

Sharpen Your Cost Estimating Skills

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ABSTRACT: This classic article reviews the current AACE International Classification System. It discusses various estimation methodologies, from conceptual to definitive, for calculating the cost of capital projects in the CPI, and identifies the technical deliverables required to prepare each class of estimate. The techniques used for each type of estimate are discussed. These estimating methodologies, and the engineering information required to support them, should be understood by all engineers.

KEY WORDS: Capital budgets, projects, cost estimates, and estimation methodologies

Increasingly limited capital budgets in the chemical process industries (CPI) force management to make effective, early decisions regarding investments in strategic assets, often with little or no engineering input. As potential projects are considered, these individuals often find themselves in situations where they must decide whether a specific project should be continued. At each stage of the funding, management requires costs estimates of increasing accuracy. Determining which estimation method to use at each stage depends on the information available at the time of preparation, the end use of the estimate, and its desired accuracy.

This article discusses various estimation methodologies, from conceptual to definitive, for calculating the cost of capital projects in the CPI, and identifies the technical deliverables required to prepare each class of estimate. The techniques used for each type of estimate are discussed. These estimating methodologies, and the engineering information required to support them, should be understood by all engineers.

Estimate Classifications

Most organizations use some form of classification system to identify the various types of estimates that may be prepared during the lifecycle of a project, as well as to indicate the overall "maturity" and quality of the estimates being prepared. Unfortunately, there is often a lack of consistency and understanding of the terminology used during classification, both across the process industries and within individual companies or organizations.

The Association for the Advancement of Cost Engineering International (AACE International; Morgantown, W.Va.; aacei.org) recently developed recommended practices for cost-estimate classification [1] for the process industries. This document, known as 18R-97, is a reference document that describes and differentiate various types of project estimates.

AACE International's 18R-97 identifies five classes of estimates, which it designates as Class 1, 2, 3, 4, and 5 (See table 1). A Class 5 estimate is associated with the lowest level of project definition or

maturity, and a Class 1 estimate, with the highest. Five characteristics are used to distinguish one class of estimate from another: degree of project definition, end use of the estimate, estimating methodology, estimating accuracy, and effort to prepare the estimate. Degree of project definition is the primary characteristic used to identify an estimate class.

The CPI rely on process flow diagrams (PFDs) and piping and instrument diagrams (P&IDs) as primary scope-defining documents. These documents are key engineering deliverables in determining the level of project definition, the maturity of the information used to perform the estimate, and subsequently, the estimate class. Incorporated into AACE International's 18R-97 is also an estimate-input checklist that identifies the engineering deliverables used to prepare a project estimate, such as PFDs, process- and utility-equipment lists, and instrumentation-and-control system drawings.

Estimating methodologies generally fall into two broad categories: stochastic and deterministic. With stochastic methods, the independent variables used in the algorithm involve modeling (or factoring) based on inferred or statistical relationships between costs and other design-related

Capacity-Factored Estimate—Changing Places

A 100,000-bbl/d hydrogen-peroxide unit is to be built in Philadelphia and completed in 2002. In Malaysia, a similar plant, with a capacity of 150,000 bbl/d and a final cost of \$50 million, was completed in 2000. Recent history shows a capacity factor of 0.75 to be appropriate. The simple approach is to use the capacity-factor algorithm:

$$\begin{aligned} \$B &= \$A(\text{Cap}_B/\text{Cap}_A)^e \\ \$B &= \$50\text{M}(100/150)^{(0.75)} = \$36.9\text{M} \end{aligned}$$

However, a better estimate is obtained when adjustments for differences in scope, location and time are made. The plant in Malaysia includes piling, tankage and owner costs that are not included in the plant to be built in Philadelphia. However, construction in Philadelphia is expected to cost 1.25 times that in Malaysia. Escalation will be included as a 1.06 multiplier from 2000 to 2002. Additional costs for the Philadelphia plant (not included in the cost estimate of the Malaysian plant) involve pollution control. The revised estimate appears below:

Plant in Malaysia	= \$50M	Escalate to 2002	
Deduct \$10M for piling, tankage and owner costs	= \$40M	\$50M \times 1.06	= \$53M
Malaysia to Philadelphia adjustment	\$40M \times 1.25	Capacity factor estimate	
	= \$50M	\$53M \times (100/150) ^{0.75}	= \$39M
		Add \$5M for pollution requirements	= \$44M

Table 1—Cost Estimate Classification Matrix

Estimate Class	Project Definition (% of complete definition)	Purpose of Estimate	Estimating Method	Accuracy Range (variation in low and high ranges)	Preparation Effort (Index relative to project cost)
Class 5	0–2	Screening	Capacity-factored, parametric models	L: –20 to –50% H: 30 to 100%	1
Class 4	1–15	Feasibility	Equipment-factored, parametric models	L: –15 to –30% H: 20 to 50%	2–4
Class 3	10–40	Budget authorization or cost control	Semi-detailed unit-cost estimation with assembly-level line items	L: –10 to –20% H: 10 to 30%	3–10
Class 2	30–70	Control of bid or tender	Detailed unit-cost estimation with forced, detailed takeoff	L: –5 to –15% H: 5 to 20%	4–20
Class 1	50–100	Check estimate, bid or tender	Semi-detailed unit cost estimation with detailed takeoff	L: –3 to –10% H: 3 to 15%	5–100

The stage of process technology and the availability of cost data strongly affect the accuracy range of an estimate. Plus-or-minus high (H) and low (L) values represent the variation in actual costs versus estimated costs, after applying contingency factors. The “preparation effort” uses an index to describe the cost required to prepare an estimate, relative to that for preparing a Class 5 estimate. For example, if it costs 0.005 percent of the project cost to develop a Class 5 estimate, then a Class 1 estimate could require as much as 100 times that, or 0.5 percent of the total project cost.

parameters. For deterministic methods, the independent variables used in the algorithm are 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 the quantities, pricing and completeness of scope to be known with relative certainty. As the level of project definition increases, the estimating methodology tends to progress from stochastic (or factored) methods to deterministic methods.

Capacity-Factored Estimates

Generated during the feasibility stage of a project, the capacity-factored estimate (CFE) provides a relatively quick, and sufficiently accurate means of determining whether a proposed project should be continued. It is a good method to use when deciding between alternative designs or plant sizes. This early screening method (Class 5 estimate) is most often used to estimate the cost of battery-limit process facilities, but may also be applied to individual equipment items.

When estimating via CFE, the cost of a new plant is derived from the cost of a similar plant of a known capacity, with a similar production route (such as, both are batch processes), but not necessarily the same end products (products should be relatively similar, however). It relies on the

nonlinear relationship between capacity and cost shown in the following equation:

$$\$B/\$A = (Cap_B/Cap_A)^e \quad \text{(equation 1)}$$

where \$A and \$B are the costs of the two similar plants, Cap_A and Cap_B are the capacities of the two plants, and “e” is the exponent or proration factor. The value of the exponent typically lies between 0.5 and 0.85, depending on the type of plant, and must be analyzed carefully for its applicability to each estimating situation.

The “e” used in the capacity factor equation is actually the slope of the log-curve that has been drawn to reflect the change in the cost of a plant as it is made larger or smaller. These curves are typically drawn from the data points of the known costs of completed plants. With an exponent less than 1, scales of economy are achieved such that as plant capacity increases by a percentage (say, by 20 percent), the costs to build the larger plant 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-tenths factor” method because of the reliance on an exponent of 0.6 if no other information is available [2,3]. With an exponent of 0.6, doubling the capacity of a plant increases costs by approximately 50 percent, and tripling the capacity of a

plant increases costs by approximately 100 percent.

In reality, as plant capacities increase, the exponent tends to increase as illustrated in Figure 1. The capacity factor exponent between plants A and B may have a value of 0.6; between B and C, the exponent may have a value of 0.65; and between C and D, the exponent may have risen to 0.72. As plant capacity increases to the limits of existing technology, the exponent approaches a value of one. At this point, it becomes as economical to build two plants of a smaller size, rather than one large plant.

Table 2 shows the capacity factors for several chemical process plants [4]. Unfortunately, most of the data are quite

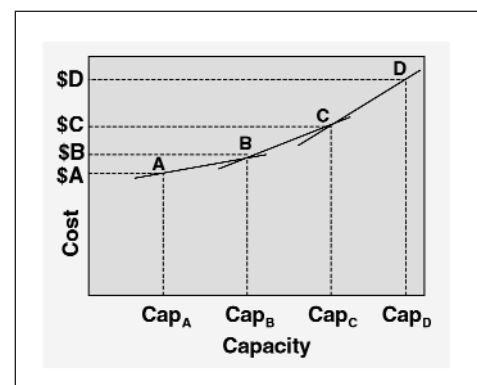


Figure 1—The capacity-factored relationships shown here are logarithmic. Exponents differ across capacity ranges Cap_A is the capacity of plant A, and so on.

old. Nowadays, however, companies are less likely to make these data available, and recent studies have been sparse. This data should be used for reference only, and with caution regarding its applicability to any particular situation.

If the capacity factor used in the estimating algorithm is relatively close to the actual value, and if the plant being estimated is relatively close in size to the similar plant of known cost, then the potential error from a CFE is certainly well within the level of accuracy that would be expected from a stochastic method. However, one must also account for differences in scope, location, and time. Keep in mind that each of these adjustments adds additional uncertainty and potential error to the estimate. Table 3 shows the percent error that may occur if an assumed capacity factor of 0.7 is used, and the actual value is different [5]. For example, if the new plant is triple the size of an existing plant, and the actual capacity factor is 0.80 instead of the assumed 0.70, one will have underestimated the cost of the new plant by only 10 percent. Similarly, for the same threefold scaleup in plant size, if the capacity factor should be 0.60 instead of the assumed 0.70, one will have overestimated the plant cost by only 12 percent. These data were generated with equation 1. The capacity-increase multiplier is Cap_A/Cap_B and in the base, e is 0.7. The error occurs as e varies from 0.7.

To use the CFE method prudently, make sure the new and existing known plant are near-duplicates, and are reasonably close in

size. Deduct costs from the known base case that are not applicable in the new plant. Apply location and escalation adjustments to normalize costs and use the

capacity-factor algorithm to adjust for plant size. Cost indices are used to accommodate the inflationary impact of time (See the "How to Use a Cost Index" box on page

Actual Exponent	Capacity-Increase Multiplier (Cap_B/Cap_A)							
	1.5	2	2.5	3	3.5	4	4.5	5
0.20	23%	41%	58%	73%	88%	100%	113%	124%
0.25	20%	36%	51%	64%	75%	87%	97%	106%
0.30	18%	32%	44%	55%	64%	74%	83%	91%
0.35	16%	28%	38%	47%	55%	63%	70%	76%
0.40	13%	23%	32%	39%	46%	52%	57%	63%
0.45	11%	18%	26%	32%	36%	41%	46%	50%
0.50	9%	15%	20%	25%	28%	32%	35%	38%
0.55	6%	11%	15%	18%	21%	23%	25%	28%
0.60	4%	7%	10%	12%	13%	15%	16%	18%
0.65	2%	3%	5%	6%	6%	7%	8%	8%
0.70	0%	0%	0%	0%	0%	0%	0%	0%
0.75	-2%	-4%	-5%	-5%	-6%	-7%	-7%	-8%
0.80	-4%	-7%	-9%	-10%	-12%	-13%	-14%	-15%
0.85	-6%	-10%	-13%	-15%	-17%	-19%	-20%	-21%
0.90	-8%	-13%	-17%	-20%	-22%	-24%	-26%	-28%
0.95	-10%	-16%	-21%	-24%	-27%	-29%	-31%	-33%
1.00	-11%	-19%	-24%	-28%	-31%	-34%	-36%	-38%
1.05	-13%	-22%	-28%	-32%	-36%	-39%	-41%	-43%
1.10	-15%	-24%	-31%	-36%	-40%	-43%	-45%	-47%
1.15	-16%	-27%	-34%	-39%	-43%	-46%	-49%	-52%
1.20	-18%	-30%	-37%	-42%	-47%	-50%	-53%	-55%

Table 3—Percentage Error Factor of 0.7 is Used for Estimate

Product	Factor
Acrylonitrile	0.60
Butadiene	0.68
Chlorine	0.45
Ethanol	0.73
Ethylene oxide	0.78
Hydrochloric acid	0.68
Hydrogen peroxide	0.75
Methanol	0.60
Nitric acid	0.60
Phenol	0.75
Polymerization	0.58
Polypropylene	0.70
Polyvinyl chloride	0.60
Sulfuric acid	0.65
Styrene	0.60
Thermal cracking	0.70
Urea	0.70
Vinyl acetate	0.65
Vinyl chloride	0.80

Table 2—Capacity Factors for Process Units [4]

How to Use a Cost Index

A cost index is table of values that relates the costs of specific items at various dates to a specific time in the past. Cost indices are useful to adjust costs for inflation over time. **Chemical Engineering** (CE) publishes several useful cost indices at the back of the magazine each month. Of particular importance to CPI are the **CE Plant Cost Index** and the **Marshall & Swift Equipment Cost Index**.

The **CE Cost Index** provides values for several plant-related costs, including various types of equipment, buildings, construction labor and engineering fees. These values relate costs of overall plants over time, using the 1957–1959 timeframe as the base period (value = 100). The **Marshall & Swift** indices provide equipment-cost-index values arranged in accordance to the process industry in which the unit is used. This index uses the year 1926 as the base period.

To use one of these indices to account for cost escalation, multiply the cost to be escalated by the ratio of the index values for the years in question. For example, suppose you want to determine the cost of a new chlorine plant using capacity-factored estimates. You discover that a similar chlorine plant built in 1994 cost \$25M. Before applying the capacity-factor equation (equation 1), the cost of the 1994 must be normalized for 2001.

The CE index value for 1994 is 368.1. The February 2001 value is 395.1. The escalated cost of the chlorine plant is therefore:

$$\$25M \times (395.1/368.1) = \$25M \times 1.073 = \$26.8M$$

Readers should note that the **CE Plant Cost Index** is being revised to account for changes in many of the individual indexes and reports upon which it is based. Look for a future article in CE that will introduce and describe the revised **CE Plant Cost Index**.

24). Finally, add any additional costs that are required for the new plant, but were not included in the known plant.

Equipment-Factored Estimates

Equipment factored estimates (EFEs, Class 4) are typically prepared during the feasibility stage of a project, when engineering is approximately 1–15 percent complete, and are used to determine whether there is sufficient

reason to pursue the project. If so, then use this estimate to justify the funding required to complete additional engineering and design for a Class 3 or budget estimate.

Equipment Factors: Understanding Them Is As Important As Learning How to Use Them

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. The factors may apply to total installed costs (TICs) or direct field costs (DFCs) for the facility. Usually, the factors generate costs for inside battery limits (ISBL) facilities, and require outside-battery-limit facilities (OSBL) costs to be estimated separately. In some cases, factors are used to estimate the costs of the complete facilities.

Hans Lang introduced the concept of using the total cost of equipment to estimate the total cost of a plant [7,8]:

$$\text{Total plant cost (TPC)} = \text{Total equipment cost (TEC)} \times \text{Equipment factor} \quad (\text{equation 2})$$

Lang proposed three separate factors based on the type of process plant. For solids, the factor is 3.10; for combined solids and fluids, 3.63; and for fluids alone, 4.74. These factors were meant to cover all the costs associated with the TIC of a plant, including the ISBL costs and OSBL costs. Here is an example of a Lang-factor estimate for a fluid-process plant:

$$\begin{aligned} \text{TEC} &= \$1.5\text{M} \\ \text{TPC} &= \$1.5\text{M} \times 4.74 = \$7.11\text{M} \end{aligned}$$

Lang's approach was simple, utilizing a factor that varies only by the type of process. Today, many different methods of equipment factoring have been proposed. The Lang factor, however, is often used generically to refer to all the different types of equipment factors [9].

W. E. Hand elaborated on Lang's work by proposing using different factors for each type of equipment (columns, vessels, heat exchangers and other units) rather than process type. Hand's equipment factors estimate DFCs, excluding instrumentation, and range from 2.0 to 3.5, which might correlate to approximately 2.4 to 4.3 if instrumentation were included. Hand's factors exclude indirect field costs (IFC), home office costs (HOC), and the costs for OSBL facilities, all of which must be estimated separately.

We will run an estimate prepared for a fluid processing plant using Hand's equipment factoring techniques in Table 4. Each equipment item has its own factor. The ratio of DFC to TEC is 2.8, whereas a typical value would range from 2.4 to 3.5. The ratio of TFC to TEC is 3.6, while a typical value would range from 3.0 to 4.2, and the ratio of total project cost (including contingency) to TEC is 5.1. A typical value would range from 4.2 to 5.5. This correlates closely with Lang's original overall equipment factor of 4.74 for fluid plants.

Three specific variables affect the equipment cost to a greater degree than they affect the cost of the bulk materials and installation [10]: the size of the major equipment, the materials of construction and the operating pressure. As the size of a piece of major equipment gets larger, the amount of corresponding bulk materials (foundation, support steel, piping and instruments) 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 expensive materials (stainless steel, titanium or Monel), or if the operating pressure increases, the equipment factor decreases. These three variables could be summarized into a single attribute known as the "average unit cost" of equipment, or the ratio of total cost of process equipment to the number of equipment items [11,12].

The Discipline Method

Another way to use equipment factors, aside from calculating DFC or TIC, is to generate separate costs for each of the disciplines associated with the installation of equipment. Here's how: Each type of equipment is associated with several discipline-specific equipment factors. For example, one discipline-equipment factor will generate costs for concrete, a second factor will generate costs for structural steel, and a third will generate the costs for piping. 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 totaled, and compared to those of similar projects [13,14].

An example of discipline-specific equipment factors is shown in Table 5. 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, HOC or OSBL costs.

Development of the actual equipment factors used for process plant estimates is time-consuming. Although some published data exists, much of these data are old, and some of the assumptions in normalizing the data for time, location and scope are incomplete or unavailable. For lack of anything better, this data is an acceptable source of equipment factors. However the best information will be that which come from a cost database that reflects the company's project history.

An EFE can be quite precise if the equipment factors are appropriate, if the correct adjustments have been applied, and if the list of process equipment is complete and accurate. These estimation techniques have an advantage over CFEs in that they are based upon the specific process design. Typically, EFEs rely on the existence of a ratio between the cost of an equipment item and costs for the associated non-equipment items, such as foundations, piping, and electrical components needed when building a plant.

The first step when preparing an EFE is to estimate the cost for each piece of process equipment [6]. Examine the equipment list carefully for completeness, and compare it against the PFDs and P&IDs. However, there is a problem—when an EFE is prepared, the equipment list is often in a preliminary stage. Although the major equipment is identified, it may be necessary to assume a cost percentage for auxiliary equipment that has not yet been defined.

This is the time to verify equipment sizing. Equipment is often sized at 100 percent of normal operating duty, but by the time the purchase orders have been issued, some percentage of oversizing has been added to the design specifications. The percentage of oversizing varies with the type of equipment, as well as with the 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 is often obtained from: purchase orders, published equipment-cost data, and vendor quotations. Since the material cost of equipment can represent 20–40 percent of the total-project costs for process plants, it is extremely important to estimate the equipment costs as accurately as possible. If historical purchase information is used, make sure that the costs are escalated appropriately, and that adjustments are made for location and market conditions.

Once the equipment cost is established, the appropriate equipment factors must be generated and applied. (See the “Equipment Factors” box on the previous page. Tables 4 and 5 and [7–14] are referenced in this sidebar). In doing so, one must make the necessary adjustments

Item Description	Equipment Cost, \$	Equipment Factor	Total, \$	Derived Multiplier
Columns	650,000	2.1	1,365,000	
Vertical vessels	540,000	3.2	1,728,000	
Horizontal vessels	110,000	2.4	264,000	
Shell-and-tube heat exchangers	630,000	2.5	1,575,000	
Plate heat exchangers	110,000	2.0	220,000	
Pumps, motors	765,000	3.4	2,601,000	
Raw equipment costs (TEC)	2,805,000			
Direct field cost (DFC) =	2,805,000	3 2.8	7,754,000	2.8
Direct field labor (DFL) cost =	DFC	3 25%	1,938,000	
Indirect field costs (IFC): Temporary construction facilities; construction services, supplies and consumables; field staff and subsistence expenses; payroll, benefits, insurance; construction equipment and tools				
IFC =	DFL	3 115%	2,229,000	
Total field costs (TFC) =	DFC + IFC		9,982,000	3.6
Home-office costs (HOC): Project management, controls and estimating criteria, procurement, construction management, engineering and design, and home-office expenses				
HOC =	DFC	3 30%	2,326,000	
Subtotal project cost =	TFC + HOC		12,308,000	4.4
Other project costs (OTC), including project commissioning costs				
Commissioning =	DFC	3 3%	233,000	
Contingency =	(TFC + HOC)	3 15%	1,846,000	
Total OTC			2,079,000	
Total installed project cost (TIPC) =			14,387,000	5.1
Note: In the table above, the multiplier is the ratio of DFC, TFC, TIPC and other costs to the raw-total equipment cost of \$2,805,000.				
In this table, the cost of each type of equipment was multiplied by a factor to derive the installed DFC for that unit. For instance, the total cost of all vertical vessels (\$540,000) was multiplied by an equipment factor of 3.2 to obtain an installed DFC of \$1,728,000. The total installed cost (TIC) for this project is \$14,387,000.				

Table 4—Equipment-Factored Estimating Example

	Factor	Cost, \$	
Equipment cost	1.0	10,000	This table showcases the equipment factors for a Type 316 stainless steel heat exchanger with a surface area of 2,400 ft ² . The purchase cost of \$10,000 is multiplied by each factor to generate the DFC for that discipline
Installation labor	0.05	500	
Concrete	0.11	1,100	
Structural steel	0.11	1,100	
Piping	1.18	11,800	
Electrical parts	0.05	500	
Instrumentation	0.24	2,400	
Painting	0.01	100	
Insulation	0.11	1,100	
Total DFC	2.86	\$28,600	

Table 5—Heat Exchanger Discipline-Equipment Factors

for equipment size, metallurgy, and operating conditions.

Specific project or process conditions must be evaluated. For example, if the plot layout of the project requires much closer equipment placement than is typical, one may want to make adjustments for the shorter piping, conduit, and wiring than would be accommodated by the equipment factors. Or, if a project is situated in an active seismic zone, one may need to adjust the factors for foundations and support steel. After developing equipment factored costs, one must account for project costs that are not covered by the equipment factors, such as by generating indirect field costs (IFCs) and home-office costs (HOCs).

Parametric-Cost Estimation

A parametric-cost model is an extremely useful tool for preparing early conceptual estimates when there are 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 and its resultant cost. Capacity- and equipment-factored estimates are simple parametric models. Sophisticated parametric models involve several independent variables or cost drivers.

The first step in developing a parametric model is to establish its scope. This includes defining the end use, physical characteristics, critical components, and cost drivers of the model. The end use of the model is typically to prepare conceptual estimates for a process plant or system and takes into consideration the type of process to be covered, the type of costs to be estimated (such as TIC and TFC) and the accuracy range.

The model should be based on actual costs from completed projects and reflect the organization's engineering practices and technology. It should use 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 factors affecting a particular project. Finally, the model should generate current year costs or have the ability to escalate to current year costs.

Data collection and development for a parametric estimating model require a significant effort. Both cost and scope information must be identified and collected. It is best to collect cost data at a fairly low level of detail [15]. 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 type of data to be collected is usually decided upon in cooperation with the engineering and project personnel. It is best to create a formal data-collection form that can be consistently used, and revised if necessary.

After the data have been collected, it must be normalized. By doing this, we make adjustments to account for escalation, location, site conditions, system specifications and cost scope. Data analysis, the next step in the development of a parametric model, is achieved by a wide variety of techniques that are too complex to delve into in this article [16].

Typically, data analysis entails performing regression of cost versus selected design parameters to determine the key drivers for the model. It is understood that regression involves iterative experiments to find the best-fit algorithms or mathematical relationships that describe how data behave. The result is a parametric model. Most spreadsheet applications provide regression analysis and simulation functions that are reasonably simple to use.

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, erratic or outlying data points will need to be removed from the input data in order to avoid distortions in the results. The algorithms will usually take one of the following forms [17]:

A linear relationship, such as,

$$\text{Cost} = a + bV_1 + cV_2 + \dots \quad (\text{equation 3})$$

or a nonlinear relationship, such as,

$$\text{Cost} = a + bV_1^x + cV_2^y + \dots \quad (\text{equation 4})$$

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 equation

that is the best fit for the data will typically have the highest r-squared (R^2) value. R^2 provides 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 input and the resulting cost are statistically significant. One still needs to examine the algorithm to ensure that it makes sense.

A cursory examination of the model can help identify the obvious relationships that are expected. If the relationships from the model appear to be reasonable, then additional tests (such as the t-test and f-test) can be run to determine statistical significance and to verify that the model is providing results with an acceptable range of error. A quick check can be performed by running the regression results directly against the input data to see the percent error for each of the inputs. This allows the estimator to determine problems and refine the algorithms. After 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) for verification.

During the data-application stage, a user interface and a presentation form for the parametric cost model is established. Electronic spreadsheets provide an excellent means of accepting estimator input, calculating costs based upon algorithms and displaying output.

Perhaps the most important effort in developing a parametric (or any other) cost model is making sure the application is thoroughly documented. Record the actual data used to create the model, the resulting regression equations, test results and a discussion on how the data was adjusted or normalized for use in the data-analysis stage. Any assumptions and allowances designed into the cost model should be documented, as should any exclusions. The range of applicable input values, and the limitations of the model's algorithms should also be noted. Write a user manual to show the steps involved in preparing an estimate using the cost model, and to describe the required inputs to the cost model. An example of developing a parametric estimating model is described in the "Parametric Equations and Data Manipulation" box. (Table 6 and figure 2 are referenced in this sidebar).

Detailed-Cost Estimation

A detailed estimate is one in which each component contained 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. Detailed estimates can be very accurate (Class 3 through Class 1). However, completeness of the design information is critical. If an engineering drawing or other information is missing, then the scope items covered by those documents will not be included in the estimate, and the results will not be on par with a Class 1 or 2 estimate.

It is not unusual for detailed estimates on very-large projects to take several weeks, if not months, to prepare, and to require thousands of engineering hours to generate the technical deliverables (the engineering and design data). At the very least, this includes PFDs and utility flow drawings, P&IDs, equipment data sheets, motor lists, electrical 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, 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).

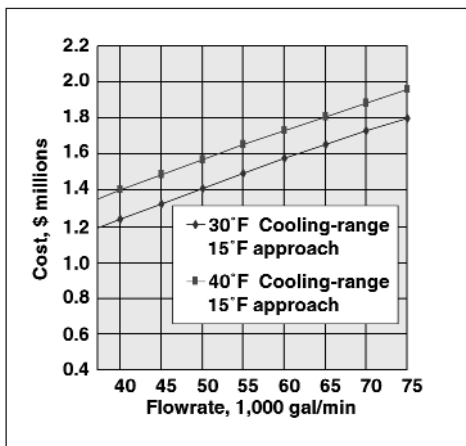


Figure 2—This graph, developed from regression data for tower cost versus design parameters (Table 6), such as flowrate, can be used to prepare estimates for future cooling towers.

There are various degrees of detail in a detailed cost estimate. In a completely detailed estimate, all costs are considered including the direct field cost (DFC), IFC, HOC and all other miscellaneous costs for both the inside battery limits (ISBL) and outside battery limits (OSBL) facilities. In a semi-detailed estimate, costs for ISBL process facilities are factored, and the costs for the OSBL facilities are detailed. In a forced-detailed estimate,

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.

Planning: The detailed estimate is typically used to support cost control during execution of the project. The first step is to establish a project-estimate basis and schedule. This may involve several

Cooling Range, °F	Temperature, Approach, °F	Flowrate, gal/min	Actual Cost, \$	Predicted Cost, \$	% Error
30	15	50,000	1,040,200	1,014,000	-2.5%
30	15	40,000	787,100	843,000	7.1%
40	15	50,000	1,129,550	1,173,000	3.8%
40	20	50,000	868,200	830,000	-4.4%
25	10	30,000	926,400	914,000	-1.3%
35	8	35,000	1,332,400	1,314,000	-1.4%

Table 6—Actual Costs Versus Predicted Costs With Parametric Equation

Parametric Equations and Data Manipulation

Induced-draft cooling towers are typically used in process plants to provide a recycle cooling-water loop. These 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, the temperature approach and the water flowrate. The cooling range is the temperature difference between the water entering the cooling tower and the water leaving it. The approach is the difference in the cold water leaving the tower and the wet-bulb temperature of the ambient air.

Table 6 provides the actual costs and design parameters of six recently completed units whose costs have been normalized (adjusted for location and time) to a Northeast US, year-2000 timeframe. These data are the input to a series of regression analyses that are run to determine an accurate algorithm for estimating costs. Using a Microsoft Excel spreadsheet, the following cost-estimation algorithm was developed:

$$\text{Predicted Cost} = \$86,600 + \$84,500 \text{ (Cooling Range, } ^\circ\text{F)}^{0.65} - \$68,600 \text{ (Approach, } ^\circ\text{F)} + \$76,700 \text{ (Flowrate, 1,000 gal/min)}^{0.7} \quad (\text{equation 5})$$

Equation 5 demonstrates that the cooling range and flowrates affect cost in a non-linear fashion, while the approach affects cost in a linear manner. Increasing the approach will result in a less costly cooling tower, since it increases the efficiency of the heat transfer taking place. These are reasonable assumptions. The regression analysis resulted in an R^2 value of 0.96, which indicates that the equation is a “good-fit” for explaining the variability in the data.

In Table 6, the actual costs and the predicted costs from the estimating algorithm are shown. The percentage of error varies from -4.4 percent to 7.1 percent. The estimating algorithm developed from regression analysis, can be used to develop cost-versus-design parameters that can be represented graphically (Figure 2). This information can then be used to prepare estimates for future cooling towers. It is fairly easy to develop a spreadsheet model that will accept the design parameters as input variables, and calculate the costs based on the parametric-estimating algorithm.

estimators and extensive support from engineering to review the organization's estimating guidelines and procedures. The schedule indicates when the deliverables are to be supplied, when each major section of the estimate should be completed, and when reviews of the estimate will take place. Any exclusions that are known at this time should be reviewed and documented. A kickoff meeting should be scheduled to inform the project team of the roles and responsibilities of the various participants, and allow them to review the plans for estimate preparation. On very large projects, it is helpful to appoint a few key contact people who will act as liaisons between estimating and engineering personnel.

Estimation activities: Preparation of the DFC estimate is the most intensive activity in detailed cost estimation. The project scope should be reviewed and understood, and all technical deliverables assembled. On large projects, engineering drawings and technical information may be submitted to the estimating department over time. All information received from engineering should be logged.

The estimate "takeoff" is determined by quantifying all of the various material and labor components of the estimate, to ensure that all quantities are accounted for, but not double-counted. Material pricing is applied using the best cost information available. The labor worker hours are assigned and adjusted for labor productivity, and wage rates are applied. Allowances, or costs that are factored from more-significant equipment, are made for bolts, gaskets, hangers for pipes and similar items. For example, bolts and fittings may be factored as 3 percent of the piping cost. Finally, the DFC estimate is summarized, formatted and reviewed for completeness and accuracy.

After the DFC estimate has been prepared, start the IFC estimate. The total manhours, identified from the DFC, serve as the basis for factoring many of the of IFC costs (refer to table 4). Indirect-labor wage rates and staff-labor rates are established and applied, and any indirect estimate allowances are taken into account. The construction manager should be involved in the initial review of the IFC estimate.

The HOC estimate follows. Project administrators and engineers should

provide detailed manhour estimates for their project activities, and the appropriate wage rates, as approved by management, are applied by the estimating engineers. Home-office overhead factors are used to project overhead costs and expenses.

Local sales-tax rates or duties may need to be included in the estimation. Estimate escalation costs based on the project schedule. Depending on the contracting strategy and schedule of delivery, project-fee estimates may be included. Finally, perform a risk analysis and include the appropriate contingency in the estimate.

Pay close attention to pricing the process equipment, as it contributes to 20-40 percent of the facility's TIC. The minimum information required for pricing equipment includes the PFDs, equipment lists and data sheets, which are usually prepared by the process-engineering group. Process and mechanical engineers are in the best position to make accurate estimates of equipment pricing, since they are usually in close contact with potential equipment vendors. Whenever possible, the vendors should provide the equipment-purchase costs to the estimator.

Slight differences in equipment specifications can sometimes result in large differences in pricing. Formal vendor quotes are preferred; however, time constraints in preparing the estimate often do not allow for solicitation of formal vendor quotes. In this case, equipment pricing may depend on informal sources, such as phone discussions, in-house pricing data, recent purchase orders, capacity-factored estimates from similar equipment, or from parametric pricing models.

Equipment-installation costs are usually prepared by the estimator, with assistance from construction personnel. Construction companies may be called upon for heavy lifts, or for help where special installation methods may be used. The placement of large process equipment in an existing facility may also require special consideration. Worker hours for equipment installation are usually based on weight and equipment dimensions, which are obtained from the equipment process-data sheets.

When referencing the labor worker hour data for equipment, the estimator must be careful to include all labor associated with the pieces of equipment

(for instance, vessel internals). Depending on the information available, the labor hours needed to set and erect a heavy vessel may not include the hours to erect, take down, and dismantle a derrick or other special lifting equipment. Special consideration may also be required to ensure that costs for calibration, soil settlement procedures, special internal coatings, hydrotesting and other tests 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.

Although detailed estimates are desirable for final budget authorization, the level of engineering progress needed and the time required for preparation will sometimes prevent 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 completely detailed estimate may be prepared later, to support project control.

When deciding upon potential investment opportunities, management must employ a cost-screening process that requires various estimates to support key decision points. At each of these points, the level of engineering and technical information needed to prepare the estimate will change. Accordingly, the techniques used prepare the estimates will vary. The challenge for the engineer is to know what is needed to prepare these estimates, and to ensure they are well documented, consistent, reliable, accurate and supportive of the decision-making process. ♦

Recommended Reading

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AACE International's 18-R97 Recommended Practice for Cost Estimate Classification - As Applied in Engineering, Procurement, and Construction for the Process Industries is available for viewing on the AACE International website, www.aacei.org.

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