Piping Foreman	12.50%	$29.94	3.00	1.33	3.70	1.02	$39.00	1.19	0.64	$40.83
Pipefitter/Welder JM	50.00%	$26.75	2.68	1.33	3.70	1.02	$35.48	1.06	0.57	$37.11
Pipefitter/Welder App	12.50%	$19.80	1.98	1.33	3.70	1.02	$27.83	0.78	0.42	$29.03
Laborer	25.00%	$24.20	2.42	1.25	3.30	0.76	$31.93	0.96	0.52	$33.41
Piping Foreman	12.50%	$3.74	0.38	0.17	0.46	0.13	[illegible]	0.15	0.08	$5.11
Pipefitter/Welder JM	50.00%	$13.38	1.34	0.67	1.85	0.51	$17.75	0.53	0.29	$18.57
Pipefitter/Welder App	12.50%	$2.48	0.25	0.17	0.46	0.13	[illegible]	[illegible]	0.05	$3.64
Laborer	25.00%	$6.05	0.61	0.31	0.83	0.19	$7.99	0.24	0.13	$8.36
Composite Piping Rate		**$25.65**	**$2.58**	**$1.32**	**$3.60**	[illegible]	**$34.11**	**$1.02**	**$0.55**	**$35.68**

The top half of Table 9.5 identifies the types and skill levels of the workers in the crew, and the percent of each. It also lists the base wage rate, and the allocations for benefits and burdens for each. The last column in Table 9.5 identifies the total wage rate, including benefits and burdens, for each type and skill level for the crew workers.

The bottom half of Table 9.5 shows the weighted calculations (i.e., the cost from the top half of the table multiplied by the percentage of each type and skill level of crew member. Thus, the overall composite wage rate for the piping crew is identified as $35.68 per hour. The foreman contributes $5.11 toward the composite rate, while the journeyman pipefitter/welder contributes $18.57 toward the composite rate, etc.

This is a simplistic example. Actual crew makeup will vary, as will individual base wage rates, and the types and allocations for benefits and burdens. Wage rates, benefits, and burdens will vary based on union versus open-shop construction. They will also vary by region and other considerations. The estimator will need to research current rates for wages, benefits, and burdens applicable to the particular project. This data may be maintained internally, or may be obtained from applicable union, trade, government, or other organizations. Occasionally, wage rates to be used may be dictated by contractual or governmental agreements.

Table 9.5 is also based on a typical 40-hour per week (straight-time) work week schedule. Overtime or other work shift schedules would also require adjustment. Also, the Table 9.5 excludes contractor overhead, profit, and risk premiums and any labor indirect factors. Owner organizations sometimes want to see "all-in" wage rates used in their estimates; including contractor overhead, profit, and risk premiums, and perhaps some level (or potentially all construction indirect costs). Additional calculations would be required to generate "all-in" costs.

Unit Rate Construction

Some projects are estimated on a unit-rate basis, in which an all-in cost including material and labor (hours and wage rate) costs are applied to each unit, instead of separating material and labor costs separately. For example, in a unit-rate estimate, and all-in rate of $435 per cubic meter of foundation concrete may be used, which includes all material and labor costs. Supporting cost information and estimating databases would have to be maintained appropriately to provide this information for use in a unit-rate estimate. Subcontract construction costs are often based on unit-rate costs.

ESTIMATE ALLOWANCES

Allowances are often included in an estimate to account for the predictable but undefinable costs associated with project scope. Allowances are most often used when preparing deterministic or detailed estimates. Even for this class of estimate, the level of project definition may not enable certain costs to be estimated definitively. There are also times when it is simply not cost effective to quantify and cost every small item included with the project. To account for these situations, an allowance for the costs associated with these items may be included in the estimate.

Allowances are often included in the estimate as a percentage of some detailed cost component. Some typical examples of allowances that may be included in a detailed construction estimate are:

- design allowance for engineered equipment
- material take-off allowance
- overbuy allowance
- unrecoverable shipping damage allowance
- allowance for undefined major items

A design allowance for engineered equipment is often required to account for continuing design development that occurs even after placement of a purchase order for the equipment. At the time of a detailed estimate, vendor quotes are usually available to account of the purchase cost of the equipment. However, for specialty engineered equipment, it is often likely that the quoted cost is not the final cost incurred by the project. We do not necessarily understand when or how the costs will increase, but we can often predict that they will be based on past project experiences. After initial placement of the order for specialty equipment, continuing design activities may tighten tolerances, increase the quality of finish required, change metallurgies, etc. The predicted additional cost will frequently be included in the estimate as an design allowance for engineered equipment (or design development allowance); and be applied as a percentage of the total cost of engineered equipment, or the total cost of specific engineered equipment types when the percentage allowance will vary by equipment type. Typical percentages are from two percent to five percent of engineered equipment cost.

Material take-off allowances are usually intended to cover the cost of undefinable materials at the time of estimate preparation. The completeness of bulk material take-off can vary widely, depending on the status of engineering deliverables at the time estimate preparation begins. For example, all of the small-bore piping may not be included on the design drawings, or perhaps not all of the embeds and related small accessories are identified in the concrete design. A material take-off allowance may be included to cover for the lack of complete project definition. It may also account for those small items it is simply not economical to take-off or detail in the estimate. Generally, material take-off allowances are included as both a material and labor cost. They are intended to cover materials which are an actual part of the project and will thus need to be installed. Material take-off allowances are typically applied as a percentage of direct commodity costs by discipline (or trade). The percentages will vary by discipline, and from project to project depending on the estimating methods used and the level of engineering deliverables to support the estimate. Percentages may run from two percent to 15 percent of discipline costs.

Overbuy allowances provide for inventory losses as a result of such things as damage at the jobsite, cutting loss or waste, misuse of materials, theft, etc. Every project experiences these types of losses depending on jobsite location and other project conditions. Some organizations may split these into several separate allowances (breakage, theft, etc.). Overbuy allowances usually apply to material costs only, may vary from two percent to ten percent of discipline material costs.

Damage to equipment and materials during shipment is to be expected on virtually every project. Usually, the cost of damage is covered by insurance if detected upon arrival at the jobsite and dealt with expeditiously. An allowance for unrecoverable shipping allowance is intended to cover such losses that are not covered by insurance. This allowance will vary based on project conditions, project material delivery and handling procedures, and the types of material and equipment being shipped.

Occasionally, an order-of-magnitude cost for a major segment of scope must be stated before definition of that work has begun. A particular area of scope may simply not have progressed in design as far as the rest of the project, but a cost for that scope must be included in the estimate. In this case, the cost is included as an allowance, and may simply be a best "guestimate" to be included in the estimate until a later time when better definition can be obtained. This is sometimes referred to as an allowance for an undefined major item.

Other miscellaneous allowances may sometimes be included in an estimate for any situation where a statistical correlation is more reliable that a detailed quantification, or where it is not economical to perform a detailed take-off. Percentage allowances are often included for such items. Material and/or labor costs routinely covered by such items include:

- Percentage of hand excavation/backfill (vs. machine excavation/backfill)
- Formwork accessories
- Structural steel connection materials
- Bolts, gaskets, etc.
- Piping hangers, guides, etc.
- Miscellaneous welding operations
- Hydro-testing, other testing operations

Specific application of estimating allowances will depend on many things. For conceptual estimates, such as a capacity factored estimate, allowances may not be required as the estimating methodology itself covers all scope and costs included in the project.

Allowances are usually more applicable to semi-detailed and detailed estimates, with the cost value of allowances (or percentage costs) becoming less as project definition increases. The specific allowances and values will usually depend on specific organization estimating procedures and experience.

ESTIMATE ACCURACY

An estimate is a prediction of the expected final cost of a proposed project (for a given scope of work). By its nature, an estimate is associated with uncertainty, and therefore is also associated with a probability of over-running or under-running the predicted cost. Given the probabilistic nature of an estimate, it should not be regarded as a single point number or cost. Instead, an estimate actually reflects a range of potential cost outcomes, with each value within this range associated with a probability of occurrence.

Typically, the preparation of an estimate results in a single value. If we prepare a conceptual estimate using capacity factored techniques, we calculate a single point value as the estimated cost. When preparing detailed estimates, as the sum of many individual estimating algorithms, we also calculate the estimate total as a single point value. What we need to understand is the uncertainty associated with that single point value, and the true probabilistic nature of an estimate.

Most of the end uses of an estimate require a single point value within the range of probable values to be selected. For example, when used to develop a project funding amount or budget, we must select a single value to represent the estimate. When taking into account the uncertainty associated with an estimate, we will often add an amount (contingency) to the initially developed point value to represent the final estimate cost. When doing so, we must take into account such things as the accuracy range of the estimate, confidence levels, risk issues, and other factors in selecting the best single point value to represent the final value of the estimate.

Estimate accuracy is an indication of the degree to which the final cost outcome of a project may vary from the single point value used as the estimated cost. It should generally be regarded as a probabilistic assessment of how far a project's final cost may vary from the single point value that is selected to represent the estimate. Accuracy is traditionally represented as a +/- percentage range around the point estimate; with a stated confidence level that the actual cost outcome will fall within this range. This common +/- percent measure associated with an estimate is merely a useful simplification, given the reality that each individual estimate will be associated with a different probability distribution explaining its unique level of uncertainty.

Estimate accuracy tends to improve (i.e., the range of probable values narrows) as the level of project definition used to prepare the estimate improves. Generally, the level of project definition is closely correlated with engineering progress; thus, as the level of engineering progresses, estimate accuracy improves. This is shown in Figure 9.9.

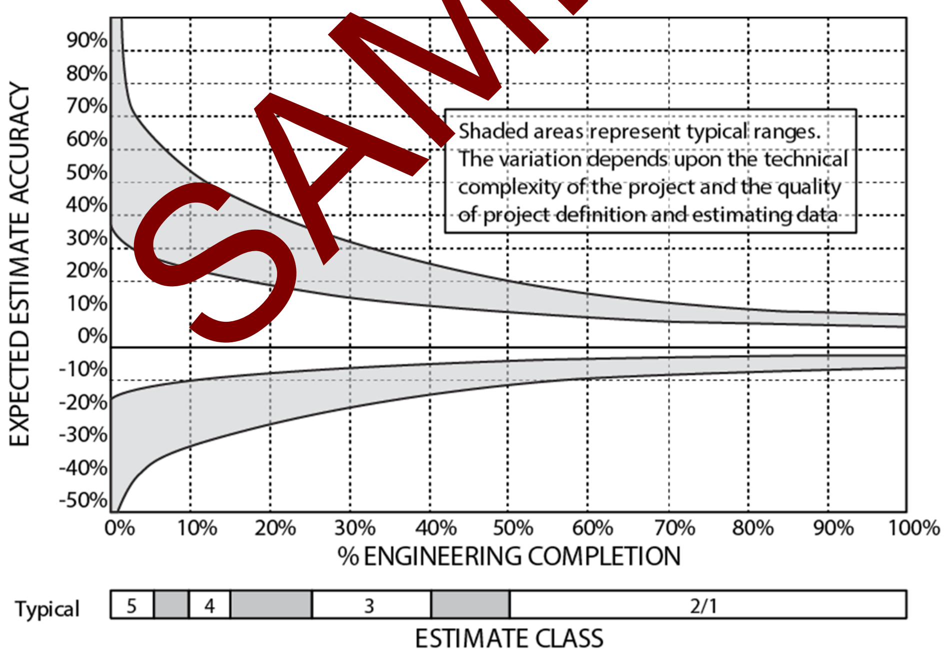

Figure 9.9—Relationship between Estimate Accuracy and Engineering Progress

This chart is intended only as an illustration of the general relationship between estimate accuracy and the level of engineering complete. As shown in Figure 9.9, and described in the AACE Recommended Practices 17R-97 and 18R-97 on Estimate Classification, there is no absolute standard range on any estimate or class of estimate.

For the process industries, typical estimate ranges are illustrated as:

- Typical Class 5 Estimate:
  - High range of from: +30 to +100 percent
  - Low range of from: –20 to –50 percent
- Typical Class 4 Estimate:
  - High range of from: +20 to +50 percent
  - Low range of from: –15 to –30 percent
- Typical Class 3 Estimate:
  - High range of from: +10 to +30 percent
  - Low range of from: –10 to –20 percent

Although the percent of engineering complete (or level of project definition) is an important determinant of estimate accuracy, there are many other factors which also affect it. Some of these other factors include the state of new technology in the project, the quality of reference cost information used in preparing the estimate, the experience and skill of the estimator, the estimating techniques employed, the level of effort budgeted to prepare the estimate, and the desired end use of the estimate. Other important factors affecting estimate reliability are the project team's capability to control the project, and the capability to adjust the estimate for changes in scope as the project progresses.

Consideration of all of these factors is the reason that the high and low ranges of typical estimate accuracy are themselves variable. It is simply not possible to define a precise range of estimate accuracy, based solely on the percentage of engineering complete or class of estimate. Any specific estimate may not exhibit the patterns shown above. It is possible to have a Class 5 estimate with a very narrow estimate range, particularly for repeat projects with good historical costs upon which to base the estimate. Conversely, it is possible to have a Class 3 or Class 2 estimate with a very wide accuracy range, particularly for first-of-a-kind projects or those employing new technologies.

The +/- percent accuracy range of the estimate should always be determined from an assessment of the design deliverables and estimating information used in preparation of the estimate. Cost risk analysis studies should always be used for individual projects to determine their accuracy range based on this type of information. The resulting output of the cost risk analysis model then establishes a final estimate cost based on the level of confidence (or risk) acceptable to management in order not to overrun the project budget.

It is very important to recognize that the estimate ranges above are simply indicative across a large portfolio of projects, and only if all of the estimating deliverables have been developed to the required level of maturity for the class of estimate; and only if appropriate contingency has been included in the project estimate. Every individual project should identify its potential estimate accuracy from a comprehensive and appropriate cost risk analysis study.

When discussing estimate accuracy, it is also important to realize that for early conceptual estimates, variations in the design basis will have the greatest impact on costs. Estimating tools and methods, while important, are not usually the main problem during the early stages of a project when estimate accuracy is poorest. In the early phases of a project, effort should be directed toward establishing a better design basis than concentrating on using more detailed estimating methods.

Contingency and Risk Analysis

Contingency is, in many respects, the most misunderstood element contained in an estimate. This is, in large part, because of how the different members of a project team view contingency from their own frame of reference. A project manager may want the project budget to include as much funding as possible in order not to overrun the budget, and may want as a large contingency value included in the estimate as he or she can get away with. An engineering manager may want contingency funds to cover any overruns in engineering, while the construction manager hopes that engineering does not use any of the contingency funding, so that he or she has the entire amount to use in funding construction overruns. Corporate management may think of all requests for contingency as "padding" the estimate, and may consider any use of contingency funds as only being required because a project is poorly managed.

To the estimator, contingency is an amount used in the estimate to deal with the uncertainties inherent in the estimating process. The estimator regards contingency as the funds added to the originally derived point estimate to achieve a given probability of not overrunning the estimate (given relative stability of the project scope, and the assumptions upon which the estimate is based). Contingency is required because estimating is not an exact science. One definition of an estimate is that it is the expected value of a complex equation of probabilistic elements, each subject to random variation within defined ranges. Since the value assigned to each individual component of an estimate is subject to variability, the estimate total itself is also subject to variation.

Figure 9.10 illustrates the potential variability of a single component of an estimate. In this example, the variability is shown as a normal probability distribution around the estimated value of \$100. Since this is a normal probability distribution, the probability of underrun (shown as the area under the curve to the left of the vertical dotted line) equals 50 percent, the same as the probability of overrun (the area under the curve to the right of the dotted line). The estimate line item has an estimated cost of \$100; however, the accuracy range of the cost varies from \$50 to \$150, or an accuracy range of +/- 50 percent.

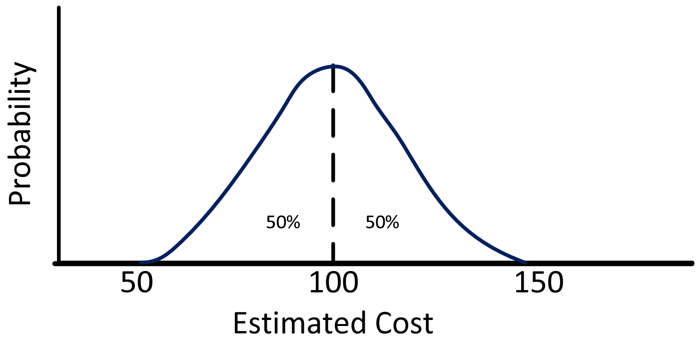

Figure 9.10—Variation of an Estimate Line Item with Normal Probability Distribution

Unfortunately, most items of cost in an estimate do not exhibit a normal probability distribution in respect to its potential variability. Most of the time, variability is more closely associated with a skewed distribution. Figure 9.11 shows the variability of an estimate line item for which the accuracy range of the cost is skewed to the high side.

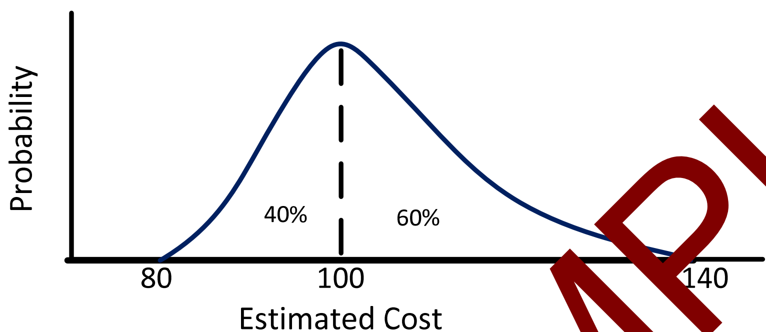

Figure 9.11—Variation of an Estimate Line Item with Skewed Probability Distribution

In this example, the item has been estimated at $100; however, the accuracy range of the cost varies from $80 to $140, or -20 to +40 percent. With an estimated value of $100, this example shows that there is only a 40 percent probability of underrun, while there is a 60 percent probability of overrun. In order to equalize the probability of underrun and overrun, an amount would need to be added to the original point value of $100. This amount would be considered contingency. Contingency would not change the overall accuracy range of $80 to $140; however, it would increase the probability of underrun while decreasing the probability (risk) of overrun.

Most items of cost in an estimate will demonstrate some measure of skewness, usually to the high side where the probability of overrun is higher than the probability of underrun. There are usually items where the skewness will be to the low side as well. The variability of the total estimate is the function of the variability associated with each individual line item. Since the probability distribution of most line items is skewed to the high side, the overall probability distribution for the estimate as a whole is also typically skewed to the high side. Contingency is thus usually a positive amount of funds added to cover the variability surrounding the point value of the estimate, and to reduce the chances of overrunning the point estimate to an acceptable level.

Items typically covered by contingency include:

- Errors and omissions in the estimating process.
- Variability associated with the quantification effort.
- At the time of estimate preparation, design may not be complete enough to determine final quantities.
- Some items required to be estimated may defy precise quantification.
- Some items to be quantified are generally computed by factored or other conceptual methods.
- Labor productivity variability.
- Labor availability, skills, and productivity may vary from that originally assumed.
- There is no such thing as an “average” tradesman that installs every incremental quantity of an item at the “average” rate typically used in preparing the estimate.
- Weather may vary from that assumed affecting labor productivity.
- Wage rate variability.

- Wages may vary from that assumed in the estimate because of inflationary reasons, changes in assumed crew mix, labor availability, and market conditions.
- Material and equipment costs.
- Material and equipment costs may vary from that in the estimate due to inflationary reasons and market conditions.
- Certain materials of construction may be substituted from that assumed in the estimate.
- Changes in actual quantities may change discount schedules from that assumed in the estimate.

Contingency specifically excludes:

- Significant changes in scope
- Major unexpected work stoppages (strikes, etc.)
- Disasters (hurricanes, tornadoes, etc.)
- Excessive, unexpected inflation
- Excessive, unexpected currency fluctuations

Risk analysis is a process that can be used to provide an understanding of the probability of overrunning (or underrunning) a specified estimate value. It provides a realistic view of completing a project for the specified estimate value by taking a scientific approach to understanding the uncertainties and probabilities associated with an estimate, and to aid in determining the amount of contingency funding to be added to an estimate. Its purpose is to improve the accuracy of project evaluations (not to improve the accuracy of an estimate).

Risk analysis generally uses a modeling concept to determine a composite probability distribution around the range of possible project cost totals. It provides a way in which to associate a level of risk with a selected project funding value. If the original point value of an estimate is assumed to be approximately the midpoint of the possible actual cost outcomes of project cost, that means that there is a 50 percent probability that the final outcome will exceed the estimated cost (without contingency). In reality, there is usually a greater probability that costs will increase rather than decrease. This means that the distribution of project cost outcomes is skewed, and there is a higher than 50 percent probability that final actual cost will exceed the point estimate (and this is historically the case). Two types of risk analysis are commonly used:

- Strategic risk analysis models that evaluate the level of project definition and project technical complexity in determining the overall risk to project cost.
- Detailed risk analysis models that evaluate the accuracy range for individual or groups of estimate components in determining the overall risk to project cost.

Both forms of risk analysis models usually generate overall probability distributions for the expected final cost outcomes for the project, and tables equating confidence levels with specific final cost values. The resulting probability distributions of final cost outcomes can be used to determine an amount to be included in the estimate as contingency. Basically, management typically makes this determination based on the level of risk they are willing to accept. The difference between the selected funding value and the original point estimate is the amount of contingency.

Table 9.6 shows an example of a cumulative probability distribution table produced by a typical risk analysis model. In this example, the original point estimate (before contingency) is $23.3 million. As can be seen from this table, the point estimate of $23.3 million results in only a 20 percent probability of cost exceeding (or underrunning) this value.

Table 9.6—Sample Cumulative Probability Distribution Table

Project Estimate			
Cumulative Probability of Underrun	**Indicated Funding Amount (Million $)**	**Estimated Contingency (Million $)**	**Percentage**
10%	$22.3		
20%	$23.3		
30%	$24.2		
40%	$24.8		
50%	$25.4	$2.1	9.0%
60%	$26.0		
70%	$26.6	$3.3	14.2%
80%	$27.4		
90%	$28.6		

If we wanted to achieve a 50 percent probability of underrun (and thus a 50 percent probability or overrun) we would need to fund the project at $25.4 million. This would mean adding a contingency amount of $2.1 million in the estimate, equivalent to nine percent of the original point value of the estimate. If we wanted to provide a 70 percent probability of not exceeding our project funding, we

would need to fund $26.6 million, which would add a contingency amount of $3.3 million to the estimate (equivalent to 14.2 percent of the point estimate).
This can also be shown in a typical graphical output from a risk analysis model for the same estimate as shown in Figure 9.12.

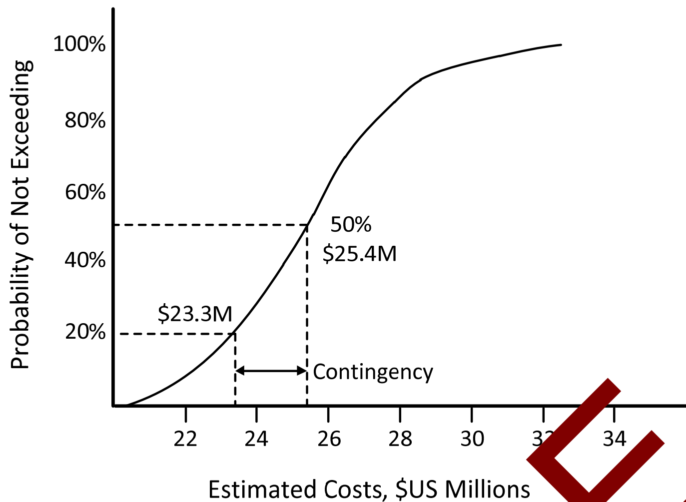

Figure 9.12—Graphical Cumulative Probability Distribution

As can be seen from this graph, increasing the amount of contingency increases the probability of not exceeding the project funding amount (the point estimate plus contingency). ***Contingency does not increase the overall accuracy of the estimate—it does not change the overall accuracy range of approximately of $18.5M to $32.5M.*** However, contingency does reduce the level of risk associated with the estimate and improve project evaluations when properly used.

Appropriately applied, risk analysis provides an effective means of determining an amount for estimate contingency, and of providing management with information about the variability of project estimates. In addition, the process of preparing a risk analysis model typically identifies specific project areas associated with both risk and opportunity. Those areas identified with high risk can then become focus areas in order to reduce and mitigate any risk issues, and the areas of low risk can become focus areas in order to capitalize on the opportunities they may provide.

Structuring the Estimate
The control structure for a project is the breakdown of the total work into manageable units or packages for the purposes of estimating and control of cost and schedule. The structure will vary with the size and complexity of the project, as well as the reporting requirements. The proper structuring of a project for control purposes contributes greatly to the effective implementation of project control procedures and the success of the project itself.

To maintain some kind of order in the estimate (and later in project execution), it is necessary to segregate costs into various categories:

- Material vs. Labor vs. Subcontracts
- Direct Costs vs. Indirect Costs vs. Home Office Costs
- Concrete vs. Structural Steel vs. Piping vs. Other Construction Disciplines

The control structure should be established as early as possible in the project life cycle, because it sets the pattern for accumulation of project costs, and should be used to form the basis for the structuring the estimate. The process of producing the project's control structure, often known as work breakdown planning, is often an ongoing process requiring updates as the scope of the project is refined during the project lifecycle. The segregation of costs can be referred to as establishing the project "coding" structure, and more specifically as the "code of accounts." Codes are the umbilical cords between cost accounting and cost engineering (estimating and cost control).

Large projects will often use Work Breakdown Structures (WBS) and Resource Breakdown Structures (RBS) as components of the overall coding structure. Smaller projects will often use a simpler code of accounts based simply on the disciplines or construction trades used on the project.

The WBS and RBS are basic project management tools that define the project along activity levels that can be clearly identified, managed, and controlled. The WBS is the division of a project, for the purposes of management and control, into sub-projects according to its functional components. The WBS typically reflects the manner in which the work will be performed, and should reflect the way in which cost data will be summarized and reported.

A WBS should be customized to be specific to a particular project, and is usually organized around the geographical and functional divisions of a project. It forms the high-level structure for an estimate. Figure 9.13 illustrates how a typical WBS might be organized.

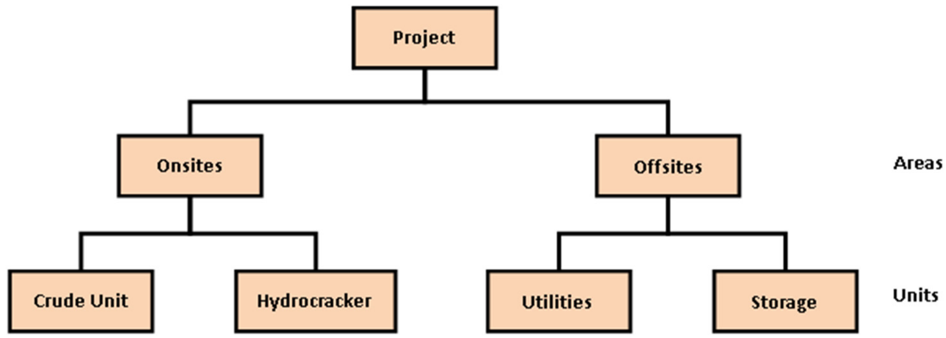

Figure 9.13—Sample WBS

The RBS is a breakdown of all labor and material resources required in the execution of the project. The RBS identifies functional lines of authority, and extends to the level at which work is actually assigned and controlled. The RBS typically remains consistent from project to project (at least for the same project types). Figure 9.14 illustrates a sample project RBS.

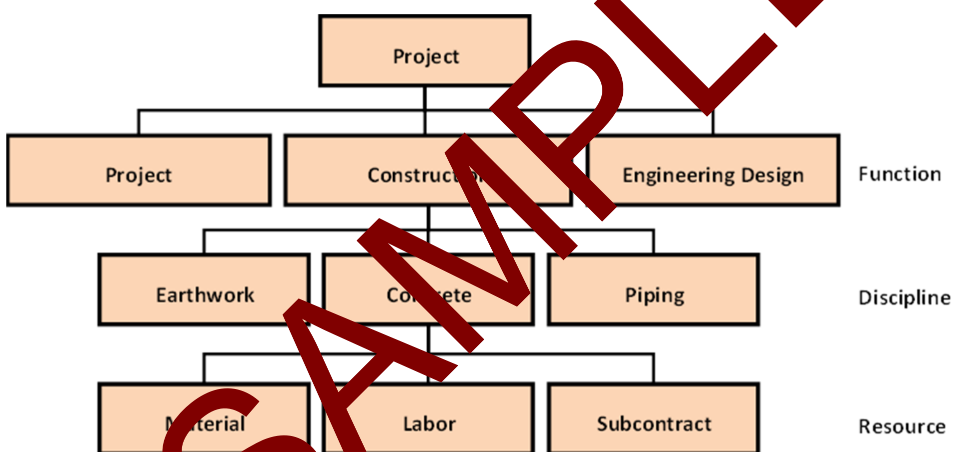

Figure 9.14—Sample RBS

The matrix of the WBS and RBS forms the full Project Control Structure or Project Breakdown System (PBS). The intersection points of the WBS and RBS structures is called a "cost center," and corresponds to a defined unit of work and the resources involved in executing that work. Each cost center equates to a specific "cost code." Figure 9.15 displays a sample Project Breakdown Structure.

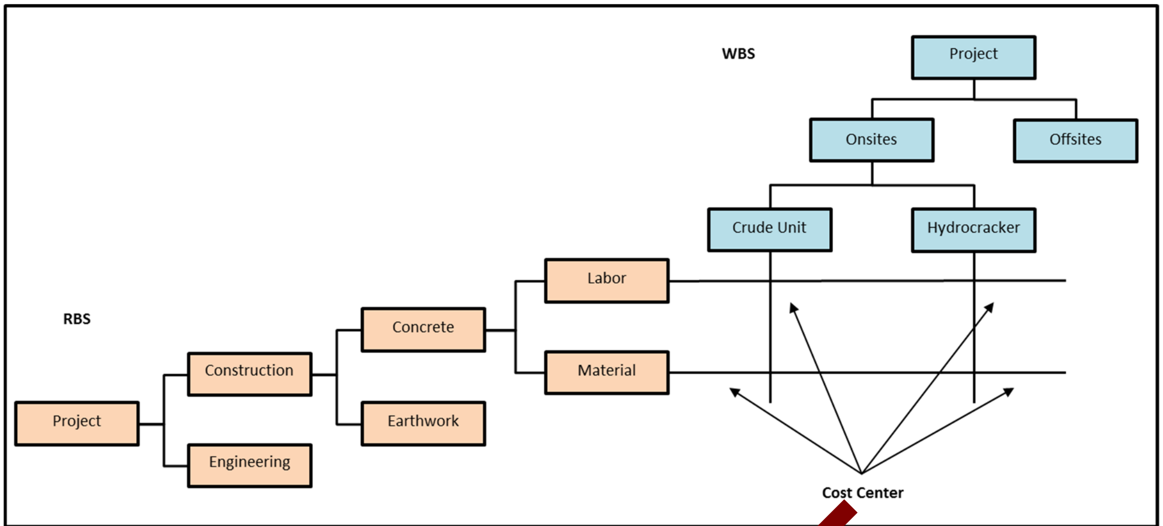

Figure 9.15—Sample Project Breakdown Structure

Corresponding with the PBS is a numbering system used to identify each cost center. The collection of codes used to designate the intersection of WBS and RBS identifiers forms the project's Code of Accounts. Figure 9.16 shows a sample coding structure.

Area	Unit	Function	Discipline	Detail	Resource
01-Onsites	01-Crude unit	A-Project Administration	1-Earthwork	001-Formwork	1-Labor
	02-Hydrocracker	B-Engineering/Design	2-Concrete	002-Rebar	2-Material
	03-Vacuum unit	C-Construction	3-Structural steel	003-Pour	3-Subcontract
			4-Piping	004-Embeds	
			5-Equipment	005-Finish	
02-Offsites	01-Utilities				
	02-Storage				
	03-Pipeway				

Figure 9.16—Sample Project Coding Structure

For a specific unit of work, the labor to pour concrete in the hydrocracker unit, the cost code would be: 01-02-C-2-003-1 (Onsite-Hydrocracker-Construction-Concrete-Pour-Labor).

The Code of Accounts formally refers to the full coding structure (including Project Identifier, WBS, and RBS elements), but the term is often used in regards to the RBS elements only. The coding structure must reflect the manner in which the project will be executed, and the way in which costs can reasonably be expected to be collected. The coding structure should also reflect the way in which your particular organization executes projects. The estimate, which predicts project execution, should be organized and structured to match the project code of accounts.

The coding structure adopted by an organization should be documented in detail. Typically, a code book is published and made available to all project personnel. The code book should contain a code by code listing which documents a description of not only what should be included under a specific code, but also what is excluded (for those items that could be easily misunderstood).

Estimate/Cost/Schedule Integration

The integration of the project cost estimate with the project schedule and cost control system is crucial for effective project management and control. Accomplishing this goal can be difficult at best; yet the estimate, schedule and cost system must share information with each other for each to be as accurate as possible. The schedule will provide dates that are essential to calculating escalation, cash flow, and commitment forecasts. The estimate provides labor hours and craft breakdowns essential to determining schedule activity durations and resource loading. The estimate also provides cost and quantities to the cost control system. The cost reporting system's record of labor and material expenditures needs to be correlated with schedule progress and remaining durations for schedule activities correlated to the forecasts-to-complete in the cost system.

The relationship between the cost estimate and schedule is not always straightforward. The natural breakdowns (or hierarchy) of cost and schedule structures are different. The cost system is organized to estimate, monitor and control dollars. The schedule system is organized to plan, monitor and control time. The control and monitoring of both variables are not necessarily compatible; and most often it is not the same people performing both tasks. The goal, then, is to align estimate cost data and schedule data at a level to support integration.

One approach is to breakdown the estimate to the level of schedule activities. This can result in a tremendous amount of detail in the cost estimate, and compromise efficient cost and schedule control. Some of the problems resulting from the one-to-one approach are:

- Collecting costs by detailed schedule activities is generally not feasible.
- Schedule activities are subject to much more change within the project than traditional cost codes.
- Tracking bulk material costs by activity is cumbersome and requires high administrative costs. And,
- Costs are often not incurred at the same time as construction activities.

The goal must be to determine an appropriate level of detail to correlate cost and schedule. It is important not to let either the estimate or the schedule drive the other down to an inappropriate level of detail. It is also important not to integrate at too high of a summary level.

Integrating at a sufficient level of detail involves keeping the estimate and schedule structures the identical to a certain level of work breakdown structure. Below this level, additional cost accounts and schedule activities are defined separately as required by each. The desire is to interface at a level where meaningful relationships exist.

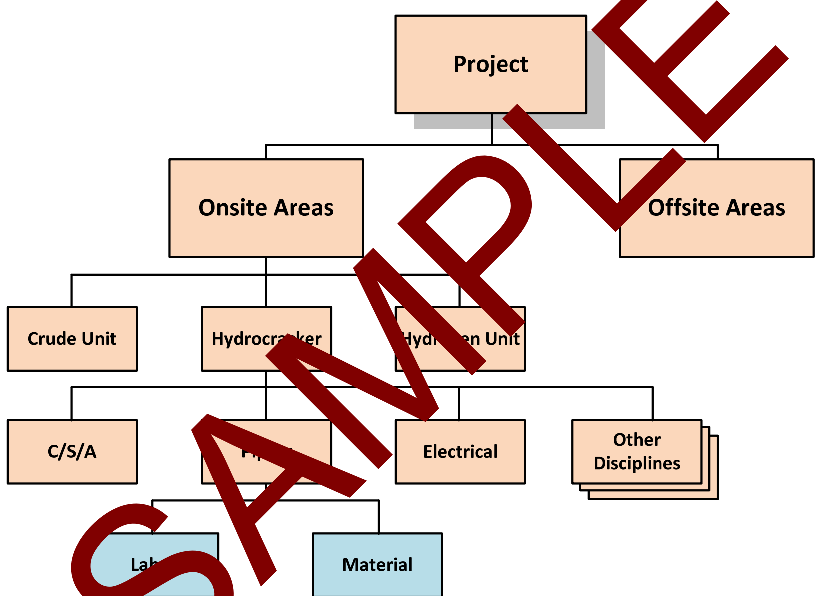

Figure 9.17—Cost/Estimate WBS Structure

Figure 9.17 illustrates a typical cost or estimate structure for a process plant, while Figure 9.18 illustrates a sample schedule structure for the same project. At some point, the cost and schedule WBS structures will diverge to meet each structure's particular control needs.

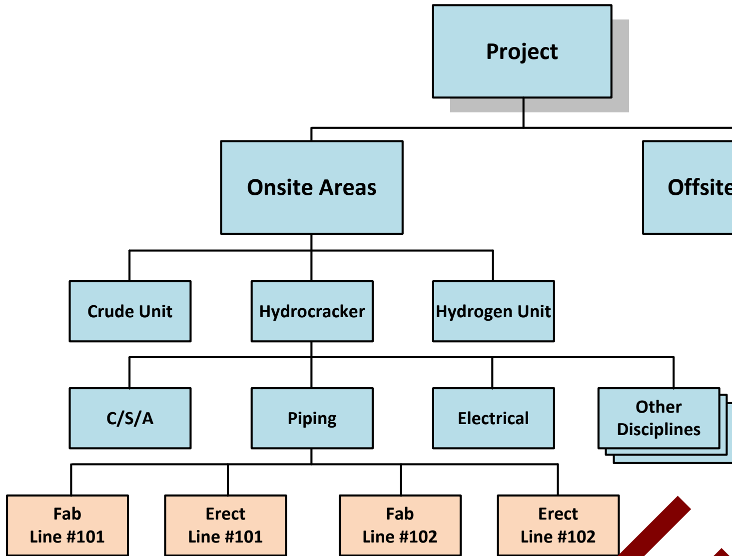

Figure 9.18—Schedule WBS Structure

The basic methodology for integrating the cost estimate and schedule therefore is to let the estimator and scheduler communicate on the high level WBS, and determine the levels at which cost items and schedule activities can be correlated. Then each further defines the lower level of detail required for particular needs. Meaningful information can then be transmitted at the appropriate level of detail between the two.

It should be acknowledged that one-to-one relationships between estimate cost items and schedule activities is not possible. Early and continuous communication between the estimator and scheduler can determine the best level at which to maintain compatibility and exchange information. The estimator can promote integration by assigning as many identification fields to the estimate line items as possible (i.e., building location, room number, system number, piping line number, foundation number, etc.). This will greatly assist in transferring estimate cost data and resource needs to the schedule. Computerized estimating and scheduling systems are making great strides in providing two-way communication between systems.

The cost estimate can be very sensitive to, and is usually prepared in correlation with a specific schedule. If the schedule is undefined or subject to change, the estimate is compromised and should reflect the appropriate cost risk. Changes to the project plan that affect either schedule duration or completion dates may significantly affect project cost. The basis estimating algorithm is:

Total $ = (Qty. X Unit Material $) + (Qty. X Unit Labor Hours X Wage Rate)

The Unit Material $, Unit Labor Hours, and Wage Rate can all be dependent on the assumed schedule and plan. Unit material costs are schedule dependent for impacts of inflation and seasonal variations. Unit labor hours are schedule dependent for seasonal labor availability, climate, and schedule impacts resulting from execution plan changes (affecting productivity). Wage rates are also sensitive for impacts of inflation, seasonal variation, and execution plan changes (affecting overtime and/or shift premiums).
Many costs in a project are very dependent on the duration. Project management and related costs are often estimated (and incurred) on a "level of effort" basis. If the project duration is extended, cost for these activities is directly affected. Construction indirect costs, such as construction management, field office, construction equipment rental, security office, site maintenance, etc., are also affected in a similar way.

Some costs are dependent on when they occur in the calendar year. Labor productivity can be adversely affected by weather (both snow and rain in the winter, or hot weather in summer). Construction indirects, such as weather protection or other construction support costs, can also be similarly affected.

Project costs can also be affected by schedule impact of execution plan changes. Changes to the execution plan to shorten the project duration may cause out-of-sequence construction, overtime, shift premiums, congestion, inefficient labor usage, etc. adversely impacting costs. A delay in equipment delivery may extend the project schedule increasing duration dependent costs. On the other hand, this may also result in increased efficiencies if labor resources can be allocated more efficiently, perhaps resulting in less overtime and shift premiums.

It is important to evaluate the effects of schedule and duration when preparing the estimate. Besides the obvious of accounting for the escalation costs to incorporate into the estimate, schedule impacts may directly affect labor productivity, as well as labor and material pricing. It is also essential to plan early for estimate/schedule integration so that estimate results can be shared with the schedule as required to assist in resource loading, and to aid in earned value analysis and progress reporting.

Estimate Review

An estimate is of critical importance to a project's success, it makes sense that the estimate should undergo a rigorous review process. The estimate should be evaluated not only for its quality or accuracy, but also to ensure that it contains all the required information and is presented in a way that is understandable to all project team members and client personnel. A structured (if not formal) estimate review process should be a standard practice for all estimating departments.

The following sequence of steps will discuss a formal review process for an internally prepared appropriation grade estimate (an estimate submitted for capital budget authorization). The level of detail and diligence used during the estimate review cycle will vary both with the strategic importance, total value, and purpose of the particular estimate. These steps can be easily adapted on a fit-for-use basis. In this discussion, we are focused on reviewing and validating an estimate – we are not discussing bidding strategies which can involve many other factors and decisions.

Estimate Review Cycles

The principle purpose of an estimate review process is to present information about both the estimate and the project in a way that allows the reviewer to evaluate that the estimate is of sufficient quality to meet its intended purpose. The estimate review process is usually comprised of a series of estimate reviews, beginning with internal estimating department reviews, engineering reviews, project team reviews, and continuing with reviews by various levels of management, depending on the importance of the project.

Estimating Team/Estimating Department Review

The first review of the estimate should, of course, be conducted by the estimating team that prepared the project estimate. This is essentially a screening review to ensure that the math is correct (extensions of pricing are correct, summaries add up properly, etc.), that the estimate is documented correctly (comprehensive basis of estimate document is prepared), and that it adheres to estimating department guidelines. Typically, this review is conducted by the lead estimator with the members of his estimating team. On very large projects or those of significant importance, this review may be conducted by the estimating department manager or supervisor.

Check the Math

When starting the estimate, review the mathematical computations to ensure they are correct. With today's computerized estimating systems, this is much less of a concern than 20 years ago when estimates were primarily prepared by hand using simple calculators; however, math errors can still occur. This can be a major concern when using an electronic spreadsheet, such as Excel, for preparing the estimate (as opposed to a commercial computerized estimating system). Surprisingly, it is very easy to make a formula error in a spreadsheet, such as inserting a row or column which does not get included in a subtotal. All spreadsheet formulas, subtotals and totals should be examined carefully for correctness. From a client's point of view, nothing will help to lose credibility in the entire estimate faster than a finding a math error that went undetected.

Basis of Estimate

The comprehensive Basis of Estimate (BOE) document should be reviewed carefully to ensure that it is both correct and complete. The BOE is an extremely important document. The dollar amount indicated on an estimate is meaningless without knowing the parameters, or what is included and not included in the estimate. The BOE serves to clearly define the design basis, planning basis, cost basis, and risk basis of the estimate.

- **Design Basis**: The overall scope of the project should be summarized, with additional detail provided for each area/unit/work package of the project. Specific inclusions, and even more importantly, specific exclusions of items or facilities should be documented. All assumptions regarding project scope should be documented. If available, equipment lists should be attached or referenced; and a listing of all drawings, sketches, and specifications used in the preparation of the estimate should be documented, including drawing revision date and number.
- **Planning Basis**: This portion of the BOE should document information from the integrated project plan which affects the estimate. It should include specific information about any contracting strategies for engineering, design, procurement, fabrication, and construction. It should include information about resourcing and project execution plans such as the length of the workweek, use of overtime, number of shifts, etc. It should include information about the project schedule and key milestone dates affecting the estimate.
- **Cost Basis**: The source of all pricing used in the estimate should be documented in this section of the BOE. This would include the source of all bulk material pricing, the pricing of major equipment (referencing quotes or purchase orders if used), and all labor rates including office, engineering, fabrication, and construction. The source of all labor workhours should be documented, along with any assumptions regarding labor productivities. All allowances included in the estimate should also be clearly identified. It is also important to document the time basis of the estimate (i.e., what point in time is assumed), and the basis for cost escalation included in the estimate.
- **Risk Basis**: Since, by definition, every estimate is a prediction of probable costs, it is clear that every estimate involves uncertainty and risk. Contingency is typically included in an estimate to cover the costs associated with this uncertainty.

This section of the BOE should document how the contingency was determined, and identify key areas of risk and opportunity in the cost estimate.

It is important to ensure that the basis of estimate is clear and easily understood, and to verify that all information and factors documented in the BOE have been consistently applied throughout the estimate (i.e., wage rates, labor productivities, material pricing, subcontract pricing, etc.). Again, the estimate can lose credibility if different pricing or labor rates have been used for the same item within the estimate detail.

Estimating Department Guidelines

A careful review should be done to verify that the cost estimate follows standard estimating guidelines for the department. This would include a review to verify that standard estimating procedures were followed regarding estimate format, cost coding, presentation and documentation. This would include items such as:

- Verify that the proper estimating methods, techniques and procedures were used that match the stage of project completeness. In other words, different estimating techniques will be used depending on the type and completeness of the engineering documents and deliverables available to create the estimate.
- Confirm that the estimate summary and details are organized and presented in the proper format (i.e., following the project work breakdown structure and code of accounts); and that the format is consistent with the intended purpose of the estimate (i.e., an estimate serving as a basis for cost control contains sufficient detail).
- Ensure that all estimate backup information is organized properly. Can all values on the summary page of the estimate be traced to the estimate detail pages, and can all information on the estimate detail pages be traced to the estimate backup or source documents? And,
- Verify that all allowances and factors are appropriate for the type of estimate being prepared, and are consistent with comparable projects and estimates.

This level of estimate review helps to ensure that all estimates prepared by the department are using established guidelines, and are presented in a consistent manner from project to project.

Engineering/Design Review

The next level of estimate review should be conducted with the engineering team, and should evaluate the estimate in terms of accurately representing the project scope. The core members of the engineering team are key participants in this review, along with the lead estimator and estimating team.

Completeness of Engineering Deliverables

One of the first items to review is the listing of all drawings, sketches, specifications, and other engineering deliverables used in preparing the estimate to ensure that it is complete (see design basis above). The lead engineers need to cross-reference this listing against their own engineering drawing and deliverable lists to make sure that all relevant information was passed on to the estimating team. The revision numbers of drawings should be checked to ensure that they match the intended revision for the estimate. If late changes to the engineering drawings have occurred, and are intended to be incorporated into the estimate, this needs to be checked to ensure that all late changes have been included.

Equipment List

For those projects involving major equipment, the equipment list and equipment pricing should be double-checked by the engineering team for completeness and accuracy. Equipment is often one of the key drivers of cost and scope, and needs to be checked carefully for completeness and accuracy.

Design Basis of Estimate

The engineers should review the basis of estimate and summary of project scope carefully to verify and correlate their understanding of the project scope with that expressed in the estimate. All exclusions expressed in the BOE should be agreed to; and all allowances and assumptions verified. If an estimator has had any questions about interpretation of the drawings or engineering deliverables, now is the time to discuss the estimator's interpretation with the engineers, and to make sure that the project scope is accurately reflected in the estimate. All drawings used for the estimate should be available during this review. Sometimes, it can help to have the estimator explain how each drawing was used in the preparation of the estimate (i.e., was a hard takeoff performed from isometric drawings; was a quantity developed from a P&ID and plot plan, etc.).

Engineering/Design Costs

The engineering team should also review the assumptions and costs associated with the engineering and design portion of the estimate. The engineering team needs to feel comfortable that the amount of money included in the estimate for engineering, design, and support is adequate for the level of effort expected to be expended on the project.

Risk Basis of Estimate
Lastly, the engineering team should review the risk basis of the estimate, and be in position to agree with the analysis of cost risk associated with the estimate. The level of risk associated with scope definition, and with engineering/design costs should be of particular interest to the engineering team, and concurrence should be sought by the team.
As mentioned, the goal of this portion of the estimate review is to make sure that the scope of the project as understood by engineering is reflected in the estimate. At the end of the engineering review, the estimate should have the full support of the engineering team during subsequent reviews.

Project Manager/Project Team Review
Once the estimate has been reviewed closely by the estimating and engineering teams, it is ready for review by the project manager and the rest of the project team. The objective now is to gain the entire project team's support of the estimate, and especially that of the project manager. This is also the first point where the estimate should be able to pass overall validation tests, in addition to a quality review.

Estimate Documentation
The first part of this review should be the examination of the estimate documentation by the project team and project manager. This includes the basis of estimate, as well as the estimate summary and estimate detail pages. The purpose is to ensure that the estimate is presented in an understandable manner. If standard estimating guidelines have been followed (as discussed above), then all estimates should be presented in a consistent, understandable style. It is very important that the project manager fully understand how the estimate is prepared because he/she often becomes the person responsible for presenting (and defending) the estimate to upper management, and later to the eventual customer. The entire project team should also understand the entire estimate package, format and contents.

Cost Review
Engineering should have already reviewed the engineering, design, and associated support costs. Now is the time for the other key members of the project team (project manager, project controls, procurement, construction manager, commissioning manager, etc.) to examine their respective costs which are included in the estimate, and to obtain agreement that they are correct. Although primarily the responsibility of the estimating team, the scope related costs should also be reviewed by the rest of the project team to gain consensus. In particular, the following areas should be discussed:

- Verify that the latest project schedule agrees with the estimate (particularly as it relates to escalation).
- Examine the project administration, and other home office related costs (engineering/design costs should have already been reviewed) for reasonableness.
- Conduct a final constructability review to ensure that the methods of installation and construction assumed in the estimate are reasonable and cost effective.
- Review the construction indirect costs (field staff, temporary facilities, temporary services, construction equipment and services, construction tools and consumables, etc.) to make sure they are reasonable. And,
- Ensure that all required start-up and commissioning materials are included (if necessary). This is often an area of costs which is overlooked.

For international projects, there may be many more items of cost that should be carefully reviewed. These may include such items as international labor adjustments for productivities and wage rates, adjustments for workweek variations, material cost adjustments for both local and globally sourced materials, international freight costs, international duties and taxes, labor camp costs, premiums for expatriate costs, etc.

Estimate Validation
In most organizations, the project manager is ultimately held responsible for the execution of the project. Therefore, the project manager has a vested interest in performing "sanity checks" or otherwise validating the estimate as reasonable. Most experienced project managers will have various "rules-of-thumb" that they will want to use to verify against the estimate. Regardless, the estimate should include an estimate review "metrics" report which summarizes and compares several key benchmark ratios and factors versus historical (and sometimes estimated) values from similar projects.

The goal is to ensure that key metrics from the estimate are in line with the same metrics from similar projects. If there is a large discrepancy, it must be explainable by the particular circumstances of the estimated project versus the similar completed projects. Such comparison metrics may include values such as: percent of administration (home office) costs, percent of engineering/design costs, equipment to total field cost ratios, equipment to totals project cost ratios, cost per piece of equipment, worker hours per piece of equipment, cost to plant capacity ratios ($/BBL, $/SM), etc. Sometimes the metrics will be generated down to the discipline level where you may look at ratios such as cost per diameter inch of piping, cost per cubic meter of concrete, cost per ton of steel, etc.

In addition to examining key benchmark metrics and ratios, another form of estimate validation may involve preparing a quick check estimate using order of magnitude estimating methods. Again, any large discrepancies between the estimates should be explainable by the peculiarities of the project.

Estimate validation is a very important activity during the project review cycle, and the proper tools need to be in place to allow this to occur. Benchmarking key estimate ratios and metrics depends upon having a project history database in place to collect, analyze and present the required information. Similarly, the capability to provide quick check estimates depends on having the correct strategic and conceptual estimating information and tools ready for use.

Risk Basis of Estimate

The project manager and project team should again review the risk basis of the estimate, and agree with the analysis of cost risk associated with the project. The project manager, in particular, should agree with the risk assessment and contingency amounts, and be able to defend it in subsequent review to upper or corporate management.

Reconciliation to Past Estimates

Lastly, the project manager will usually be interested in reconciliation of the current estimate to the preceding estimate (or estimates). This is an important, but often overlooked, aspect to the overall estimate review process. The current estimate can gain credibility by comparing it with earlier estimates, and clearly explaining the differences and reasons for the differences. The reconciliation can usually be presented at a high level, without excessive detail, but the backup should be available in case it is required during the review.

Management Reviews

The last series of reviews is usually conducted by various levels of corporate management. The number of upper management reviews, and the level of management they are presented to, typically vary with the strategic importance and/or total estimated cost of the particular project. These reviews are typically conducted at a very high level of analysis and usually do not involve the details of the estimate. Upper management reviews often focus on substantiating the overall adequacy of the estimate in regards to its intended use. In other words, can management be assured that the level of detail available for the estimate, the estimating methods employed, and the skills of the estimating and project teams support their decision making process on whether to proceed.

As with the project manager review, estimate validation is a key element of the upper management reviews. It is important to be able to explain and demonstrate that metrics for the current estimate are in line with data from other similar projects, (i.e., that the estimate is reasonable). It is also important to show where the metrics may be substantially different from other projects, and provide explanations for the differences.

Management will also be interested in the cost risk assessment. It is important to clearly and concisely explain how the contingency amount was developed, and what the levels of risk are. It is then up to management to accept the level of risk indicated, or change the amount of contingency and accept more or less risk for the project. When reviewing the risk analysis, it is always important to discuss the areas of high risk, and what is being done to mitigate these risks.

Up until the management reviews, the estimate review will have typically concentrated on the project as defined by the project scope documents. If the project was built according to the defined project scope alternative, what will it cost? Usually, the recommended alternative for project scope has long since been determined and agreed to by the project team; and the engineering deliverables created for preparing the estimate have been focused on a single design alternative. However, many times management will start asking questions concerning other alternative scopes or designs. One of the certainties is that management will always think the project cost is too high, and will now be probing to determine if there are lesser cost options. Therefore, it is important to have available for the management reviews any earlier design/cost alternatives, and the decision tree leading to the selected design.

The effectiveness of an estimate review relies on the information which is presented, and the manner in which it is presented. The above discussion has concentrated on how to structure a sequence of estimate reviews for internally prepared estimates to ensure that estimates are well documented, consistent, reliable, and appropriate for their intended use. After this review cycle, the level of estimate accuracy should be apparent, reflective of the scope information available for preparing the estimate, and capable of supporting the required decision making process for the project. Next, we will discuss techniques for reviewing estimates prepared by others.

REVIEWING ESTIMATES PREPARED BY OTHERS

The foregoing discussion has focused on structuring an estimate review process for the estimates that we internally prepare to ensure that the estimate is of a high quality and supports the decision making process of our management. Often, we may also find ourselves in a position to review (and/or approve) estimates prepared by others; and that may or may not have gone through a rigorous internal review cycle as described above. When reviewing estimates by others, we always want to keep in mind the basic fundamentals previously described. Complicating the matter, however, is the problem that many times the amount time allowed for a complete estimate review is very short. Thus, the review of an estimate prepared by others is usually accomplished by a critical assessment of the estimate and its documentation, and a series of questions to assist in evaluating the level of diligence used in preparing the estimate. The following discussion centers on guidelines that we can use to efficiently review estimates prepared by others.

Basis of Estimate

The first thing to assess is the basis of estimate. Is it well organized and complete? Does it provide the required information regarding the design basis, planning basis, cost basis, and risk basis of the estimate? Does the design basis clearly document the scope of the project, and have all engineering deliverables used in developing the estimate been identified? Have all scope assumptions been acknowledged? Is the planning basis (schedule, resource plan, construction plan, etc.) reasonable? Is the basis of cost (material prices, labor rates, labor productivities) reasonable, in line with expectations, and consistently applied throughout the estimate? Has the risk basis been clearly defined, and is it reasonable for the level of information available to prepare the estimate?

Estimating Personnel Used

Next, you will want to know who prepared the estimate, and what their level of estimating experience is. Do they have established estimating procedures and guidelines? Was the estimate checked and reviewed before publication?

Estimating Methodology and Procedures

What estimating methods, techniques and procedures were used in preparing the estimate? Are they appropriate for the level of information available and project type? Were different estimating methods used for different parts of the estimate? Is the level of detail in the estimate sufficient for the purpose of the estimate? Were parts of the project difficult to estimate, and why? Was sufficient time available to prepare the estimate? What adjustments were made to the estimate for location, complexity, etc., and are they reasonable? Was the estimate prepared using a code of account structure?

Estimate Documentation

Is the estimate documented clearly? Are the estimate summary and detail pages well organized, and presented at an appropriate level of detail? Is every cost appearing on the estimate summary traceable to the estimate detail and other estimate backup?

Estimate Validation

Hopefully, the estimate for review will include a metrics report showing key estimating metrics and benchmark ratios for the estimate and similar past projects. You should review this report, and question any significant differences. You should also have your own set of metrics and statistics from your own project history to compare against.

At this point, you may also develop your own quick check estimate (using conceptual estimating techniques) for comparison purposes. This is always a good technique to see if the estimate being reviewed is reasonable. If there is a significant difference, then question the estimator and listen to their explanations and opinions for the deltas. Significant differences between the check estimate and the estimate being reviewed may indicate the need for taking a more thorough examination of the estimate detail.

Estimate Detail

If the preceding inquiry (or should we say interrogation) has gone well, and you are confident that the estimate appears to have been prepared in a professional manner, you are ready to delve into some of the estimate details to verify estimate quality. The goal is to check that selected areas of the estimate can withstand further scrutiny. The key here is to not get too deep into the details, and lose sight of the forest for the trees.

An important point to remember here is the 80/20 rule. This principle generalizes that 80 percent of the cost will come from 20 percent of the estimate line items. For any particular estimate, the significant cost drivers may vary. Sometimes, the main cost driver may be a particular process unit of the project; other times it may be the type of process equipment or machinery throughout the project, and still other times it may be the overall bulk material quantities or labor worker hours. You should examine the estimate summary and detail pages closely to ascertain which aspects of the estimate you may want to examine in closer detail. Basically, you should examine in detail those items of the estimate which will have the most significant cost impact if estimated incorrectly.

One review technique which is often employed is to thoroughly examine and review the estimating steps which were used for a particular part of the estimate. Select an area of the estimate, and ask how the quantities were derived. Don't just take their word for it however. Ask the estimators to show you the drawings from which the quantities were generated. Perform a quick takeoff to see if the quantities can be verified. Ask what the basis was for the unit material price and labor workhours. Have these been consistent throughout the estimate? What adjustments were made and why? If the answers to your questions are evasive, it may call into question the credibility of the entire estimate, and a more thorough review of the complete estimate may be necessary. If your questions are answered confidently, and the answers can be verified against the engineering deliverables and scope information, then you may decide to check the rest of the estimate details in a more cursory fashion.

Typically in this situation, once you have shown the wherewithal to compel the estimator to back up any claims or explanations, then he or she discovers he/she can't just "pull the wool over your eyes." From that point forward, you will usually find that you are getting honest answers to your questions.

The goal of an estimate is to predict the probable cost of a project. The goal of an estimate review is to determine that a high quality and sufficiently accurate estimate has been prepared. The review should ensure that the proper estimating methods, procedures, techniques, data, and guidelines have been employed in the preparation of the estimate. The use of a structured estimate review cycle and estimating review techniques will help to ensure that quality estimates are consistently prepared which effectively support the decision making process by management.

Presenting the Estimate
The method in which you present an estimate to your customer (internal company management or external client) is extremely important. An estimate should never be presented as just a list of numbers, or estimating calculations. A number (or even a range of numbers) is meaningless without the supporting information that describes what the number represents, and sometimes even more importantly what it doesn't represent. In general, a complete estimate report will include the following:

- Basis of Estimate (BOE)
- Estimate Summaries
- Estimate Detail
- Estimate Benchmarking Report
- Estimate Reconciliation Report
- Estimate Backup

We have previously talked about the basis of estimate in the prior discussion on estimate reviews. This is a critically important document in describing the scope that is represented by the estimated cost; and in conveying all the assumptions that have been embedded into the estimate. A well-written basis of estimate document can go a long way towards providing confidence in the estimate itself.

Typically, various estimate summaries may be prepared according to the Project Work Breakdown Structure. For example, one estimate summary may be prepared by project area, and then broken down by process system; while another summary may be prepared by process system and then broken into project areas within each process system. The various parties interested in the estimate will all have different ways in which they want to see the estimate summarized, depending on the classification and end use of the estimate being prepared. It is very important that every value appearing on the estimate summary be easily tracked back to the estimate detail.

The estimate detail typically shows all of the individual Cost Estimating Relationships (CER's) used in preparing the estimate. For a conceptual estimate, it may be a page or less of calculations; however, for a large detailed estimate it may include hundreds of pages of individual line items. This report is also prepared according to the Project Work Breakdown Structure, and may be provided in a variety of different sort options.

An Estimate Benchmarking Report will often be included. It should show benchmark information and metrics with other similar projects. For example, for a building estimate, this report may show the cost per square meter of building area ($/SM) compared to recent similar projects. The key benchmark metrics and ratios presented may include:

- Project administration costs as percent of total project cost
- Engineering costs as percent of total project cost
- Ratio of equipment cost to total project cost
- Construction labor as percent of total field cost
- Total field costs as percent of total project cost
- Project cost per unit of capacity
- Average composite crew rate by trade

An estimate reconciliation report should also be prepared which reconciles the current estimate with any previous estimates prepared for the same project. This report should identify the cost differences dues to changes in scope, changes in pricing, changes in risk, etc.

Lastly, all estimate backup should be compiled and available. This information may not need to be presented to the estimate customer, but should be available if questions arise. This will include all notes, documentation, drawings, engineering deliverables, vendor quotes, etc. that were used in preparation of the estimate.

ESTIMATING RESOURCES
Reliable estimate preparation depends on information. Besides the engineering and design information needed to quantify the scope of the project, other information is also required such as:

- Conceptual estimating factors
- Material cost and pricing information
- Labor workhour charts and information
- Labor productivity information
- Labor wage rates, composite crew mixes, etc.
- Other estimating factors and information

Successful estimators will rely on a myriad of resources to obtain this information. Estimating guideline and procedure manuals will be used to promote standard estimating methods and procedures. In-house cost history manuals will provide historical cost data for completed projects. Special cost studies may have been developed to serve as resources for particular estimating applications, such as special scaffolding studies, concrete placement studies, labor productivity studies, etc. Engineering and design manuals and specifications will be used to identify the specific materials of construction, and all related labor operations required to complete the scope of work.

Every completed project should be documented by a final job report covering everything about a project from design considerations to construction execution strategy to cost summaries. Selected data should from the final job reports should be collected and stored in a computerized database and made available to all estimators. Estimators continually rely on past project information and cost data in the preparation of new estimates.

Collections of labor charts will typically provide standard labor workhour units by task. These are generally normalized for location and time, and serve as a base for estimate preparation, and then adjusted for specific project requirements. They will often be supplemented by commercial estimating database publications. In-house and commercial material cost databases and publications will also be needed. Current wage rate information should be maintained, including union agreements, for all locations the estimator may be involved with. A library of vendor catalogs should also be maintained. Many of these are now available on the internet. These may provide technical information, pricing information, and other data required by an estimator.

There are hundreds of sources published every year that contain useful information for an estimator. This includes AACE publications (Recommended Practices, Professional Practice Guides, Cost Engineering journal, etc.), as well as publications from other professional organizations and commercial sources.

Estimating software is another important resource. Estimating software can enhance the accuracy and consistency of estimates, while reducing the time required for preparing estimates. The software may be commercial estimating software or be developed in-house. When using the cost databases supplied with commercial estimating software, it is always important to calibrate the data to your specific needs and estimating situations. Estimating software should also be regarded as simply a tool to facilitate the preparation of estimates by estimators. Estimating software doesn't convert a non-estimator to be an estimator.

All of the resources described above serve to help the most important resource to successful estimating –well trained and experienced estimators. Estimating is a profession requiring an ongoing commitment to training and development.

CONCLUSION

As potential projects are considered as investment opportunities, management will require various estimates to support key decision points. At each of these points, the level of engineering and technical information available to prepare the estimate will change. Accordingly, the techniques and methods to prepare the estimates will also vary. The basic estimating techniques are well established, and this chapter has been intended to review the estimating process and relevant estimating methodologies for the various types of estimates.

The determination of using a conceptual approach versus a detailed approach will depend on many factors: the end use of the estimate, the amount of time and money available to prepare the estimate, the estimating tools available, and the previous historical information available. A conceptual estimating approach (capacity factored, equipment factored, parametric) requires a significant effort in data-gathering and methods development before estimate preparation ever begins. In contrast, a detailed estimating approach requires a large effort during the actual preparation of the estimate.

With either approach, the challenge for the estimator is to evaluate the unique combination of required material and labor resources in order to prepare a cost estimate for a project to be completed in the future. The use of structured estimating techniques and tools, high quality engineering deliverables, good historical data and pricing information, combined with estimating skill and experience, will assure that the best possible estimate is prepared. The desired end result is to prepare estimates that are well documented, consistent, reliable, appropriate, accurate, and that support the decision making process for the project.

Estimating is obviously a vital component to project success. Estimates are used not only to establish project budgets, but also to provide accurate information to support scheduling, cost monitoring, and progress measurement of a project during execution. Estimating is thus but one component to total cost management – the integration of cost engineering and cost management principles used in managing the total life cycle cost investment in strategic assets.

REFERENCES

1. AACE Recommended Practice 17R-97, *Cost Estimate Classification System.* Morgantown, WV: AACE International.
2. AACE Recommended Practice 18R-97, *Cost Estimate Classification—As Applied in Engineering, Procurement, and Construction for the Process Industries*, Morgantown, WV: AACE International.
3. Lang, H.J. (1947). Cost Relationships in Preliminary Cost Estimation. *Chemical Engineering.*
4. Hand, W.E. (1964). Estimating Capital Costs from Process Flow Sheets. *Cost Engineer's Notebook*. Morgantown, WV: AACE International.
5. Miller, C.A. (1965). New Cost Factors Give Quick Accurate Estimates. *Chemical Engineering*.
6. Rodl, R.H., Prinzing, P. and D. Aichert, (1985). *Cost Estimating for Chemical Plants*. AACE Transactions. Morgantown, WV: AACE International.
7. Nushimura, M. (1995). *Composite Factored Engineering*. AACE Transactions. Morgantown, WV: AACE International.
8. Guthrie, K.M. (1969). Data and Techniques for Preliminary Capital Cost Estimating. *Chemical Engineering.*
9. NASA, Parametric Cost Estimating Handbook.
10. Black, J.H. Dr. (1984). *Application of Parametric Estimating to Cost Engineering*. AACE Transactions. Morgantown, WV: AACE International.
11. Dysert, L.R. (1999). *Developing a Parametric Model for Estimating Process Control Costs*. AACE Transactions. Morgantown, WV: AACE International.
12. Rose, A. (1982). *An Organized Approach to Parametric Estimating*. Transactions of the Seventh International Cost Engineering Congress.
13. AACE Recommended Practice 73R-13, *Establishing Labor Productivity Norms*. Morgantown, WV: AACE International.

RECOMMENDED READING

1. AACE Recommended Practice 10S-90, *Cost Engineering Terminology*. Morgantown, WV: AACE International
2. AACE Recommended Practice 20R-98, *Project Code of Accounts*. Morgantown, WV: AACE International
3. AACE Recommended Practice 20R-98, *Project Code of Accounts – As Applied in Engineering, Procurement, and Construction for the Process Industries*. Morgantown, WV: AACE International
4. AACE Recommended Practice 28R-03, *Developing Location Factors by Factoring – As Applied in Architecture, Engineering, Procurement, and Construction*. Morgantown, WV: AACE International
5. AACE Recommended Practice 31R-03, *Reviewing, Documenting and Validating the Estimate*. Morgantown, WV: AACE International
6. AACE Recommended Practice 34R-05, *Basis of Estimate*. Morgantown, WV: AACE International
7. AACE Recommended Practice 35R-09, *Development of Cost Estimate Plans – As Applied for the Building and General Construction Industries*. Morgantown, WV: AACE International
8. AACE Recommended Practice 36R-08, *Development of Cost Estimate Plans – As Applied in Engineering, Procurement, and Construction for the Process Industries*. Morgantown, WV: AACE International
9. AACE Recommended Practice 46R-11, *Required Skills and Knowledge of Project Cost Estimating*. Morgantown, WV: AACE International
10. AACE Recommended Practice 47R-11, *Cost Estimate Classification System – As Applied in the Mining and Mineral Processing Industries*. Morgantown, WV: AACE International
11. AACE Recommended Practice 56R-08, *Cost Estimate Classification System – As Applied for the Building and General Construction Industries*. Morgantown, WV: AACE International
12. AACE Recommended Practice 58R-10, *Escalation Estimating Principles and Methods Using Indices*. Morgantown, WV: AACE International
13. AACE Recommended Practice 59R-10, *Development of Factored Cost Estimates – As Applied in Engineering, Procurement, and Construction for the Process Industries*. Morgantown, WV: AACE International
14. AACE Recommended Practice 69R-12, *Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Hydropower Industry*. Morgantown, WV: AACE International
15. AACE Recommended Practice 71R-12, *Required Skills and Knowledge of Decision and Risk Management*. Morgantown WV: AACE International
16. AACE Recommended Practice 74R-13, *Basis of Estimate – As Applied for the Software Services Industries*. Morgantown, WV: AACE International
17. Chilton, C.H. (1950). Six Tenths Factor Applies to Complete Plant Costs. *Chemical Engineering*.
18. Dysert, L.R. (2008). *An Introduction to Parametric Estimating*. AACE Transactions. Morgantown, WV: AACE International.
19. Dysert, L.R. and B.G. Elliott, (2000). *The Estimate Review and Validation Process*. AACE Transactions. Morgantown, WV: AACE International.
20. Dysert, L.R. and B.G. Elliott, (1999). *The Organization of an Estimating Department*. AACE Transactions. Morgantown, WV: AACE International.
21. Guthrie, K.M. (1970). Capital and Operating Costs for 54 Chemical Processes. *Chemical Engineering.*
22. Hamilton, A.C. and R.E. Westney, (2002). *Cost Estimating Best Practices*. AACE Transactions. Morgantown, WV: AACE International.
23. Hollmann, J.K. (2012). Estimate Accuracy—Dealing with Reality. *Cost Engineering, 54*(6).

24. Hollmann, J.K. (2009). *Recommended Practices for Risk Analysis and Cost Contingency Estimating*. AACE Transactions. Morgantown, WV: AACE International.
25. Lang, H.J. (1948). Simplified Approach to Preliminary Cost Estimates. *Chemical Engineering*.
26. Miller, C.A. (1978). Capital Cost Estimating—A Science Rather than an Art. *Cost Engineer's Notebook.* Morgantown, WV: AACE International.
27. Querns, Wesley R. (1989). *What is Contingency, Anyways?* AACE Transactions. Morgantown, WV: AACE International.
28. Uppal, Kul B. (2011). Pitfalls of Early Estimates and Scope of Work. *Cost Engineering, 53*(4).
29. Williams, R. Jr., (1947). Six-Tenths Factor Aids in Approximating Costs. *Chemical Engineering*.
30. Woodward, C.P. and M.T. Chen, (2002). Cost Estimating Basics, *Skills and Knowledge of a Cost Engineer* (4th ed.). Morgantown, WV: AACE International.
31. Woodward, C.P. and M.T. Chen, (2002). Order-of-Magnitude Estimating, *Skills and Knowledge of a Cost Engineer* (4th ed.). Morgantown, WV: AACE International.

Chapter 24—Strategic Asset Management

John K. Hollmann, PE CCP CEP DRMP FAACE AACE Hon.Life

Abstract
Management of strategic assets involves any and all of the unique physical and/or intellectual property that is of long term, ongoing value to the project. Keeping this definition in mind, this article discusses strategic asset management from the perspective of AACE International's concepts of cost engineering. Emphasis is on the responsibilities of the project owner and implementing contractor to manage the strategic assets. The interaction between the owner's strategic asset management and the contractor's project control systems form the links for successful planning and execution of the entire project. Measurements of success are found in: safety, operational efficiency, and resource consumption. Each of these planning factors must be effectively evaluated and followed through the course of development and implementation of the project.

Keywords
Asset Life Cycle, Benchmarking, Capital Asset/Economic Life Cycle, Capital Budget, Product Life Cycle, Project Life Cycle, Enterprise, Enterprise Resource Planning, Front End Loading, Gated Project System, Influence Curve, Project System, Strategic Asset, Strategic Asset Management, Total Cost Management, and Value Improving Practice.

INTRODUCTION

Learning Objectives
The objective of this chapter is to show how the skills and knowledge of cost engineering work from an asset owner's perspective (as opposed to a project team perspective). For the asset owner, the concepts, tools, and resources of cost engineering are applied in an integrated way through the Strategic Asset Management sub-process of Total Cost Management (TCM). This chapter describes Strategic Asset Management and provides examples of how it works in practice. After completing this chapter, the reader should be able to:

- Understand how cost engineering practices can be applied in an integrated way using the Strategic Asset Management process
- Understand how Strategic Asset Management is applied in different industries and for different asset types
- Understand typical roles and responsibilities of cost engineers in Strategic Asset Management

CONCEPTS—TCM AND STRATEGIC ASSET MANAGEMENT
AACE International's Total Cost Management Framework defines TCM as the sum of the practices and processes that an enterprise uses to manage the total life cycle cost investment in its portfolio of strategic assets [1]. The practices are called Cost Engineering and the process through which the practices are applied is called TCM. The TCM Framework further defines a strategic asset as any physical or intellectual property that is of long term or ongoing value to an enterprise. Strategic assets may vary from industrial plants to transportation systems to software programs. Essentially anything that an enterprise makes significant investments in can be considered a strategic asset.

Each asset has a life cycle. For example, a building owner evaluates designs, builds, leases, maintains, renovates, and eventually demolishes a building during its life cycle—at each stage of the building's life the owner makes cost investments in it that must be managed. As part of the cost management process, the building owner monitors the operating cost and profitability of the existing building, evaluates the performance of competitor's buildings, assesses alternate building investment opportunities, and initiates, plans and controls new building construction, and/or building maintenance projects. The building owner may manage a large portfolio of operating building assets, as well as construction and maintenance projects in various stages of their life cycles.

In the building example, Strategic Asset Management is the process where the building owner measures the building's operating performance, assesses improvement ideas, and conceives, evaluates, and initiates building investment projects. Project resources and costs are managed through the Project Control process (see the Integration chapter in the text introduction). The Strategic Asset Management and Project Control sub-processes are linked in TCM.

The bridge or link between the owner's Strategic Asset Management and Project Control processes is called its "project system." The project system is a subset of the Strategic Asset Management process that includes the steps for planning asset investments, implementing investment decisions, and then measuring project system and asset performance. In a stages-and-gates or "gated" project system, the performance of planning tasks is done in successively more definitive stages. At the completion of each planning stage, plan deliverables (e.g., scope description, designs, estimates, schedules, etc.) are reviewed by the asset owner at a gate review. If the project is meeting its stated objectives at the review, the asset owner approves sufficient funds to complete the next stage of plan development or to complete the project. If the project is not meeting objectives, it can be cancelled, re-scoped, or redirected.

Business conditions and objectives are in constant flux and projects do not always go as planned. Asset owners use gated project systems to ensure that the project's portfolio is always aligned with current objectives, and that limited resources are invested judiciously. After a project is completed and the asset has been in use for some time, a final gate review is conducted to assess the operational performance of the asset. A project system that results in fast, low-cost projects, but assets that do not function properly, is not a successful project system. Project and asset performance must be measured and assessed together. This last review, or measurement step, closes the link between the Strategic Asset Management and Project Control processes.

Figure 24.1 illustrates the steps above as a process map (i.e., TCM). In Strategic Asset Management on the left half of the TCM process map, the asset owner performs the following steps for each asset in their portfolio, and for their project system.

- **Performance Measurement**—Measurements (e.g., safety, cost, operability, etc.) are taken of how well existing assets and the project system is performing.
- **Performance Assessment**—Performance measurements of assets and the project system are compared to strategic plans. Corrective, mitigating, or improvement actions are taken as needed. Ideas are considered for new or improved assets or project systems.
- **Planning**—Considering the enterprise's objectives and requirements, asset portfolio and project system improvement ideas are conceptualized, evaluated, and converted into plans for investing resources in new or improved assets or project systems.
- **Implementation**—Investment plans and requirements are communicated to and executed by project teams. Project teams request resources as necessary. Project performance is measured and reported, thus continuing the Strategic Asset Management cycle.

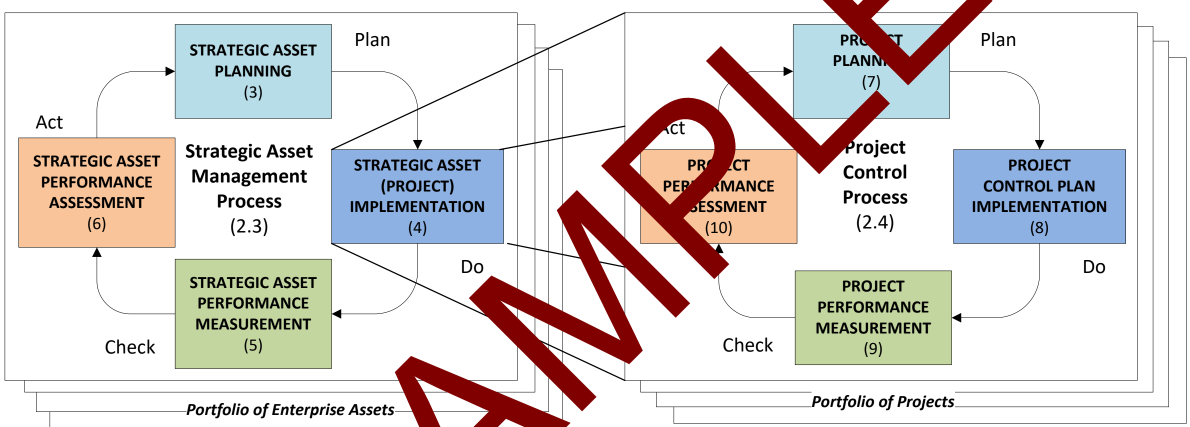

Figure 24.1—The Total Cost Management Process

In the Project Control process on the right of Figure 24.1, strategic asset investments are implemented through the execution of projects or programs. The role of contractors (and others that contribute to the process, but do not own the asset) on project teams increases as projects get larger and require more resources; however, the asset owner, not the project team or contractors, remains accountable for overall TCM process performance. Note the utilization of the PDCA (Plan, Do, Check, Act) Cycle in Figure 24.1

The asset owner's "project system" is the subset of the Strategic Asset Management planning, implementation, and measurement steps, as well as the Project Control performance assessment step; (i.e., the bridge between Strategic Asset Management and Project Control).

Figure 24.2 breaks the Strategic Asset Management process map into more detailed steps that are recognizable as cost engineering practices. The next few paragraphs walk through these steps starting with asset and project system performance measurement on the right hand side of the figure.

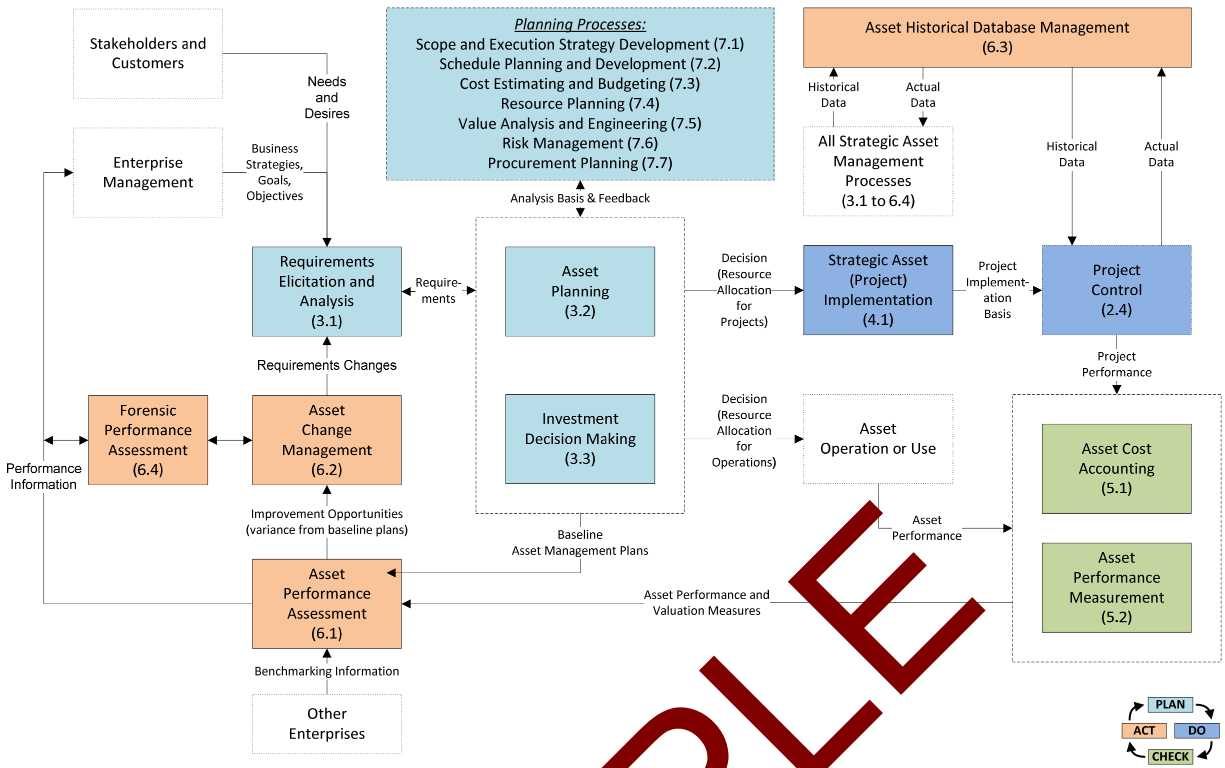

Figure 24.2—The Strategic Asset Management Process

Asset and Project System Performance Measurement

In the first step of Strategic Asset Management the asset owner measures the performance of existing assets and operations, as well as the performance of projects that have been implemented. Measures for the project system may include, but are not limited to, safety, cost, and schedule. Measures for assets in use may include, but are not limited to, safety, operational efficiency, and resource consumption (e.g., materials, labor, energy, etc.).

Existing assets and ongoing projects demand from and return resources to the owner, the most common resource being money. Information about the flow of resources is captured in the accounting element of the performance measurement step. Traditionally, accounting systems have focused on monetary transactions. However, accounting systems have expanded to Enterprise Resource Planning (ERP) systems that, as the name implies, capture information about the input and output of resources for the entire enterprise (e.g., procurement, inventory, etc.).

TCM requires that ERP implementations measure both asset costs (e.g., cost by asset to support depreciation calculations and profitability assessment) and project costs (e.g., costs by activity to support earned value assessment). Unfortunately, many owners' ERP system implementations account for project costs as a type of asset ledger work-in-progress holding account. Using that approach, the ERP system is useless for assessing project system performance; project system information must be captured and assessed using a separate information system.

Fortunately, ERP systems now offer project modules to better meet project management needs. The ERP system is a key interface point between cost engineering and accounting/finance. Working together, owner cost engineers and accountants need to ensure that their ERP systems address both asset and project information needs. Interestingly, ERP software system implementations have become a major class of project themselves in the last decade.

Asset Performance Assessment

Continuing the process to the left side of Figure 24.2, the asset owner evaluates the asset and project system performance measures in comparison to performance plans, as well as internal and external historical performance data. The asset owner looks for variances between measurements and plans for performance aspects—such as safety, quality, reliability, schedule, operability, and of course, cost. The owner investigates any variances found to determine if they are caused by isolated events or systematic problems. In many cases, the immediate user of the asset, or the manager of the project system, identifies the cause of the variance and fixes it through an immediate corrective action. In other cases, the problem requires further assessment.

At the highest level of abstraction, owners assess the total long-term economic return or financial profit from its asset investments and project system performance. Return-on-Investments (ROI) and Return-on-Assets (ROA) are common financial measures. The pressure to improve financial performance is relentless, while the availability of resources to make improvements is limited. Various parts of the enterprise will be competing for those resources. Because the business environment is dynamic, competitive, and uncertain, the Strategic Asset Management performance and requirement assessment steps attempt to balance opportunities and risks against demand and supply for resources in such a way that the enterprise's objectives are met.

The enterprise's objectives are inputs to the Strategic Asset Management requirements assessment step. These objectives are determined in the enterprise's strategy formation process (e.g., what is our mission?; what business should we be in?; etc.). For those with interest in the topic, one source identifies at least ten schools of strategic management thought [2]. Cost engineers should be aware that Strategic Asset Management, as defined in TCM, is related to, but not synonymous with strategic management as a general field of study.

A key requirements assessment tool for the asset owner is benchmarking. This compares the enterprise's asset and project system performance measures to external peer enterprise measures. Benchmarking also identifies internal and external best practices that have been shown to improve performance. Internal benchmarking recognizes that there is diversity in practices and performance within most enterprises. External benchmarking helps ensure that performance is not only on plan, but competitive within their own industry and across other industries.

When asset or project system performance problems cannot be fixed without the investment of significant resources, investment opportunities for improving performance must be identified and evaluated. The effort to identify and develop improvement ideas can itself be a project that consumes considerable resources; therefore, the owner needs to reassess their overall business objectives, requirements, and resource constraints in the strategic requirements assessment step. In this step, constantly changing regulations, industry standards, competitive positions, and market strategies are monitored and evaluated. External benchmarking can help identify competitive positions and strategies.

With their knowledge of both the technical and cost characteristics of the owner's assets and projects, and their analytical skills, cost engineers are often called upon to lead or support performance assessment endeavors, such as benchmarking and profitability evaluations.

Asset Planning

In the performance assessment step, the owner identified assets or project system improvement challenges that required the investment of significant resources for resolution. In the asset planning steps, the owner identifies asset investment and project system options, defines and evaluates them, and decides upon which option(s) to pursue. Every investment decision is made in consideration of strategic objectives and requirements. Once an investment decision is made, owner management communicates the decision to the asset operator and/or the project team, making sure that the scope of the decision and performance objectives for the asset and/or project is clearly understood.

The investment options identification step in the top left center of Figure 24.2 finds ways to improve asset or project system performance. This step is highly creative; it seeks to understand both the nature of the opportunity, as well as the entire range of alternative solutions. A major challenge in this step is to get fresh ideas from both partial and impartial perspectives. Options identification includes a wide variety of continually evolving practices such as benchmarking, cost driver analysis, brainstorming, problem solving, market research, business process analysis, and so forth.

Larger enterprises often have centralized asset planning departments. Common department titles include Strategic Planning, Capital Planning, Facility Planning, or Product Planning. Whether there is a planning department or not, the asset owner's business management creates special teams to tackle specific challenges identified by the assessment step. The planning team thus formed includes a cross-section of personnel with technical, operating, and finance experience. The asset planning effort is generally business-driven (i.e., led by business managers, not technical personnel) because of the need to keep a close eye on enterprise business objectives and strategies at this phase. Owner cost engineers are key participants (though generally not leaders of) the planning effort, because of their skills in key planning practices and their knowledge of asset and project system technology and life cycle costs.

In brainstorming or other option identification sessions, the planning team generates improvement ideas; most are discarded out of hand, while others pass subjective evaluation tests of their potential. For those ideas that look promising, the planning team further develops the scope and definition to a point where their feasibility in terms of potential cost, risk, value, and profitability can be quantitatively analyzed and measured. At some point, the measures reach a level of confidence such that business management can make a decision to discard or continue developing the ideas.

The options analysis and decision steps are in the top center of Figure 24.2. Analysis is an iterative process (i.e., if an idea is still feasible after initial analysis, it is refined and evaluated again and again until it is either discarded or selected for implementation). Many ideas are going through this process simultaneously. Therefore, a gated project system is desirable so that planning resources are regularly redirected to those concepts that have the most potential.

At some point, the cost of every improvement option is estimated because cost is a component of most decision making criteria (e.g., ROI). The scope definition at early planning stages is minimal, early estimating techniques are stochastic in nature (i.e., parametric analysis, conceptual estimating, factored estimating, etc.). The owner cost engineer, with thorough knowledge of the owner's assets and project system, prepares these estimates using the cost estimating and analysis tools described elsewhere in this publication. Owner cost engineers that initiate and improve on ideas rather than just analyze them (hence the term engineer) are highly valued members of the planning team. The cost engineer also analyzes the options using risk analysis, value engineering, and economic analysis including profitability. These practices all provide quantitative measures upon which owner business management can base its go/no-go decisions.

While go/no-go decisions during the earliest phases of idea generation are usually made subjectively; decisions on options in later stages of definition are usually based on quantitative decision analysis techniques. These techniques include decision tree analysis and other decision-making tools. .

Implementation

Once owner business management makes a decision to implement an asset or project system improvement idea, a project team is formed to implement it. While management is represented on the project team, project responsibility is handed off to a project team manager who often has an operating or technical background depending on the nature of the improvement idea. The planning focus is now on developing the technical scope and execution plans.

At the responsibility hand-off, management conveys formal documentation to the project team of the project's business objectives, conceptual scope, and performance requirements. Objectives and requirements include both the expected conduct of the project (e.g., use the established project system) and the performance of the final asset to be delivered back to the owner. At this point, the project is added to the enterprise's capital budget (or operating budget if costs are not capital). However, the project team is not authorized to spend the full budgeted amount; only enough funds are authorized to carry project definition to the next project system gate review.

The scope of the project at the hand-off is still conceptual in nature. For example, the scope of a chemical plant may include little more than the desired production capacity of the plant, the chemical product specifications, the location for the plant, and the expected date of first production. During implementation, the project team further evaluates and defines the technical scope and project execution plan until they are well enough defined (and the project estimate is considered reliable enough) to ask management for full funding for project execution.

The project definition phase is often called the Front-End Loading (FEL) phase. It is called FEL because the goal is to remove significant uncertainties about the project scope and execution plan during the front-end of the project (i.e., before full funding is authorized by management). Good early definition practices result in more competitive and predictable project outcomes in terms of safety, cost, quality, schedule, and asset performance. With good FEL, late changes in scope are minimized. At the completion of FEL, the project has a detailed budget and schedule that serves as the basis for project control during project execution.

Some project systems call the Asset Planning phase Business FEL, and the Implementation phase Project FEL. The most effective Business and Project FEL systems not only define the scope and reduce the uncertainties of options, they use practices such as value engineering to improve their value (value improving practices or VIPs). The potential to influence the value of an asset diminishes as asset planning and implementation progress. Figure 24.3 illustrates this basic principle known as the Influence Curve.

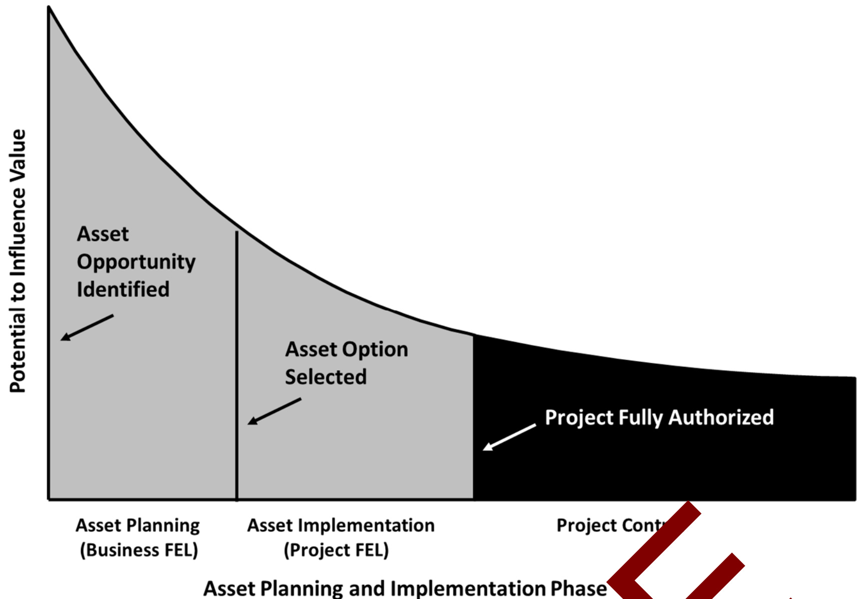

Figure 24.3—The Influence Curve

As projects are implemented and fully authorized (at which point the project team is in full control), the owner asset planning department measures the project portfolio's performance as part of the project system. The owner also continues to measure the performance of its existing assets and operations as well. Asset and project system performance measurement is where we began our discussion of the Strategic Asset Management cycle. Having closed the theoretical loop, some basic examples are provided below of how the theory might work in practice for various types of strategic assets.

APPLICATION—CAPITAL OR FIXED ASSETS

Capital or fixed assets include manufacturing plants and equipment, buildings, roads, and similar items that are not easily moved and have significant useful life spans. Fixed assets are generally created, modified, and retired through a project process rather than a manufacturing process. When determining the profit of an enterprise, the costs of capital assets are generally depreciated rather than being deducted as a current expense. Some items such as commercial airplanes may be a capital asset, but not a fixed asset. The process of creating something as complex as an airplane, is a cross between a project process (i.e., a temporary endeavor with a defined beginning and end) and an ongoing manufacturing process.

As an application example of Strategic Asset Management for capital assets, consider the case of a company that produces photographic film. One of the company's existing assets, at location X, is a machine that coats rolls of specially prepared plastic sheet with photosensitive chemicals and then dries the coating before winding the coated sheet back up for later conversion to a finished product (i.e., rolls of consumer film). This large film-making machine, housed in a light-tight and environmentally-controlled building, continually coats, dries, and winds up thousands of square meters of film per day.

The production planning department of the film manufacturing plant continually monitors film production costs using the company's ERP system. The system tracks the inventory, usage and cost of the rolls of plastic sheet material, the scores of different coating chemicals, the labor of the plant operating personnel, and many other resources. For costs that are difficult to associate with any particular product (such as the cost of planning department personnel), the production planning department uses activity-based costing methods to allocate these costs to specific products. The production planning department includes people with a mix of operations, business (e.g., accounting, finance, etc.), and engineering (e.g., industrial, chemical, etc.) backgrounds. This large plant makes frequent (though individually small) capital investment decisions, so the planning department staff includes a cost engineer.

The consolidated cost and resource measurements of film production for plant X and other company plants are reported through the ERP system to the company's film manufacturing division Strategic Planning Department. In addition to ERP information about the company's internal plant operating costs, the Strategic Planning Department monitors external film technical, business, and cost trends. The internal and external measurements are constantly in flux. The strategic planners observe and assess problems with film production quality and costs that cannot be readily dealt with at the plant level. The planners also observe and assess the market actions of competitors in the film business and they measure the competitor's cost performance through industry benchmarking. Finally, the planners flag division management when their assessment shows that there are significant threats to, or opportunities for, greater profit. Like the plant-level planners, the division-level planners work on a team that has personnel with operations, business, and engineering backgrounds. Cost engineers, depending on their knowledge of a particular class of assets, are part of this team as well.

At any time, the list of opportunities and challenges identified by the strategic planning department is long. There is constant cost pressure because silver prices (a key coating ingredient) and operating labor costs are escalating, while consumer film market prices are dropping. The technology used by competitors is also improving. In this case, through market intelligence and benchmarking, the strategic planners determine that a competitor will probably lower their prices when a film plant they are constructing is completed. In order to match the expected market price, while keeping profits at least level, the planning group's profitability analysis indicates that the unit manufacturing cost component of the product cost must be decreased by about 10 percent within 18 months. Division management agrees with the planning group's assessment and directs the planning team to present them with several feasible improvement options and a decision analysis within 30 days.

The strategic planning team, including cost engineering, holds several days of brainstorming sessions to identify alternative solutions. Most of the alternatives were considered in the past, but the previous analyses are out-of-date and must be revised. Among the ideas considered: make changes in how the film machine at plant X is operated to cut waste and increase uptime; increase the line speed of the film machine at plant X; move some production to plant Y that has some available capacity at lower unit manufacturing costs; build a new production line at either plant X or Y; or build a new film making facility at a very low operating cost location Z. The new plant Z idea is discarded because there is no reasonable way that a complete new facility, with its effects on the entire company's strategies, could be analyzed, designed and built in 18 months. However, the other ideas cannot be discarded out of hand.

At this point, the cost engineer's role becomes significant because each option requires conceptual cost estimating, schedule analysis, risk analysis, value engineering, and ultimately decision analysis; all the tools in the owner cost engineer's skill set. The planning team now starts outlining the conceptual scope of each option and assigns team members to analyze various scope components. Operational specialists consider enterprise and manufacturing resource elements, design engineers consider technical approaches, and cost engineers tie the analysis together with their understanding of design and the cost, schedule, and risk of capital projects.

The cost engineer is prepared for this role. The cost engineering department has an extensive historical database of the cost and schedule of capital projects for film manufacturing [3]. Through benchmarking, they also know what similar projects and facilities cost for their competitors. In addition, they have used the internal and external historical data to develop conceptual estimating, scheduling, and risk-analysis tools. These tools permit the cost engineer to rapidly analyze the numerous technical approaches that the design engineers develop. The cost engineer works closely with the operations specialist and the design engineers to refine approaches and discard unworkable options. The strategic planning team, including the cost engineer, works with the plant planners and engineers to get additional ideas and work out options. However, because coordination with the plant is difficult (some options adversely affect the jobs of plant personnel), it is important that the strategic planning team be very familiar with the plant.

During the course of several weeks of analysis, the team narrows the ideas down to two that meet business objectives: operational changes to cut waste and increase uptime of the machine at plant X, or increase the line speed of the film machine at plant X. In the final week of analysis, the team documents the scope of each option and conducts an early value engineering session for each. The cost engineer prepares a final conceptual estimate and schedule for each and conducts a risk analysis to determine the range of possible cost and schedule outcomes. The team then performs decision tree analysis that weighs the risks and ROI of each option. At the end of 30 days, division management holds a review meeting, and based on the decision analysis, decides to increase the line speed of the film machine at plant X. The division's capital budget is then updated, and funding for further project scope definition is approved.

After the management decision, the division planning team documents the conceptual scope and objectives and holds a kick-off meeting with a newly-formed project team. From there, the project team begins to further define the technical aspects of the accelerated line speed in accordance with the company's project system/FEL process. The cost engineer from the division planning team continues to support the project team. The cost engineer is an important knowledge-bridge from business to technical FEL.

Many design decisions still need to be made; for example the X machine dryer length needs to be extended to accommodate the accelerated line speed and there are a number of equipment layout options for the drying area. The layout options involve building options as well; one option saves on plant real estate by using a multi-story layout with a costly heavy structure, the other option is spaced out on a single floor level that needs only a low cost building shell. Value engineering sessions are again conducted to optimize the function and cost of the process flow, layouts, and building additions. Again, the owner cost engineer has the cost database, estimating, and risk evaluation tools to support these planning efforts.

Eventually, the project team completes the equipment layouts, piping diagrams, instrumentation diagrams, and other project definition deliverables. A project control level cost estimate and a CPM resource-loaded schedule are also prepared to serve as the basis for a management review session, and approval of full project funding. The project execution plan serves as the basis for project control during project execution. At this point, the owner cost engineer's role is as advisor and consultant to the owner project manager. Cost engineers for the project contractors, with owner oversight, take the lead role for day-to-day project control.

APPLICATION—PRODUCTS

Products include manufactured goods and similar items that have a limited useful life span and are not fixed in place. Products are generally created through an ongoing, discrete or continuous manufacturing or production process, rather than a project process. When determining the profit of an enterprise, the costs of creating products are generally deducted as a current expense rather than being depreciated over a number of years as with a capital asset.

As an application example of Strategic Asset Management for products, consider an expansion of the film company case previously described. At the same time that the division planning team was informing management that a ten percent manufacturing cost reduction within 18 months was needed, they also noted that the competitor's new film plant was likely going to be able to make film with better image capture capability. The division management was apprised of the product technical challenges and they direct the planning group to present them with several feasible options and a decision analysis within 30 days that will meet the cost, time, and product improvement objective.

Fortunately, a program had been underway in the research and development laboratories that offered the company two alternative coating formulations that would provide comparable or better capabilities. One formulation adds an additional coating layer, while the other changes the chemistry of an existing coating layer. Furthermore, the additional layer option requires a modification to the company's one-hour film developing machine product used by photo shops. The product improvement is such that the planning department thinks it can support a premium price. As the division planning team enters the asset planning phase, they now have to deal with product decisions, as well as capital asset decisions, and, as they so often are, the capital and product planning are highly intertwined.

The planning team now includes personnel with operations, business, and engineering backgrounds, as well as a representative from the research department, specialists in product planning, and a design engineer from the one-hour developing machine group. Sub-teams are formed to concentrate on the manufacturing cost alternatives, the film product alternatives, and the developing machine alternatives. They all report to a lead planning manager and regularly meet as a group to integrate the assessment of the many alternative branches.

The film product sub-team considers consumer perception of the images produced by the alternative formulations. They also evaluate marketing, sales, distribution, inventory, and other considerations for the new alternative products. The developing machine sub-team considers the implications of modifying the several models of machines in their customer's photo shops. The manufacturing team considers the alternatives discussed previously, but now they also must deal with modifications to the film coating process to address the formulation options.

Eventually the team performs a decision tree analysis that weighs the risks and ROI of each option. At the end of 30 days, division management conducts a review meeting, and based on the decision analysis, decides to increase the line speed of the film machine at plant X and upgrade its coating and drying process to handle the extra coating layer, and to modify the one-hour developing machines as needed. The division's capital budget is then updated and additional funding is granted for further program definition. This decision initiates both capital and product development projects that will be managed as a program.

After the management decision, the division planning team documents the conceptual scope and objectives and holds a kick-off meeting with the newly-formed program team. Capital and product project teams are formed within the program. The capital project team begins to further define the technical aspects of the accelerated line speed and modified coating process. The film product development team begins to further define the business plans (sales, marketing, inventory, distribution, price, etc.) for the new film. The one-hour developer machine product team begins to further define both the technical aspects of the modified machine design, as well as the business aspects of dealing with its customers in whose shops the machines are used.

As the teams continue with scope development, cost engineering practices are used for capital and product planning—including cost estimating, risk analysis, and value engineering. The basic processes are the same for both capital assets and products, but the details of how they are used differ. Product estimates deal with the assembly process versus the construction process for capital estimates. Product value engineering focuses on product (e.g., the one-hour developer machine) functions that can be combined or eliminated as opposed to plant manufacturing process (e.g., the film dryer) functions for capital project value engineering. The owner cost engineer's major role has traditionally been to support capital planning; however, the more the cost engineer understands both of the products and capital planning aspects, the more valuable their input will be to the program.

APPLICATION SOFTWARE

Software is difficult to classify as either a capital asset or a product. As a manufactured good, it is captured in the form of a plastic disk or a silicon chip, but the value and cost of the software has little relationship to the manufactured good (i.e., the disk or chip). Software may or may not have a limited useful life span depending on its function; some software is quickly outdated while other software is used for decades. Finally, software may or may not be fixed in place depending on what device it is installed in. Software's ambiguous nature (is it an asset or product?) is reflected in wide variations in how companies expense or depreciate software development costs. In any case, many things require software in order to perform their functions, and software is a "strategic asset" of long term or ongoing value to the enterprise holding the software copyright or patent.

As an application example of Strategic Asset Management for software, consider a final extension of the film company case. Previously, the case described how the one-hour developing machine sub-team had to consider the implications of modifying the several models of machines in their customer's shops. Furthermore, this sub-team has to consider both the developer machine operating software and user interface associated with the machine.

The existing operating software is based on coding and a chipset for a now defunct machine model and the software's capabilities for modification and improvement are limited. Also, the planning department has received feedback that shop owners are complaining about the hard-to-understand user interface. So now, the overall planning team includes a one-hour developing machine sub-team design engineer and a software engineer as well. The developing machine sub-team must now consider the implications of modifying the several models of machines in their customer's shops, and the known software limitations and user interface complaints.

Eventually, the overall planning team performs a decision tree and other analyses that weigh the risks and return on net assets of each option. At the end of 30 days, division management conducts a review meeting, and based on the decision analysis, decides to increase the line speed of the film machine at plant X and upgrade its coating and drying process to handle the extra coating layer, and to design and manufacture a new developing machine model using the latest software and user interface (a modified version taken from the prototype of a different, but related model that had been in research and development.)

As the developing machine sub-team continues with scope development, cost engineering practices are used for software development. Software estimates deal with software configuration and coding activities versus the construction or assembly activities for capital and product estimates. Software value engineering focuses on software and interface functions that can be combined or eliminated or developed as object code modules. Again, the more the cost engineer understands the capital, product, and software planning aspects, the more valuable their input will be to the program.

CONCLUSION

This chapter outlines the basics of Strategic Asset Management with its measurement, assessment, planning, and implementation steps. Gated project systems that link the Strategic Asset Management and Project Control are described. Examples were provided of how the asset management steps could be applied to three types of strategic assets: a capital asset, a product, and software. The examples show that the same basic asset management steps and systematic approach apply to all strategic asset types. The examples also show that while the approach is basic, Strategic Asset Management implementation can be complex because the assets in an enterprise's portfolio are often interrelated in myriad ways. Many example applications can be described by simply substituting specific descriptors of a given asset type and asset management organization. The Strategic Asset Management process of TCM is universal.

The application example also illustrates the typical roles and responsibilities of cost engineers in Strategic Asset Management teams. The teams feature personnel from all relevant parts of the enterprise, including, business, operations, engineering, product planning, software development, and research and development. While there may not be anyone on the team with the title of cost engineer, someone on the team must practice the cost engineering skills of estimating, planning and scheduling, and value engineering. Few cost engineers will perform each skill for each asset, however, it is important to understand the Strategic Asset Management process so that no matter what your role is, you can communicate and work effectively with the asset management team.

REFERENCES

1. AACE International. (2015). *Total Cost Management Framework*, (2nd ed.). Morgantown, WV: AACE International.
2. Mintzberg, H., B. Ahlstrand, and J. Lampel, (1998). *Strategy Safari: A Guided Tour Through the Wilds of Strategic Management.* New York, NY: The Free Press.
3. The International Association of Database Professionals Dictionary. Retrieved from: www.teamdatabase.com/dictionary.