V.B

Economic Evaluation

CHAPTER 88

Product Cost Analysis and Estimating

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1. ESTIMATING: IT HAPPENS ALL THE TIME

Cost estimating is a popular activity within engineering. Even though the professional person may be titled a cost estimator, cost engineer, cost analyst, labor estimator, or material planner, the emphasis remains the same. He or she is required to answer a familiar question: "How much will it cost?" Although the purposes that underlie this question are varied, we find that businesses, government, and not-for-profit organizations desire timely and reliable measures of economic want. For it is an engineer who does the appraisal, analysis, forecasting, and compiling of a pro forma document that extends from the basic cost ingredients to the bottom line of an estimate. Using this evaluation, other management people may determine a price, make vs. buy decision, return on investment (ROI), or public fiscal-year budget. Thus the engineer finds a future value of a product that responds to a specified need.

This historical trail of the development of formal cost estimating is intimately tied to industrial engineering. The original concept of a labor "standard" was seminal in the development of standard cost plans found widely throughout business. The genesis of formal cost estimating is circa 1900 since it was connected closely with manufacturing and construction. Cost estimating is a long-established job and an everyday occurrence for many engineers.

2. WHY ESTIMATES OF COST ARE MADE

Every size and type of organization needs cost estimates to make intelligent decisions. Some organizations employ persons skilled in the area of cost estimating whose primary function is developing estimates. But employees in most functional areas should understand good cost-estimating techniques. With concurrent engineering practices, teamwork philosophies, and total employee involvement, more people need cost-estimating knowledge and skills.

Cost-estimating procedures must be performed quickly and accurately because of tough customer demands and global competition. Listed below are several types of cost estimates that organizations routinely make.

2.1. New Product Cost

When new product concepts or product changes are being considered, detailed estimates of cost aid management in making proper decisions. Detailed estimates include costs of material, processing of material, fabrication, assembly, labor, and purchased components. The processing, fabrication, and assembly costs include estimates for tooling, dies, fixtures, inspection instruments, and so on. Costs for capital equipment investments, space, and facilities are also major estimate areas. If a management decision is to proceed with the new product, the detailed estimate may likely become the budget for the project. This type of estimate should be detailed and cover needs and costs from cradle to grave. Today the end of the product life has been extended to include recycling and disposal of the product and components of the product. It is not uncommon for companies first to determine the market selling price and then work backwards to determine how much cost can be absorbed by different areas of the company. Within each organizational area, costs must be constrained to limits allowed.

2.2. Make or Buy

Companies should consider whether to make components or the final product "in-house" or purchase them from "outside" vendors. Price is usually the deciding factor, but other factors can affect the final decision. Some of these factors are: can production demand requirements be fulfilled, can quality expectations be met, and can delivery schedules be met? Likewise, it might be better to use a supplier because they may have been producing similar parts for years and have the expertise to produce better parts than the company making the estimate. It is always wise to develop these estimates for comparison.

2.3. Selling Price Determination

These estimates can work two ways. First, estimates are used to determine selling price. The estimate establishes the cost to produce, market, deliver, and so on. Then a profit margin can be attached to establish a selling price. If entering an existing market, the competitive selling price can be used to work backwards to determine if producing the product is appropriate.

2.4. Equipment and Technology Acquisition

Companies frequently make decisions about purchasing new equipment, software, or complete systems to replace or add to the present resources. Often this involves comparing different alternatives that comprise new technology and/or changing from manual to automated procedures. Developing accurate cost estimates for new and unfamiliar areas is not easy.

2.5. Cost Control

Some companies, especially job shop-type organizations, use cost estimates as a form of cost control. Lot sizes vary and are usually small and almost every job is different. For these and other reasons, job shops seldom develop work standards to help determine costs. If a management decision is made to proceed with the new product, the detailed estimate may likely become the budget for the project. This type of estimate is not to be considered temporary work standards, because the objective is to determine whether the job can be done profitably and less expensively than by the competition.

2.6. Temporary Work Standards

Flow shop companies producing products in high volume use estimates as temporary work standards. It is to be hoped that these temporary standards will be replaced as soon as possible with accurate time studies, work sampling, or predetermined time standards.

2.7. Vendor Quote Checks

Cost estimates are sometimes used to check vendor bid quotations on outsourced work. This estimate can be used to not only verify appropriate costs for outsourced work but also as a part of the total product cost estimate.

3. MEASURES OF ECONOMIC WANT

The task facing the engineer is to provide a fact or number that represents the economic want of the design. A ‘‘want’’ is a value exchanged between competing and selfish interests. The price a consumer is willing to pay for an item stocked on the grocery shelf, a contractor–owner agreement on the bid value of a building project, and the fiscal-year budget value for a weapons system that the U.S. Department of Defense proposes and Congress accepts are typical examples of wants exchange.

The measure of want for a product estimate is called *cost*. It usually means full cost, as all items contributing to the manufacture and purchase of material, subcontract materials, and services must be included.

4. REQUEST FOR ESTIMATE

It is not common practice for cost engineers to initiate a request for an estimate. The request is typically generated from sales and marketing sources. Another source is engineering design from a potential customer. A request for quotation (RFQ) or request for proposal (RFP) is received by engineering design or generated in sales or marketing. A customer usually does not communicate with cost engineers; usually external communication goes through another function before coming to the cost engineer. Therefore, a request for estimate (RFE) is generated internally after an RFQ, RFP, or production inquiry is received. The customary form is not intended here, but the image is a generated signal on the computer screen.

Information needed varies for each RFE, but there are general areas of information that every engineer seeks. Some of these are status of the design, quantity and production rate expectations, quality specifications, legal requirements including environmental impact, delivery requirements and location. Information necessary to the nature of the design and needed to make a complete and accurate estimate should be provided to the engineer. But it is the engineer’s responsibility to request proper information to develop the estimate. As in all decision making, the cost estimate can be no better than the quality and completeness of data used to create the estimate.

Sources of estimating information are both internal and external to the organization. If the product is going to be produced within the organization, the product estimation is probably internal. Project data, which usually involve capital types of designs, are typically external sources of information. Commercial data and published and private indexes are sources of external data.

Before starting an estimate, it is essential that analysis of elements of cost be understood. Analysis of labor, material, and overhead costs must be undertaken. Once again, the estimate will not be better than the quality and thoroughness of the analysis that precedes the estimating calculations. It is also vital that timely, up-to-date information be used.

The internal elements of cost details making up the estimate are primarily obtained from the accounting department. Cost accounting is the function that collects actual cost data on the various internal elements needed to develop the estimate. Listed below are the primary elements of a cost estimate and a brief description of each.

4.1. Direct Labor

Direct labor is the labor expended to add value to the product, sometimes described as the cost related to individuals who ‘‘touch’’ the product. Process operators, assemblers, and inspectors are included in this area.

4.2. Indirect Labor

Indirect labor supports direct labor. These people are essential to the operation of an organization, but they add no value to the product being produced. Material handlers, tool room employees, shipping and receiving employees, and maintenance people are some in this category.

4.3. Direct Materials

Direct materials consist of both manufactured and purchased components that are part of the product being produced.

4.4. Indirect Materials

Indirect materials are necessary to manufacture, test, and ship the product. Indirect materials are not part of the finished product. Sand used to build a sand-cast mold is an example of indirect material. There is a cost associated with indirect material, and in some situations the indirect material can be used over.

4.5. Overhead

This is an accounting term. Included in this category are salary and management costs. Overhead also includes all costs not covered in categories above. Elements such as machinery costs, shop and office supplies, and insurance are included in this area. Often in developing estimates, overhead is expressed as a percent of direct labor cost. For information on allocating overhead cost refer to Chapter 89.

4.6. General and Administrative

Many companies list general and administrative costs as part of overhead. Other companies list these elements separately. Usually G&A are added to the estimate in the form of a percentage factor developed in the organization. As part of this category, such items as sales commissions and top executive salaries might be included. These costs are provided by the accounting department and not by the cost engineer.

4.7. Profit

Profit that must be obtained from the product must be included in the cost estimate. This margin above production cost is provided by the marketing and accounting department and by top management.

5. PRELIMINARY AND DETAILED METHODS

There are many methods used to make estimates. They range from techniques that are quick and crude, or preliminary estimates, to the comprehensive and more accurate methods, detailed estimates. Regardless of the type of design, the methods used in estimating are similar.

Preliminary methods are used in the formative stages of design, are meant to be fast, and are not expected to be as accurate as those used to prepare detailed estimates. Detailed methods, at the other extreme, are used to set prices, make competitive bids, or allow organizational decisions to be made on what type of economic action to take. As might be expected, detailed methods are much more quantitative. Arbitrary and judgmental factors are suppressed though not fully eliminated.

Quantitative estimating is desirable because it tends to provide more accurate estimates than do nonquantitative methods. The quantitative area of estimating with the use of mathematical formulas is called parametric estimating, or sometimes statistical modeling. Although parametric estimating methods have been used for many years, they are becoming more favorable for estimating because many of the calculation techniques and estimating procedures have been developed into computer software. Several methods are discussed in some detail below. They are presented in order from preliminary to detailed methods. This order also goes from nonquantitative to quantitative, or parametric. When broadly defined, these methods can be used for a variety of designs.

5.1. Judgment and Conference Method

Judgment is an important part of any estimating process. In the absence of data, and when time is of the essence, guesstimates may be the only way to find some cost components of an estimate. The best-suited engineer for the task should be the person developing the cost estimate. This means that the engineer has qualified experience, common sense, and knowledge of the design. Time, cost, and/or quantities, with regard to minor or major line elements, are chosen using the engineer's experience. The engineer must remain objective in properly measuring all the present and future factors that could affect costs. When possible, judgmental estimating should be done collectively.

If time and resources allow, the nonquantitative consensus method of estimating, called conference estimating, can be used. The more pertinent knowledge that can be obtained from various sources about a particular detail of the estimate, the better the chance of the decision being correct. In addition to cost information, other information such as savings, potential, and marginal revenue, can be included. The conference method relies on the collective judgment of the differences between previously determined estimates and their associated relationships with the new designs being considered.

Conference estimating usually involves bringing together representatives from various departments conferring with the engineers in round table discussions. These groups of people determine costs for the features of the design for which they have been given responsibility. These conference estimates might be limited to specific areas such as direct labor, materials, and processing equipment. Overhead, distribution, selling price, and profit are later added, using the organization's various values and formulas. The engineers can add these indirect type costs to the estimate later if the various functional representatives helping develop estimate costs do not allow access to specific organization costing data.

The conference method is not typically analytical, and verifiable facts are usually lacking. When using the conference method, proper group managing techniques should be applied to ensure that the decisions are group decisions and are developed properly in the group setting.

5.2. Unit Method

The unit method, or some variation of it, is the most widely used preliminary estimating tool. This method may also be known as the order of magnitude method, lump sum method, module estimating, or flat rate method. Individuals often use the unit estimating method to estimate costs for their private needs. For example, for estimating what a new home may cost to build, the cost per square foot estimate can provide a good ballpark figure. If construction cost in a geographical area is valued at $105/ft², then a family could calculate the rough cost of having a 2075 ft² house built = $217,850 for the estimate of the cost of the house. Some other examples of unit estimates are:

- Cost of components per kilogram of casting
- Manufacturing cost per machine shop man-hour
- Chemical plant cost per barrel of oil capacity

All of these examples for estimating are per something. The information for these types of estimates can be obtained from the Internet, technical literature, government, banks, data files of cost engineering or accounting, and the service providers.

Contributing to the popularity of unit estimating techniques is their ease of use. Consider the manufacturing machining operation of turning. Using similar parts routings, the total time for several jobs and many part types for a lathe can be compiled. Taking averages of length of cut and time to cut, and knowing the direct labor charge, a cost per unit of length of cut can be determined.

5.3. Comparison

The comparison method is similar to the previously discussed unit method, the difference being that formal logic is applied. If an extremely difficult design is being estimated or part of the design has an unsolvable section, it is given an identifying name such as design A. A simpler design problem is then constructed so an estimate can be made. The simpler problem is given a title such as design B. The simpler design might be developed from creative and clever manipulations of the original, more difficult design. The simpler estimate may also be made up of relaxed technical constraints from the original problem. If known facts already exist about design B, the engineer can gain information useful in developing an estimate for A. The alternative design problem B must be selected to relate to the original design by the following inequality:

$$C_A(D_A) \leq C_B(D_B) \tag{1}$$

where C_A and C_B are the cost values of the estimate for designs A and B, respectively. Likewise, D_A and D_B are the designs for A and B. Obviously, estimates are better when B approximates A as closely as possible. The cost value C_A of the estimate should be something less than C_B. A conservative position may be taken initially, as can be construed from Eq. (1). It may be management's policy to estimate the cost a little high at the beginning. Once the detailed estimate of design A is thoroughly explored, it may be found that $C_A(D_A)$ is less than the original comparison estimate.

A comparison estimate can be developed where high and low bounds are placed on either side of the estimate for design A. If a similar design is known for, or approximately known for, a design A, the logic from above can be used to expand the comparison inequality to the following:

$$C_C(D_C) \leq C_A(D_A) \leq C_B(D_B) \tag{2}$$

The assumption is made that designs B and C satisfy the technical requirements and bond the economic estimate for A. In practice, many engineers use comparison logic to develop estimates. Standard cost plans can provide "similar-to" approaches, and analogy plans and computer retrieval schemes use this technique.

5.4. Factor Method

The factor method is an important method used for project estimating. Methods such as ratio, percentage, and parameter are approximately the same. The factor method is an extension of the unit method discussed previously. The unit cost estimating method was limited to a single factor for calculating overall costs. A natural extension of the unit method achieves improved accuracy by using separate factors for different cost items. For example, the estimate for the house construction from the unit method could be enhanced by added factors for certain types of heating and cooling units, tiled or wood floors, landscaping costs, etc. All the various unit costs can be summed and a more accurate estimate than using the unit method can be obtained. The equation takes the form

$$C = C_e + \sum f_i C_e (I + f_I) \tag{3}$$

where C = cost of design being evaluated
C_e = cost driver or subdesign used as base
f_i = factor for estimating instruments, structures, site clearing, etc.
f_I = factor for estimating indirect expense such as engineering, contractor's profit, and contingencies
i = 1, 2, . . . , n factor index

The general idea is that C_e is chosen as the cost driver. In the example, the house would be the cost driver. Where in a community the house is desirable to be built would be a contributing factor as would the specific design chosen and the amount of land the house would sit on. These factors can all be correlated and historical data, design parameters, and indexes can be referred to for factor estimate.

5.5. Cost- and Time-Estimating Relationships

Cost estimating relationships (CERs) and time-estimating relationships (TERs) are mathematical or graphical models that estimate cost or time. CERs and TERs are formulated to give estimates in either final or line item form for a cost estimate. Rule-of-thumb estimates are not to be confused with CERs and TERs, which are analytical.

5.5.1. Learning Curve

An excellent example of a CER and TER is the learning curve. There are two types of learning curves; unit cost and average cumulative cost, shown as

$$T_U \quad \text{or} \quad T_{AC} = KN^S \tag{4}$$

where T_U = cost or time value per unit of production, such as dollars, or man-hours required to produce the Nth unit
T_{AC} = average cumulative cost, time, or value of N units.
N = unit number, 1, 2, 3, . . . N
K = constant or estimate for $N = 1$, dimensions compatible with T
S = slope parameter of the improvement rate, equal to $\log L/\log 2$, where L = learning as percent of time (S is negative)

For example, if learning improvement requires only 85% of the previous time, then $S = \log 0.85/\log 2 = -0.2345$. The learning theory is based on the percentage of time or cost to build a quantity when doubled from the known time or cost. For example, assuming an 85% learning curve and assuming it takes 10 hours to build the first unit, then doubling that quantity, which is 2, it would require only 8.5 hours to build the second unit. Doubling the quantity again, it could be estimated that it would require only 7.225 hours to build the fourth unit, which is 85% of 8.5 hours.

Learning curves have either the unit or the cumulative average line as the linear line when drawn on a log–log graph format. In one presentation, on log–log paper, the cumulative average line is straight and the unit line curves under from unit 1 until 10 or 20 units. From then on, the unit line parallels the cumulative line. The other presentation form allows the unit line to be straight or linear when plotted on log–log paper, and the cumulative average line, though starting together with the unit line at unit 1, curves above the unit line, and at about the 10th to 20th unit the two curves will run parallel. Either way is acceptable, but it is important that the engineer understand and clarifys for the other readers of the estimate which presentation is being used. For estimating to build N number of units, the cumulative average time may be more meaningful. A company is more likely to want to know how much time it will take to build N units (N times the cumulative average time) rather than know how long it will take to build the *N*th unit. Table 1 shows the factors for an 85% learning curve. The two approaches are shown.

Different types of manufacturing have general learning curve slopes that are peculiar to them. Electronic manufacturers, ship builders, and so on have learning curve rates that generally apply to their area of production. Each company should have historical data for various types of products to obtain data for developing cost and time estimates for any size production demand. With knowledge of these slopes, or other learning experiences, the engineer determines the appropriate factor for the job being estimated.

Ostwald (1992) is one source of information on the development and application of learning curves. Many cost-estimating and work-measurement books give information on learning curve techniques.

5.5.2. *Power Law and Sizing Model*

Another application of the CER is the power law technique. The power law and sizing model is frequently used when estimates for equipment or components are given as a lump sum. This concept is concerned with designs that vary in size but are similar in type. An example might be estimating the design of a new and larger size electric motor. The cost to produce a 50 hp motor can be estimated from data for manufacturing a 25 hp motor, provided both are similar in design. Anyone familiar with manufacturing cost or the law of economy of scale would not necessarily expect the larger 50 hp motor to be twice the cost of the smaller 25 hp motor. The power law and sizing model can be expressed as

$$C = C_r \left(\frac{Q_C}{Q_r} \right)^m \tag{5}$$

TABLE 1 Sample Learning Theory table for 85% for Two Methods of Learning: Unit and Average

	Learning Table $\phi = 85\%$				
N	T_U or T'_a	T_c	T_a	T'_c	T'_u
1	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.8500	1.8500	0.9250	1.7000	0.7000
3	0.7729	2.6229	0.8743	2.3187	0.6187
4	0.7225	3.3454	0.8364	2.8900	0.5713
5	0.6857	4.0311	0.8062	3.4284	0.5384
6	0.6570	4.6881	0.7813	3.9419	0.5135
7	0.6337	5.3217	0.7602	4.4356	0.4937
8	0.6141	5.9358	0.7420	4.9130	0.4774
9	0.5974	6.5332	0.7259	5.3766	0.4636
10	0.5828	7.1161	0.7116	5.8282	0.4516
11	0.5699	7.6860	0.6987	6.2693	0.4411
12	0.5584	8.2444	0.6870	6.7012	0.4318
13	0.5480	8.7925	0.6763	7.1246	0.4235
14	0.5386	9.3311	0.6665	7.5405	0.4159
15	0.5300	9.8611	0.6574	7.9495	0.4090
16	0.5220	10.3831	0.6489	8.3521	0.4026
17	0.5146	10.8977	0.6410	8.7489	0.3968
18	0.5078	11.4055	0.6336	9.1402	0.3913
19	0.5014	11.9069	0.6267	9.5264	0.3863
20	0.4954	12.4023	0.6201	9.9079	0.3815
21	0.4898	12.8920	0.6139	10.2850	0.3771
22	0.4844	13.3765	0.6080	10.6579	0.3729
23	0.4794	13.8559	0.6024	11.0268	0.3689
24	0.4747	14.3306	0.5920	11.7536	0.3616
30	0.4505	17.0907	0.5697	13.5141	0.3462
40	0.4211	21.4252	0.5356	16.8435	0.3233
50	0.3996	25.5131	0.5103	19.9811	0.3066
100	0.3397	43.7539	0.4375	33.9680	0.2603
500	0.2329	151.4504	0.3029	116.4542	0.1783

where C = total cost sought for design size Q_c
C_r = known cost for a reference size Q_r
Q_C = design size expressed in engineering units
Q_r = reference design size expressed in engineering units
m = correlating exponent, $0 < m \leq 1$

An equation expressing unit cost C/Q_C can be used as

$$\frac{C}{Q_C} = \left(\frac{C_r}{Q_r}\right)\left(\frac{Q_C}{Q_r}\right)^{m-1} \tag{6}$$

As total cost varies as the mth power of capacity, C/Q_C will vary as the $(m - 1)$th power of the capacity ratio. When $m = 1$, a linear relationship exists and the law of economy of scale is ignored. For chemical processing equipment, for example, m is frequently approximately 0.6 and is sometimes called the "sixth-tenth model." The units of Q are required to be consistent since it enters only as a ratio. For situations such as inflation and deflation, the model can be altered to consider price change. A change factor C_I is placed in the equation along with index factors I_C and I_r, as follows:

$$C = C_r\left(\frac{Q_C}{Q_r}\right)^m\left(\frac{I_C}{I_r}\right) + C_1 \tag{7}$$

where C_I is the constant unassociated cost.

For estimating projects, a CER that can be used is $C = KQ^m$. K is a constant for a project that might be a processing plant, new computer system, or a highway bridge. The concept of economy of scale is derived from this CER, where capital cost per unit produced reduces as the plant size increases. The scale factor m is not constant for all project designs. General scale-up or scale-down by more than a factor of 10 should be avoided.

Multivariable CERs are also possible. For instance, where symbols have been previously supplied, an equation such as the one immediately following could be used:

$$C = KQ^mN^S \tag{8}$$

5.6. Probability and Statistical Techniques

There are a range of estimating methods that are based on applying probability and statistics. Cost is usually treated as a single-point value under conditions of uncertainty. Engineers, knowing the weakness of information and techniques applied, recognize that there are probable errors in the developed estimates. Knowing the cost determined while developing the estimate is a random variable; using probability to estimate is appropriate. In the realm of statistics, a random variable is a numerically valued function of the outcomes of a sample of data. Four probabilistic techniques are discussed below.

5.6.1. Expected Value

When an engineer can assign a probability estimate to elements of uncertainty, as represented by the economics of the design, the method of expected value can be applied. Nonnegative numerical weights associated with design elements are assigned in accordance with the likelihood of the event occurring. The probability of the occurrence must equal 1. The probabilities describe the likelihood of that the predicted event occurring. The method incorporates the effect of risk on potential outcomes by means of a weighted average. Each outcome of an alternative is multiplied by the probability that the outcome will occur. The sum of the products for each alternative becomes the expected value. It is mathematically stated as

$$C(i) = \sum_i P_i x_{ij} \tag{9}$$

where $C(i)$ = expected cost of the estimate for alternative I
p_j = probability that x takes on value x_j
x_{ij} = design event

The p_j represents the independent probabilities that their associative x_{ij} will occur with $\Sigma p_j = 1$. For example, it may be predicted that the cost of fuel for use in the design might be charged at the following discrete cost pattern: 20% probability that fuel will cost \$3.00/gallon, 30% probability that fuel will cost \$3.50/gallon, and 50% probability that fuel will cost \$3.75/gallon. Multiplying the discrete probability rates times their related fuel costs and summing gives the expected cost of \$3.525/gallon.

5.6.2. Percentile Method

Estimates reflecting uncertainty may be specified by three values representing the 10th, 50th, and 90th percentiles of an unstated probability distribution. The best value for an engineer to use is the 50th percentile. The 10^{th} percentile cost is the best-chance scenario and represents a 1-in-10 chance that the actual cost will be lower. The 90^{th} percentile cost is the worst-case scenario and represents a 1 in 10 chance the cost will be greater. An example is shown below.

	Percentile			Difference	
Item	10th	50th	90th	(50 − 10)	(90 − 50)
1	$25	$33	$44	$8	$11
2	9	13	15	4	2
3	3	4	7	1	3

These costs can be assumed to combine independently, that is, a low cost with a mid-cost with another low cost. After estimating, the 10th and 90th percentiles are expressed as differences from the 50th (or mid-value). The next steps are to square the differences and sum.

	(50 − 10)	Mid-value	(90 − 50)
	$64	$33	$121
	16	13	4
	1	4	9
Total	81	50	134
Square root	9		11.58

Total estimate at 10th percentile = $50 − 9 = $41
Total estimate at 50th percentile = $50
Total estimate at 90th percentile = $50 + 11.58 = $61.58

Sensitivity analysis can be applied to the percentile method in a simple way, as shown next.

Item	Contribution to Low Uncertainty	Contribution to Total Cost	Contribution to High Uncertainty
1	79% (64/81 × 100)	66% (33/50 × 100)	90.3% (121/134 x 100)
2	19.8% (16/81 × 100)	26% (13/50 × 100)	3% (4/134 × 100)
3	1.2% (1/81 × 100)	8% (4/50 × 100)	6.7% (9/134 × 100)

This simple sensitivity analysis will identify items to be monitored for possible cost reduction.

5.6.3. PERT-Based Beta Distribution

Project evaluation review technique (PERT), was developed for use in predicting the expected duration of projects and monitoring the progress of the project's activities. It is based on using the most likely cost estimate, optimistic estimate (lowest cost) and pessimistic estimate (highest cost). These estimates are assumed to correspond to the beta distribution, which can be symmetrical or skewed left or right. Using the three estimates, a mean and a variance for the cost element can be calculated as

$$E(C_i) = \frac{L + 4M + H}{6} \tag{10}$$

$$\mathrm{var}(C_i) = \left(\frac{(H - L)}{6}\right)^2 \tag{11}$$

where $E(C_i)$ = expected cost for element I
L = lowest cost, dollars (optimistic)
M = modal value of cost distribution, dollars (most likely cost)
H = highest cost, dollars (pessimistic)

If several elements are estimated using this method, and if their costs are assumed to be independent of each other and are summed together, the distribution of the total cost is approximately normal. This follows from the central limit theorem. Figure 1 illustrates the use of the PERT method. The example shows how to find the contingency effects for a project design. Several elements must be combined when making the estimate to satisfy the conditions of the central limit theorem.

$$E(C_T) = E(C_1) + E(C_2) + \dots + E(C_n) \tag{12}$$

$$\text{var}(C_T) = \text{var}(C_1) + \text{var}(C_2) + \dots + \text{var}(C_n) \tag{13}$$

$E(C_T)$ represents the expected total cost in dollars, and $\text{var}(C_T)$ is the variance of total cost in dollars.

5.6.4. Computer Simulation

Simulation techniques are more acceptable as tools for engineers developing costs of projects and systems. As computer simulation packages become more user friendly and computers' memory grow larger and computation speeds become faster, simulation as a tool for estimating is becoming more popular.

Simulation is defined as the manipulation and observation of a synthetic (logical and mathematical) model representative of a real design, that, for technical or economic reasons, is not susceptible to direct experimentation. The simulation model is developed to represent the essential characteristics of the real system, with many minor details omitted. Product estimates are not suited generally for simulation techniques, although simulation could be applied to determine costs and times for manufacturing systems being estimated to produce the product.

5.7. Standard Data

Standard data are defined as standard time values for all manual work in an estimate. Standard data provide the opportunity to be consistent when developing an estimate.

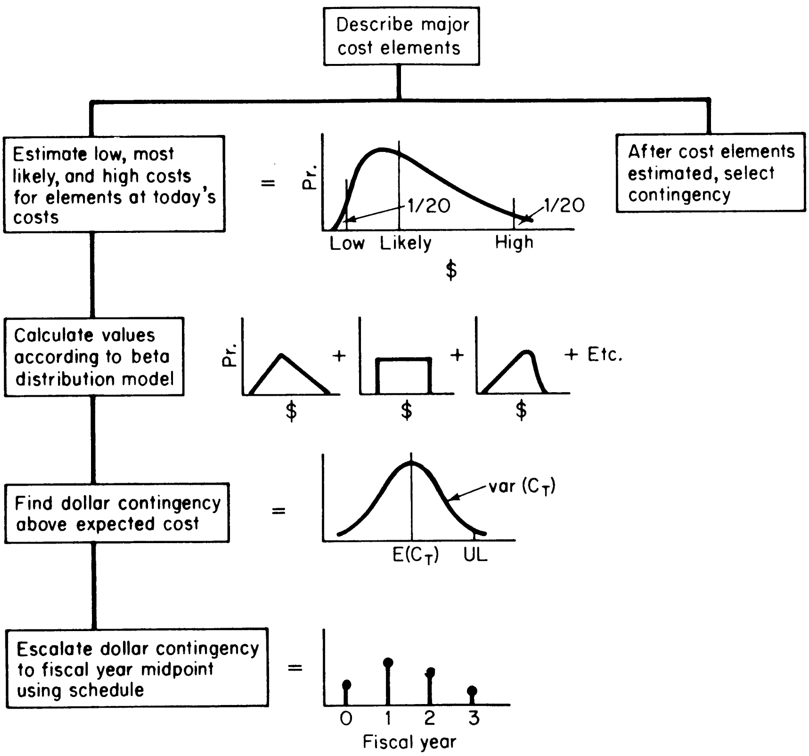

Figure 1 Flowchart of PERT-Based Estimating.

The most accurate way to estimate direct labor cost is with standard time data developed from one of the formal time-measurement techniques. (see Chapters 53 and 54). It is not the original time measurements that the engineer desires, but a set of engineering performance data or standard time data that are needed to make the estimate. Frequently, raw data or times for specific methods are incorrect because methods are altered, equipment is replaced, environmental conditions change, and so on. Industrial engineers may use regression analysis or other techniques to extend these raw data into a more usable form, such as standard data. It is easier to calculate standard time data for processes such as machining operations than fabrication processes. Most of the work content in metal removing on a machine tool is fixed machine time. In fabrication, much of the time may be manual and subject to variation depending on individuals performing work activities.

Standard time data may be divided into preliminary or detailed data. As with preliminary and detailed estimates, the engineer is more likely to be interested in preliminary standard data early in estimating, and later detailed data will become more important. Standard time data are ordinarily determined from any of the various methods of observing work.

5.7.1. Time Study

Some companies develop standard data from stopwatch time studies. Time studies are used to establish rates of production. When time studies are used to establish standard data, care must be taken in defining element content so that work content can be isolated.

5.7.2. Predetermined Time Standards

Usually, one of the commercial systems, such as MTM or MOST, will be used, but sometimes companies will develop their own system. The main advantage of predetermined time standards is the consistency of the data. The major disadvantage is the amount of time necessary to develop the data. The major commercial systems are computerized, and this allows for much faster development time.

5.7.3. Work Sampling

This technique of work measurement used the fundamentals of probability and statistics to develop work standards by making random observations on jobs over a specific period of time. This method is widely used in white-collar environments. It is a desirable technique for studying team activities and long-duration activities.

5.8. Historical Data

Past history or actual performance on jobs produced can be used to develop standard data. A disadvantage of this technique is that it rarely considers the best method of organizing work. This method is popular in smaller companies that do not have the resources to use the other work-measurement methods to develop standard time data.

In manufacturing, time study and predetermined motion time data are the major sources for obtaining standard data. In construction and white-collar environments, work sampling and man-hour reports are the principal means of information. Likewise, in certain government agencies, such as the post office and the military depots, work sampling and man-hour methods are used.

Computer databases allow for the easy and readily accessible time standard data. Often charts and tables are used in hard copy, especially when the engineer is familiar with such estimating tools. Charts and production information can be found in Ostwald (1992). When developed properly, standard time data are considered to be accurate and relatively inexpensive for labor estimating.

6. LABOR ANALYSIS

Labor constitutes one of the most important items of operation designs. Labor has received intensive study, and many recording, measuring, and controlling schemes have been developed in an effort to manage it. Labor can be classified in a number of ways, including direct–indirect, recurring–nonrecurring, designated–nondesignated, exempt–nonexempt, wage–salary, blue collar–management, and union–nonunion. Other ways in which to classify labor are according to social, political, and educational divisions and type of work. Payment of wages may be based upon attendance or performance. For cost–estimating operation designs, the direct–indirect classification is the most appropriate.

For operation designs, there is an unquestioned dependence upon the simple qualitative formula

$$\text{Labor cost} = \text{time} \times \text{wage} \tag{14}$$

The selection of time matches the requirements of the operation design. Time is expressed relative to a unit of measure, which is denoted by terms such as *piece, bag, bundle, container, 100 units,* or *1000 board feet*. The usual ways to measure labor are by time study, predetermined motion–time systems work sampling, or man-hour reports.

Job tickets, especially for smaller organizations, are analyzed and allocated to units of work. For instance, a job ticket may state, "136 units turned of part number 8641" and list "6 person-hour." Simple analysis would show 0.044 hr/unit. The engineer would use 0.044 hr the next time this part was run. Although hardly accurate because of the nature of historical work reports, man-hour reports are used because of their simplicity. Man-hour estimating data are especially popular in construction work.

Direct observation and measurement of labor are of little use to the engineer except for guesstimates of similar work or reruns of the same work. Although the cost engineer may not be directly involved with the measurement of labor, he or she does depend on work measurement. The engineer is satisfied if such labor measurements are objective, as far as that is possible, and is willing to use the information, provided that engineering techniques were used in the determination of time. Although the time measurements are of value, it is immensely more important that work-measurement data be transformed into information that can be applied prior to the time of the operation design.

The time measurements are more valuable when expressed as standard time data (see Chapter 54) and presented in a table or computer format. The estimating data may be described in terms of elements, which are the subwork descriptors of operations, or be expressed as time-estimating relationships (TERs) for operations.

Standard data expressed at the predetermined motion–time level are too detailed for much cost-estimating work. But a typical TER is satisfactory for much cost-estimating work. A typical TER for a drill press operation of sheet metal parts is for setup 0.2 + 0.05/tool hr and for run time 0.015 + 0.003/tool + 0.001/hole hour per unit. Thus, if a sheet metal part requires two different countersinks for 22 holes, setup would be 0.3 hr and run time 0.043 hr/unit.

In some situations the estimate of time may be done from a guesstimate and be unrelated to measured, referenced, and analyzed data. A guesstimate is based on the engineer's observational experience. There are circumstances where these judgmental numbers are unavoidable.

The second part of Eq. (14), wage, is defined in the context of the operation design that is being estimated. The operation design may be for one worker and one machine, for a crew with one machine, or for a crew with several machines or processes. In the simplest case, one on one, the job description and job design are specifications available to the engineer. The number used for the wage corresponds to the time period of work and is money out of pocket. Regression methods, labor contract, and personnel planning are sources for wage trend information.

The practice of what is included in the wage amount is coordinated with the finding of the overhead. Fringe additions could include effects of paid holidays and vacations, health insurance and retirement benefits, Federal Insurance Contributions Act (FICA) benefits, workers' compensation, bonuses, gifts, uniforms, special benefits, profit sharing costs, education, and so on.

7. MATERIAL ANALYSIS

The term *direct materials* includes raw materials, purchased parts, standard commercial items and interdivisional transfers, and subcontracted items required for the design. Direct material cost is the cost of material used in the design. The cost should be significant enough to warrant the cost of estimating it as a direct cost. Some material, by virtue of the difficulty of computation and estimating, may be classified as either indirect or direct costs. The latter estimates are preferred. Paint material of irregularly shaped objects is an example of material that can be classified either way.

The engineer begins by calculating the final exact quantity or shape required for a design. To this quantity, losses for scrap, waste, and shrinkage are added. The general model for cost of direct material is

$$S_a = S_t(I + L_1 + L_2 + L_3) \tag{15}$$

where: S_a = actual shape in units of area, length, mass, volume, count, etc.
L_1 = loss due to scrap, decimal
L_2 = loss due to waste, decimal
L_3 = loss due to shrinkage, decimal

Scrap is material that is lost because of human mistakes, whereas waste is necessary because of the design. Shrinkage losses are due to theft or physical law deterioration. In estimating of foodstuffs, if direct material is not processed at the appropriate time or if it is mishandled, shrinkage of the quantity will result. It is required that these three losses be estimated and that their percentages be added to the theoretical finished requirement.

An example of material estimating is given by the 12 oz. (355 ml) beverage can, which is composed of the body, top, and pull ring. The container body is blanked from 3004 H19 aluminum coils, with the layout given in the Figure 2. An intermediate cup is formed, without any significant change in thickness. The cup is drawn in a horizontal drawing machine, and metal is squeezed to side-wall thickness of 0.0055 in. (0.140 mm), while bottom thickness remains unchanged. The can is trimmed to final height to give an even edge for later rolling to the lid. Various mensuration formulas are used to find first the volume and weight of the object. For a popular soda drink can, there is about 25% waste. These calculations eventually relate to the amount of coil aluminum stock.

8. NEED FOR ACCOUNTING DATA

Cost accounting has always been important to the performance of diverse estimating functions. As colleagues in the gathering, analysis, and reporting of business data, accountants provide overhead rates, standard costs, and budgeting data. The engineer reciprocates with labor and material estimates for the several designs. In many situations the estimate can serve as a mini-profit-and-loss statement for special products. Thus, there is interdependence between these two professions. The engineer is less interested in balance sheets, profit-and-loss statements, and the intimate details of the structure of accounts. Overhead rates are vital for the estimating functions, however, since the engineer may apply these rates in the estimate.

By definition, overhead methods would include the following:

- Indicating whether the rate includes fixed costs, as in absorption costing, or not, as in direct costing.

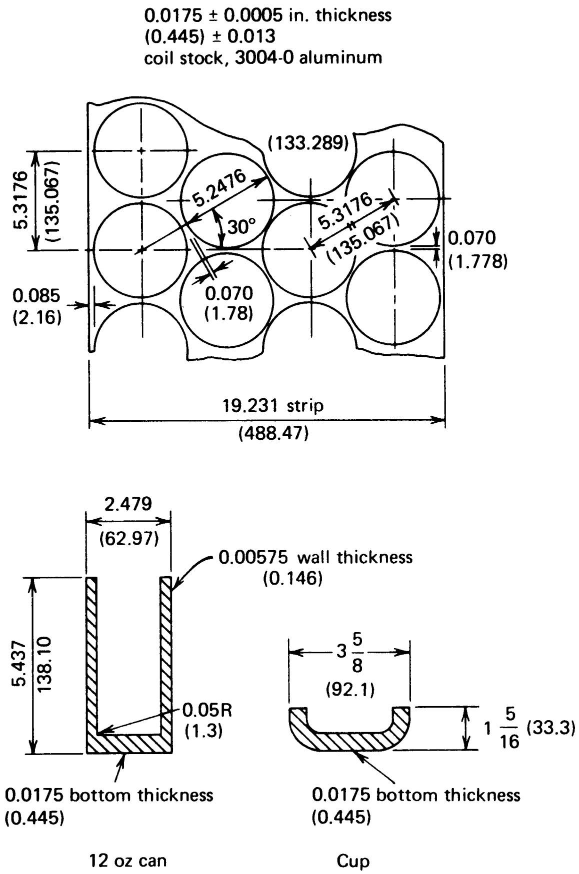

Figure 2 Simple Design for a Beverage Container, the Common 12 oz Can.

- The base used to distribute overhead, such as direct labor dollars, direct labor hours, or machine hours.
- The scope of the application of the rate, whether it is for the plant, cost center, machine, or design.
- Whether the rate applies to all designs (such as product lines) or to one line of the design.

9. FORECASTING

Many forecasting techniques have been developed to handle a variety of problems. Each has its special advantage, and care is necessary in choosing techniques for cost estimating. Selection of a method depends on the context of the forecast, availability of historical data, accuracy desired, time period to be forecast, and value to the company. The engineer should adopt a technique that makes the best use of the data. He or she should initially use the simplest technique and not expect more from the advanced technique than is justified.

For estimating requirements, we are concerned with data about labor and material overhead and their quantities and cost. The forecast should reflect those values under the proposed actions of the company and environment. It is necessary to recall that forecasting is a future prediction about line elements of the estimate. Forecasts should not deal in overall or grand average cost, time, and quantities, but should be matched to line items required by the pro forma estimate. Forecasting is not estimating, as the term is used here, since forecasting takes data and frames it in a new picture, and judgment is suppressed as much as possible.

10. INDEXES

Cost-estimating indexes are useful for a variety of purposes. Principally, they are multipliers to update an old cost to a new cost. Some examples of indexes are material, labor, material and labor, regional effects, and design type. C is the reference cost associated with a reference index I_r. The cost C to be determined is linked in terms of time to the index I.

$$C = C_r \left(\frac{I}{I_r} \right) \tag{16}$$

Indexes are prepared and published by the government, private industry, banks, consultants, associations, and trade magazines. It is important to determine one's own indexes, especially for materials or labor not charted by other groups.

A cost index is meaningful only in that it expresses a change in price level between two specific times. A cost index for steel in the year 2008 alone is meaningless. An index for material A has no relationship to the index for material B. Similarly, the cost indexes for material A in two geographical areas may not be directly comparable.

To compute a price index for a single material, a series of prices must be gathered covering a period for a specific quantity and quality of the material. Index numbers are usually computed on a periodic basis. The federal government gathers data and calculates and divulges index numbers for periods as short as a month. The prices gathered for the material may be average for the period (month, quarter, half year, or year) or may be a single observed value as found on invoice records for one purchase.

Assume that the following prices have been collected for a standardized unit of silicon laser glass material:

Period	0	1	2	3	4	5
Price	\$43.75	\$44.25	\$45.00	\$46.10	\$47.15	\$49.25
Index, %	94.9	96.0	97.6	100.0	102.3	106.8

Index numbers are computed by relating each period price to one of the prices that has been selected as the base. If period 3 is the benchmark period, because the index is 100 or 1, period 2 price divided by period 3 price = \$45.00/\$46.10 = \$0.976. When period 3 price is expressed as 100.0, period 2 price can be expressed as 97.6.

Movements of indexes from one period to another are expressed as percent changes rather than as changes in index points. Period 6, 7, and so on can be projected, and if a reference price is known, a future price can be calculated. For instance, if C_2 = \$3700, and if we want to know C_7, then projecting C_7 = \$3700 × (110.0/97.6) = \$4170.

Assume that a product called ‘‘10-cm disk aperture laser amplifier’’ is selected for a composite index. Although the 10-cm disk amplifier was produced only during period 0, tracing of selected cost items has continued. To worry about all amplifier components is too involved, so major items were picked for individual tracking, and spot prices have been gathered for 4 years. The quantity of each of the five materials is in proportion to the initial one-time cost of the material to the total cost. Some materials have declined in price, whereas others have increased. Prices for each material have been gathered (or imputed for periods where no information was available) and are shown in Table 2.

The prices conform to quantity and quality specifications. With the index at 100 for benchmark period 0, the following indexes are calculated as 94.1, 89.6, and 93.3. If the unit cost is $43,650 during period 0, the estimated cost is equal to $37,953 at period 5.

One may argue that cost facts, materials, quantities, and qualities are not consistent as given in Table 2. Indeed, if technology is active, a decline in the cost and index is possible. Indexes should reflect basic price movements alone. Index creep results from changes in quality, quantity, and the mix of materials or labor. Table 2 is an example of a product index. The components in this case are selected on the basis of their contribution to the product value. Selection of components could be 100%, random, or stratified in accordance with the needs of cost estimating. Quantity is determined proportional to the design requirements. Specifications provided by engineering are used to fix quality characteristics. Product indexes can be maintained by noting the changes when they occur, inputting all previous data, and recalculating the previous year’s indexes. Every so often it may be necessary to reset the benchmark year whenever delicate effects are influencing the index and are not being removed.

11. OPERATIONS ESTIMATING FOR MANUFACTURING

The operations sheet is fundamental to manufacturing estimating. It is also called a route sheet, traveler, or planner. There are many styles, and each plant has its own form. The purpose of the operations sheet, however, is the same:

- To select the machine, process, or bench that is necessary for converting the material into other forms
- To provide a description of the operations and tools
- To indicate the time for the operation

The order of the operations is special too, as this sequence indicates the various steps in the manufacturing conversion.

Each operations sheet has a title block indicating the material part number, date, quantity, engineer, and other information that may be essential to the company. Following the writing of this information on the form or its entry into the computer, the instructions to the plant are provided.

TABLE 2 Simple Calculation of Index for Composite of Several Materials

			Period				
Material	Quantity	Quality	0	1	2	3	4
Laser glass	3- to 10-cm disk	Silicate	$26,117	$24,027	$22,345	$21,228	$22,713
Stainless steel tunings	18 kg	AISI 304	1,913	2,008	2,129	2,278	2,460
Aluminum extrusion	4 kg	3004	418	426	439	456	479
Fittings	3 kg	Mil Std 713	637	643	656	657	689
Harness cable	4 braid	Mil Std 503	2,103	2,124	2,134	2,305	2,466
Annular glass tubing	4 m	Tempered	$ 4,317	4,187	4,103	4,185	4,311
Total sample cost, $	12 m	3/16 in. wall PPG # 27	$35,505	$33,416	$31,808	$31,112	$33,122
Index, %			100.0	94.1	89.6	87.6	93.3

Suppose that we want to machine an aluminum casting that is on material consignment (meaning that the material is being supplied at no transfer cost). The casting is called SOHO and the part number is unknown. This casting is a consignment material and is part of a larger product. This casting will have a bored hole enlarged and deburred and it will be packaged in a carton. Your parts and assemblies are more complicated than this, but we only want to identify the process of estimating. A typical and simple operations sheet would appear as shown in Figure 3.

11.1. Preparing the Operations Sheet

The operations sheet (1) begins in the upper left-hand corner of Figure 3. The final product name (2) is often given along with the assembled product (3). The operations sheet is for a specific part name (4), which in this case is called SOHO. A part number (5) can be identified and listed if available. The part number and name are removed from the design and repeated on the operations sheet title block. The engineer will enter lot quantity (7) and material specification (8). Knowing the final amount of material required by the design, the engineer will add material to cover losses for scrap, waste, and shrinkage and multiply by the cost per pound rate of the material. Material cost, using the formula given earlier, is used to enter the value. A unit material cost is required for entry (9).

The sequence of the operation number and selection of the machine, process, or bench are made to manufacture the part. These are required at circle 10 and are shown specifically at (18) and (19). A complete operations sheet will show this column. Even though they are vital in operations planning, their importance is less in detailed estimating once that operation has been selected.

The column titled ‘‘Table’’ (12) corresponds to the equipment number for the plant. For example, ‘‘Table 7-4’’ refers to the ram milling machine class. The operations sheet column titled ‘‘Process Description’’ (13) are instructions to the shop that they will follow in making the part or subassembly. The instructions for operation number 10 to the shop are listed in Figure 3. The process description gives a listing of the elements that are pertinent to estimating the operation.

The ‘‘Process Description’’ lists the elements of the operation. These correspond to the element description listed in the estimating tables. It is an elaboration of the description given in the operations planning sheet described earlier; there is no basic difference, except that the number of lines or elements are greater for estimating than for planning. The ‘‘Process Description’’ may also indicate additional information such as length of cut, tooling used, type of NC manuscript order, and so forth.

The ‘‘Table Time’’ column (14) is a listing of the values removed from the estimating tables. These time values are posted in this column.

The ‘‘Table Time’’ column identifies the estimating table and element number. For example, if a sheet metal operation of braking were necessary, the number 3.6 would be first posted. Similarly, for a drill press operation, 9.3 would be written on the row corresponding to the machine selection. Notice, for any estimating table, that clusters of elements have a number too, starting with 1, 2, and so on. These clusters are generally related. The element ‘‘handle’’ may have many possibilities and be listed as element 1. Following the machine number, we list the element number, and it is preceded by a dash. For example, 3.6-1 is a power press brake element called ‘‘brake.’’ Also, 9.3-2 is a cluster of elements for ‘‘clamp and unclamp’’ for the upright drilling machine.

The adjustment factor (15) column operates upon the time column. Once adjusted, the time is either entered into the cycle minutes (16) or the setup hours (17) column. There is more discussion on the adjustment factor column later.

The columns titled ‘‘Cycle Minutes’’ and ‘‘Setup Hours’’ are very important, and the instructions that follow describe the methods and selection of the elements and time that are necessary to manufacture the part for that operation.

The sequence number (18) of the operation is given in the left-hand column along with the equipment (19) necessary for the operation.

The total (21) of the cycle minutes column and the total (22) of the setup hours column are summed. The lot estimate is calculated and presented (23) with the dimensions in hours. Lot time is calculated as follows:

The total of ‘‘Lot Estimate’’ is a computation that is shown on the operations sheet. The calculation is made using the setup, unit estimate, and lot quantity.

This operations sheet can be altered to consider simple assemblies or complicated products, but the approach remains the same. The purpose of estimating is to provide time or cost for the direct labor or material component of the product. The preparation of the operations sheet is important for the finding of part operational costs. Notice that the part cost is the sum of the operational costs, and this fact allows us to concentrate on the important steps that are necessary for estimating operations. Once the operational sequence, the selection of the machine, process, or bench, and a basic description of the work have been roughed out, cost estimating begins.

11.2. Setup Hours Column

Setup includes work to prepare the machine, process, or bench for product parts or the cycle. Starting with the machine, process, or bench in a neutral condition, setup includes punch in/out, paperwork,

(1) OPERATIONS SHEET

(2) Product Name: X-152
(3) Product Part No. 2224534-03
(4) Part Name: SOHO

(5) Part No. (Unknown)
(6) Part Material Cost: $0.00 (Consignment)
(7) Lot Quantity: 87

(8) Material: Aluminum casting
(9) Unit Material Cost: 0.00
(10) Plant Location: Chicago

(11) Process Op. No.	(12) Table Number	(13) Process Description	(14) Table Time	(15) Adjustment Factor	(16) Cycle Minutes	(17) Setup Hours
(18) 10	(20) 7.4	Ram Milling				
Vertical Milling	7.1-S1	Table setup, part length >12 in.	1.45			1.45
Machine	7.1-S2	Make piece	0.02	2		0.04
(19)	7.1-S3	Tolerance addition	0.13			0.13
	7.4-1	Pick up, move	0.20		0.20	
	7.4-2	Clamp, unclamp star wheel				
		clamping	0.09	2	0.18	
	7.4-1	Pry part out	0.06		0.06	
	7.4-4	Start and stop mach	0.06		0.06	
	8.2-1	Traverse element	0.08	2	0.16	
	7.4-5	Clean, lubricate	0.05		0.05	
	11.3-4	End milling, 2-in length of cut				
		Depth of cut = 1/32				
		Weight = 6.28 lb	0.01	2	0.02	
	7.4-5	Clean area	0.15		0.15	
	11.4-2A	Mill tool life	0.00		0.00	
	22.1-3	Inspection	0.29		0.29	
		(21) Total			(23) 1.17	1.62
		(22) Lot Estimate	3.32 hr			(23)
20	18.5	Hand Deburring				
Deburr Bench	18.5-S	Setup	0.05			0.05
	18.5-1	Handling, repos				
		Box L+W+H = 22.3	0.15		0.15	
	18.5-2	Tool handling				
		Handle tools twice	0.04	2	0.08	
	18.5-3B	Holes over 1/2 in.	0.08		0.08	
	18.5-1	Handling, repos	0.05		0.05	
	18.5-4A	Break edges	0.11		0.11	
		Total			0.47	0.05
		Lot Estimate	0.73 hr			
30	24.1	Pack				
Package	24.1-S	Setup	0.15			0.15
Bench	24.1-1	Order paperwork	2.00	4	0.50	
	24.1-2	Get and position	0.09		0.09	
	24.1-10	Paper carton	1.51	4	0.38	
	24.1-10	Paper carton	0.22	4	0.05	
	24.1-16	Miscellaneous	0.26	4	0.06	
		Total			1.09	0.15
		Lot Estimate	1.73 hr			

Figure 3 Example of Process Sheet with Balloons for Instruction Sequence.

obtaining tools, positioning unprocessed materials nearby, adjusting, and inspecting. It also includes return tooling, cleanup, and tear-down of the machine, process, or bench to a neutral condition ready for the next job. Unless otherwise specified, the setup does not include the time to make parts or perform the repetitive cycle. If scrap is anticipated as a consequence of setup, the engineer may optionally increase the time allotment for unproductive material.

Setup estimating is necessary for job shops and companies whose parts or products have small to moderate quantity production. As production quantity increases, the effect of the setup value lessens its prorated unit importance, although its absolute value remains unchanged. Setup values may not be estimated for some very large quantity estimating. In these instances, setup is handled through overhead practices. Our recommendation is to estimate setup and to allocate it to the operation because it is a more accurate practice than costing by overhead methods. This recommendation applies equally to companies manufacturing their own parts or products and vendors bidding for contract work.

Some operations may not require setup. Flexible manufacturing systems, continuous production, or combined operations may not require setup time. Nonetheless, even a modest quantity may be appropriate in these circumstances. Discussion of the details regarding setup is given for each machine, process, or bench.

11.3. Cycle Minutes Column

Cycle time or run time is the work needed to complete one unit after the setup work is concluded. It does not include any element involved in setup. Besides finding a value for the operational setup, the engineer finds a unit estimate for the work from the listed elements, which is called estimating minutes.

The term *estimating minutes* implies a national norm for trained workers. These times include allowances, in addition to the work time, that take into account personal requirements, fatigue where work effort may be excessive due to job conditions and environment, and legitimate delays for operation-related interruptions. Since the allowances are included in the time for the described elements, and therefore part of the allowed time for several elements and hence several or many operations, then the allowed time is fair. The concept of fairness implies that a worker can generally perform the work throughout the day.

12. PRODUCT ESTIMATING

The cost summary (24) is for the part SOHO and the header information is repeated (see Figure 4). It is an important principle that estimating for manufacturing requires that each operation be estimated. Each operation (18) is identified and these correspond to the basic operations sheet. The table number (12) identifies the basic data set for that operation. Balloon (25) specifies the description of the machine, process, or bench necessary to perform the operation. Lot hours (28) are transferred from the operations sheet. These lot hours differentiate between quantity. For low quantity the setup becomes more important, while the cycle minute influences the lot hours if the quantity is large. Whether the part is for small or large quantity, the method is acceptable. The system is acceptable even with very large quantities that mechanization would require.

Productive hour cost (PHC) is entered as balloon (26). These company values are the costs for the labor and the machine. Overhead is included for this case. These company values are calculated by accounting.

The lot hours are multiplied by the PHC and given the total operational cost shown as column 27. For example, $3.32 \times 43.50 = \$144.27$. The PHC includes the cost of overhead, and the method can include absorption- or activity-based methods. The sum of the operation cost is given by the total operational productive hour cost, identified as column 29. The value of \$207.81, when divided by the lot quantity of 87 (7), gives the unit operational productive hour cost of \$2.39. In this case, this value is for labor and the machine process cost. Because the material is a consignment between the buyer and the manufacturer, no cost is assessed for unit material cost identified by column 31. If a unit cost exists, it is entered here. The sum of the material and the unit operational productive hour cost gives the total direct cost per unit (32). This value is multiplied by the lot quantity and the total job cost is entered as column 33.

This cost summary is used to provide information to the bill of material cost summary, which is the means of collecting all costs to obtain the full cost. Except in the case of a single part, the bill of materials is a vital and important document. For those manufacturers who only produce a single part, the cost summary is adequate since it provides the total job cost.

13. BILL OF MATERIAL EXPLOSION FOR PRODUCT ESTIMATES

The estimating of labor and material cost and its extension by overhead calculations will lead to the quantity known as full cost. This in turn will be increased for profit to give price. Before that routine

(24) COST SUMMARY

(2) Product Name: X-152
(3) Product Part No. 2224534-03
(4) Part Name: SOHO

(5) Part No. (Unknown)
(6) Part Material Cost: $0.00 (Consignment)
(7) Lot Quantity: 87

(8) Material: Aluminum casting
(9) Unit Material Cost: 0.00

(18) Operation Number	(12) Cost Estimator Table No.	(25) Machine, Process, or Bench Description	(21) Lot Hours	(26) Productive Hour Cost ($)	(27) Total Operation Cost ($)
10	7.4	Vertical-Spindle	3.32	43.50	144.27
20	18.5	Hand Deburring	0.73	21.35	15.62
30	24.1	Bench, Machines	1.73	27.75	47.92
		(28) Total Lot Hours:	5.77		
		Total Operational Productive Hour Cost ($):			(29) 207.81
		Unit Operational Productive Hour Cost ($):			(30) 2.39
		(31) Unit Material Cost ($):			0.00
		(32) Total Direct Cost Per Unit ($):			2.39
		(33) Total Job Cost ($):			207.81

Figure 4 Example of Product Cost Summary.

is executed, it is necessary to find the total bill of material cost for several or many parts, subassemblies, and major assemblies. The bill of material explosion is unnecessary if the manufacturer only sells single-item parts, as the cost estimate serves as the principal summary document for price setting. But in the case of several or many parts and assemblies, it is necessary to organize the cost estimates effectively. A bill of material handles a scheme of this organization.

14. COMPUTERS AND ESTIMATING

Very few cost estimates are done without the aid of a computer. At least a microprocessor is used for word processing, spreadsheet calculations, database queries, and small, engineer-developed programs. At the other end of the spectrum, companies have developed their own in-house estimating software systems. Some companies with cost-estimating expertise have developed commercial cost-estimating packages for organizations wishing to use turnkey-type estimating packages.

Computer estimates are very consistent. Because of this consistency, they have an advantage of being able to be made with more accuracy. Estimates can be adjusted higher or lower as needed, or observed from previous cost estimates.

More detail concerning an estimate can be done because of computers. Details that might be tedious and time consuming if done long-hand can be done quickly and accurately on a computer. Work standard data and machining data can be accessed and inserted into an estimate easily. Also, level of detail relating to risk can easily be determined with the aid of a computer.

Cost-estimating software can provide refinements that would not be possible for an engineer to handle. For example, tool types, tool materials, material conditions, and so on. can easily and quickly be factored into cost, making the estimate more accurate and reliable.

15. CONCLUSION

Of the many paper or paperless documents a manufacturer will prepare, few are as important as the product estimate. This is the principal method for pricing that the firm will use. If the cost estimate is such that a profit will ensue, the enterprise continues the development of bringing the product to market. If the estimate gives an indication that a profit is unfeasible in the competitive market, the firm will cancel the product development or return the design to engineering for reconsideration, redesign, value engineering, or outsourcing. This chapter considers the techniques for bringing small pieces of information from data warehouses that the manufacturer will cultivate. This preparation of the cost estimates answers the question, ‘‘What will this product cost?’’

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