PARAMETRIC COST ESTIMATING
IN
THE NEW MILLENNIUM

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ABSTRACT

This paper begins with a review of the various types of cost estimating methodologies with an emphasis on parametric estimating. It then addresses the role of the engineer in the cost estimating process. It concludes with description of a methodology and tool to assist engineers in carrying out their designated role in the cost estimating process.

INTRODUCTON

Today, cost is on the mind of every business. Every business is expected to do more with less. The objective is to minimize cost, maximize profit, and maintain the competitive edge. This can only be done if the firm can accurately estimate the cost of its products. Estimating the cost of current products is no problem. Actual costs, from which projections can be made, exist. The real challenge is in estimating the cost of future products. This is particularly true if the company is exploring new product lines.

In many firms, the job of costing is considered the domain of the financial department. In the most progressive firms, however, the costing of new products extends to every part of the company and, in particular, into the engineering department and function. Bringing new products to market requires a combination of three things: performance, schedule, and cost, as illustrated in Figure 1. With regard to performance, the product must meet its intended purpose. It must be reliable, dependable, and maintainable. With regard to schedule, "timing is everything." Time to market can mean the difference between success and failure. Lastly, but not least, the product must be competitively priced. All three, performance, schedule, and cost, are required to ensure success.

During development when trade studies among alternative designs are being performed, it is difficult to determine the cost of new products, but cost must be a part of the design process just like performance and schedule. All three are important to success. This paper examines some methodologies for making cost an independent variable, a decision variable, in the design process.

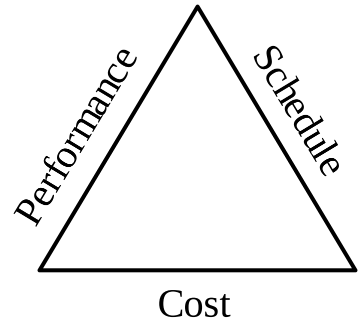


Figure 1 Product Success Formula

COST ESTIMATING METHODOLOGIES

There are various cost estimating methodologies used throughout industry. These include parametric, analogy, and grass roots. When choosing a methodology, the analyst must always remember that cost estimating is a forecast of future costs based on a logical extrapolation of available historical data. The type of cost estimating method used will depend on adequacy of product definition, level of detail required, availability of data, and time constraints.

Parametric Estimating

The "parametric" method of estimating involves collecting relevant historical data, usually at an aggregated level of detail, and relating it to the product to be estimated through the use of mathematical techniques. Since parametric methods typically capture cost at a very high level, less detail is required for this approach than for other methodologies. At the heart of the parametric estimating methodology are cost estimating relationships (CERs).

A CER relates cost as the dependent variable to one or more independent variables. A CER defines cost as a function of one or more technical parameters, such as physical characteristics or operating characteristics. It is expressed as a mathematical equation and once established is fairly simple to use. A CER may compare cost-to-cost or cost-to-non-cost relationships. A cost-to-cost example is using manufacturing hours (independent variable) to estimate quality assurance hours (dependent variable). A classic example of a cost-to-non-cost CER is estimating manufacturing cost (dependent variable) by using product weight (independent variable). In essence, the estimator uses top-level actual data to estimate future costs. CERs allow the estimator to provide quick estimates without a great deal of detailed information. When developing CERs, the emphasis should be on cost drivers. Cost drivers are those characteristics of a product or item that have a major effect on the product or item cost. A cost driver may be a physical, chemical, visual, functional, or any other identifiable property of a product or item. The parametric methodology is illustrated in Figure 2.

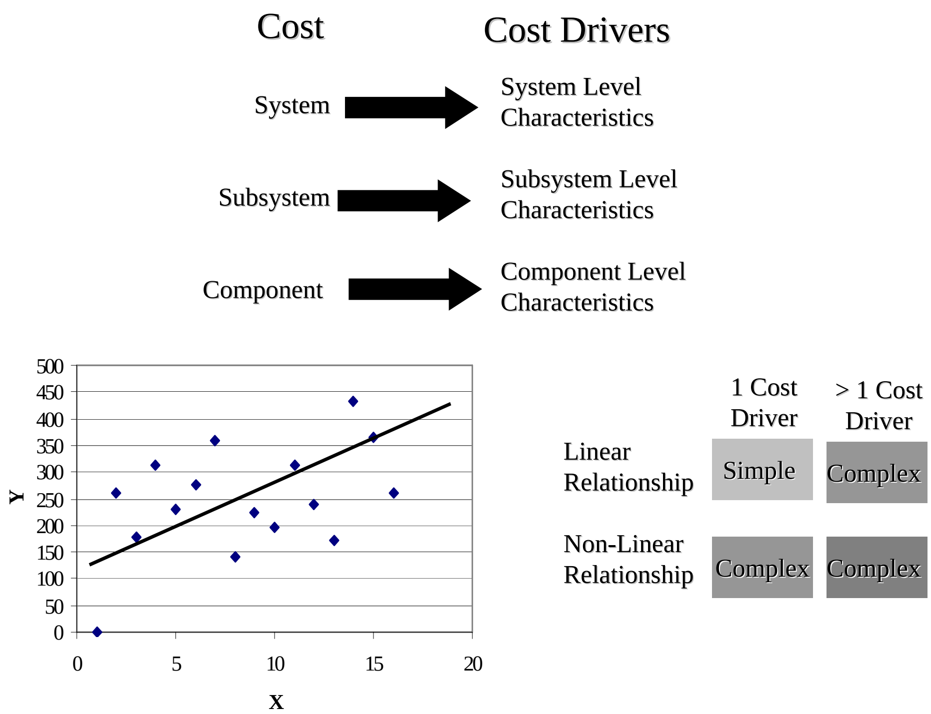


Figure 2 Parametric Cost Estimating Methodology

Figure 2 shows the hierarchical relationship among system, subsystem, and component costs and the data necessary to estimate those costs. It also points out that CERs can be linear or non-linear with one or several independent variables or cost drivers. As one moves from linear to non-linear relationship, complexity increases. As one moves from a single cost driver to more than one cost driver, complexity also increases. The most complex situation is a non-linear relationship with more than one cost driver.

A widely used CER example is the cost improvement curve. The theory states that as the total number of units produced doubles, the cost per unit declines by some constant percentage. The mathematical form of this relationship is

$$Y_x = T_1X^b$$

where

Y_x = The cost to produce the X^{th} unit
T_1 = The theoretical cost of the first unit
X = The number of the unit for which the cost is desired
b = A constant reflecting the rate of cost decrease as the production quantity doubles

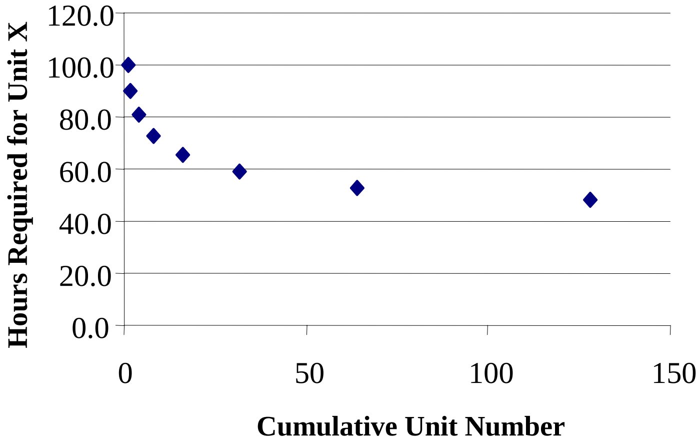
where

$$b = \log S/\log 2$$

where

S = The cost/quantity slope expressed as a decimal fraction.

In this CER, quantity is the independent variable and cost (measured by hours or dollars) is the dependent variable. Figure 3 illustrates a ninety percent cost improvement curve. As the quantity doubles, the hours to produce a unit decrease by a constant ten percent.



X Cumulative Unit Number	Y Hours Required for Unit (X)	Difference in Hours Required
1	100.0	
2	90.0	10.0
4	81.0	9.0
8	72.9	8.1
16	65.6	7.3
32	59.0	6.6
64	53.1	5.9
128	47.8	5.3

Theory

- Efficiency improves with repetition
- Improvement rate varies
  - 90%
  - 80%
- Constant rate of improvement
- Measured as quantities doubled

Figure 3 Cost Improvement Curve CER Example

The use of factors and/or ratios is also considered a form of parametric estimating. As with other parametric approaches, using a factor or a ratio allows the estimator to capture a large part of an estimate with limited historical data. Factors are often used in such areas as training, data, support equipment, systems engineering, and program management when lack of definition or time prohibit detailed estimating. Ratios are used in a similar manner and include relationships such as recurring to nonrecurring cost and first unit production to first unit prototype cost. Both factors and ratios can be invaluable, accurate estimating tools.

The major advantage to using parametric techniques is that they capture major portions of an estimate in a limited amount of time with limited product definition. Additionally, when using some of the more complex parametric models, the estimator is able to encompass the majority of the total product cost with this one method. Since CERs are based on actual product cost history, they reflect the impacts of cost growth, schedule changes, and engineering changes. There are, however, limitations to this methodology that should be recognized by the estimator. When the CER captures cost at a very high level, it will not provide low-level visibility into specific areas. As a result, subtle changes in design or manufacturing techniques may not be reflected in the estimate. Another limitation is that individual pieces of the estimate may not be separable.

Analogy Estimating

The "analogous" or "comparative" method assumes that no new product, no matter how advanced, is totally new. Most "new" products originated or evolved from already existing products or simply represent a new combination of existing components or manufacturing processes. Analogy uses this idea as a foundation for estimating new products. Simply stated, it takes actual costs of a similar existing or past products, and makes adjustments for complexity, technical, or physical differences to derive the new product estimate.

An estimator would normally choose this method early in a product life cycle when there is insufficient actual cost data to support a detailed approach, but there is a sufficient amount of program and technical definition based on study results and test data. Comparisons may be made in terms of product capabilities, product weight, material composition, number and size of components, or design complexity. A detailed engineering assessment is required to ensure the best analogy has been selected and that the proper adjustments are made. Using this engineering insight, the ability to break the estimate down into a low-level of detail further enhances the credibility of the estimate as separate analogies can be chosen for each component. The analogy methodology is illustrated in Figure 4.

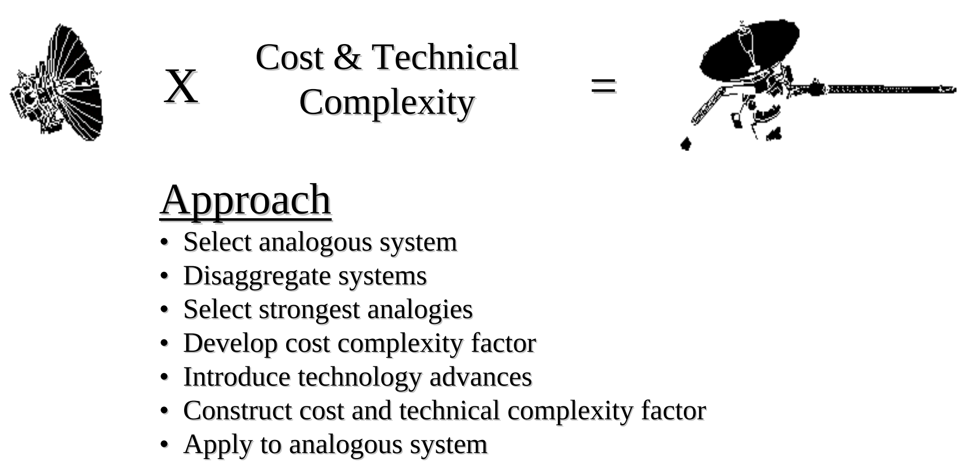


Figure 4 Analogy Cost Estimating Methodology

There are two limitations in using an analogous approach. First is the requirement for a detailed technical definition of both the analogous product and the new product being estimated. Engineering judgment becomes the mainstay of this approach and, at the same time, a limitation. Without access to sound engineering support, this methodology is difficult to employ. Secondly, once the technical assessment has identified the analogous product, actual cost data on that product is then required. Without this, the transition from the analogous product to the current product cannot be made.

Grass Roots Estimating

The "grass roots" methodology, also referred to as "engineering build-up", “bottoms-up”, or "detailed estimate," is performed at the functional level of the product work breakdown structure (WBS). A WBS is a management technique for subdividing a total job into its component elements, which then can be displayed in a manner to show the relationship of these elements to each other and to the whole. The grass roots methodology is illustrated in Figure 5.

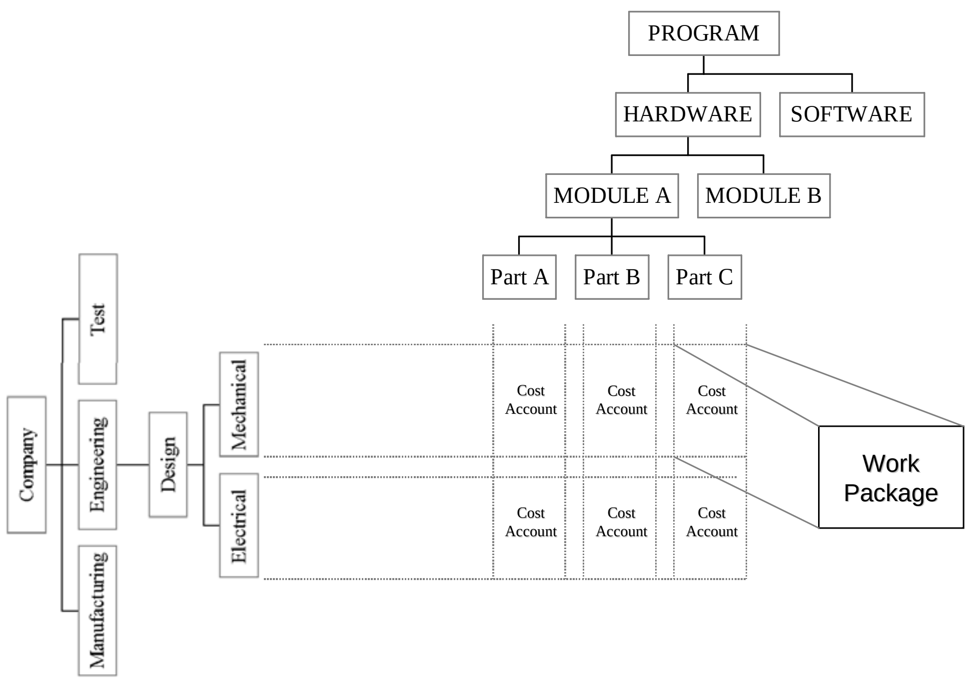


Figure 5 Grass Roots Cost Estimating Methodology

Figure 5 actually looks at the product from two perspectives: that of the WBS where the product is divided into its components, such as hardware and software, and that of a functional breakout based on the manufacturing organization’s skills. The two meet in the cost account that reconciles these perspectives. The cost account consists of one or more work packages that further refine and capture the effort and its cost.

The grass roots method would normally be used during the late development and production phases of the product life cycle. At or near production, the configuration has been stabilized, test results are available, and some actual costs have accrued. The need for other functional support, particularly engineering, is limited in the grass roots approach as product technology and configuration are now expressed in the actual cost data. The underlying assumption of the grass roots methodology is that future costs for a product can be predicted with a great deal of accuracy from historical costs of that product. The disadvantages and limiting factors for this approach are the time consuming nature of the tasking, the need for very detailed actual cost data, and applicability in the late development and production phases.

The various cost estimating methodologies, parametrics, analogy, and grass roots, are not all applicable at the same time in the product life cycle. Table 1 shows the applicability of the methodologies by phase. Note that only the parametric methodology is applicable in all life cycle phases, conceptual, development, production, and operating and support (O&S).

Table 1 Methodology Applicability by Phase

	Parametric	Analogy	Bottom Up
Conceptual	X	X	
Development	X	X	X
Production	X		X
O & S	X		

PARAMETRIC COST ESTIMATING INITIATIVE

Parametric estimating is an acceptable method, according to the Federal Acquisition Regulation (FAR), for preparing proposals based on cost or pricing data or other types of data. The primary benefit from developing a parametric estimating capability is a more streamlined estimating and proposal process for both industry and Government.

To this end, in December 1995, a Reinvention Laboratory was established by the Commander, Defense Contract Management Command (DCMC) and the Director, Defense Contract Audit Agency (DCAA) so that companies could test the expanded use parametric estimating techniques on proposals submitted to the Government. Thus was born the Parametric Cost Estimating Initiative (PCEI). One of the PCEIs primary goals was to demonstrate that when properly applied, estimates prepared using parametric techniques are at least as reliable as other routinely accepted estimating methods. The PCEI wanted parametric estimating to be recognized equally with other traditionally accepted estimating methods. Thirteen Reinvention Laboratory integrated product teams (IPTs) participated by testing a wide variety of parametric techniques. The IPTs experiences provided insight on the best practices for implementing and evaluating parametric techniques. The techniques employed covered the spectrum of complexity from simple, stand alone CERs to complex parametric models. The complex models included company-developed models, commercial hardware models, and commercial software models. These IPTs demonstrated that using properly calibrated and validated parametric estimating techniques can result in:

- Better estimates
- Reduced contract award cycle time
- Reduced proposal preparation, evaluation, and negotiation costs.

The thirteen Reinvention Laboratory sites included Lockheed Martin Tactical Aircraft Systems, Lockheed Martin Astronautics, Northrop Grumman, Boeing, and Raytheon (E-Systems). Some results from these sites are shown in Table 2. All sites reported positive results with respect to using parametrics as the basis of estimate on proposals. In light of these results, Michael J. Thibault, Deputy Assistant Director of the Defense Contract Audit Agency (DCAA), concluded "Parametric estimating, whenever and organization believes it is applicable, should be a cornerstone of the estimating system." He further stated that "the DCAA policy is clear – parametric cost estimating is a preferred approach based on proven statistical concepts and techniques." In addition to Mr. Thibault, the then Department of Defense (DoD) Director of Defense Procurement, Ms. Eleanor Spector, unqualifiedly supported using parametric cost estimating techniques as a means to reduce the burden of providing detailed cost or pricing data.

Table 2 PCEI Pilot Program Site Results

Site	Faster	Cheaper	Accuracy
Raytheon (E-Systems)	25%	33%	More Accurate
Northrop Grumman ESSD	33%	33%	Equal or Better
Lockheed Martin Astronautics	25%	25%	More Accurate
Boeing SSD	40%	35%	More Accurate

COST ESTIMATING FROM THE ENGINEERING PERSPECTIVE

In times past, the engineer could just concentrate on the technical, performance aspects of the product and leave the remaining two aspects, cost and schedule, to others. Not so now. The engineer must consider and make cost and schedule part of the design process. The engineering process with a cost perspective is illustrated in Figure 6.

The cost engineering process begins with a requirement or set of requirements. The requirement or requirements lead to some form of functionality to meet those requirements. Once the functionality is determined, components can be designed or acquired to satisfy the functionality. After the components are decided, a cost can be assigned to those components and, in turn, to the product or system. In this way, the engineer can determine the cost of the requirement or requirements and, likewise, the cost of the functionality.

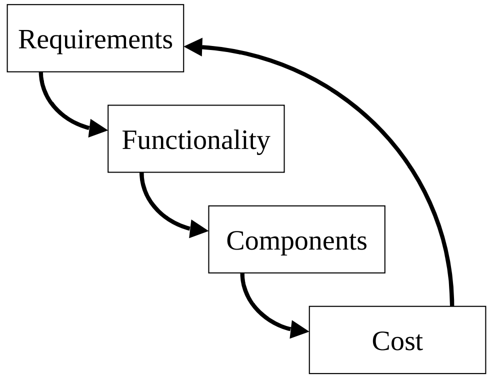


Figure 6 Cost Engineering Process

This process then sets the stage for a series of tradeoff analyses. If the cost of the new product is too high, the engineer can first try a set of alternative components. If this approach is not effective, the engineer can then examine the functionality and address the requirements from a different perspective. If this approach is still not effective, the engineer can then seek relief on the requirement or requirements. This entire process can only be effective if the engineer can trace the costs to the components, the components to the functionality, and the functionality to the requirements.

An example may help to clarify the cost engineering process. Suppose there is a shortage of electricity and the requirement is levied to design a toaster that does not require electricity. The functionality would be to design a product that would brown the surface of a slice of bread by heating. One design alternative may be a nuclear toaster, one that warms the bread from the heat of a nuclear reactor. Necessary components would then consist of a miniature nuclear reactor with the appropriate shielding and a device to bring the bread close enough to the reactor to heat it. A timer may also be required to ensure that the toast does not burn.

Now that the requirement, functionality, and components have been defined, a cost can be applied to this option. At this point the engineer may discover that the cost is too high or that the option is infeasible due to the weight of the toaster caused by the necessary nuclear shielding. It may be necessary at this point to investigate a new approach or perhaps relax the requirement of no electricity such that battery power or solar power could be used. At any rate, the design engineer has all the necessary tools to do the trade studies and arrive at an optimal or near optimal solution.

This type of real-time cost analysis can only be done through parametrics. Both the analogy and grass roots methodologies would take too much time. Further, at this point in the development process, there is not enough definition to do a grass roots estimate. Only through the power of parametrics can the estimate be accomplished in seconds or minutes rather than days or weeks.

THE IDTC CONCEPT

A good example of the cost engineering process is PRICE Enterprise (PRICE E), a Computer Aided Parametric Estimating (CAPE) tool that translates physical design and schedule parameters from any existing tool, including Computer Aided Design/Computer

Aided Manufacturing/Computer Aided Engineering (CAD/CAM/CAE) tools, into cost and schedule estimates. PRICE Enterprise encapsulates the PRICE cost models in a shell that allows external tools to drive design data in and extract cost and schedule estimates out automatically. PRICE Enterprise facilitates design to cost objectives, decreases estimating costs, improves estimating capability and accuracy, and reduces time to market. PRICE E integrates the activities of all the disciplines involved with contracting, engineering, costing, manufacturing, and supporting a product. It does so through an integrated database supplying information to all the disciplines through common software applications. Thus the entire process from cradle to grave is automated in a truly integrated environment.

A specific example of applied PRICE E is Integrated Design to Cost (IDtC), integrating Ascent Logic Corporation's RDD-100 and PRICE Systems' Parametric Estimating Models, making design to life cycle cost or Cost as an Independent Variable (CAIV) a reality. With IDtC, engineers can use cost as an engineering parameter and view the cost impacts of design decisions as the project evolves. Cost analysts can obtain engineering input in real time as the design process unfolds. IDtC supports any type of IPT effort or any cross discipline philosophy. The IPT can now take control of the total product development process starting with the concept and requirements. The result is cost conscious development of high quality products designed to meet and even exceed user expectations.

IDtC combines the full capabilities of RDD-100 and PRICE E to create an optimized team environment in which accurate cost estimates can be seamlessly derived from design requirements at the start of the program. The result is faster cycle times between engineering and costing, lower life cycle costs due to requirements-driven design, and accurate costs derived early in the process. This interface is graphically shown in Figure 7.

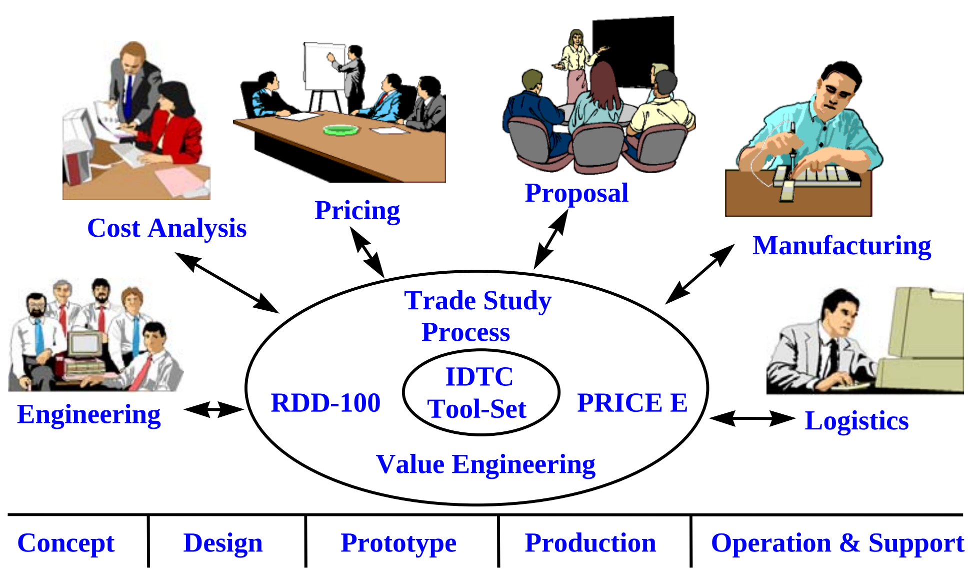


Figure 7 Integrated Design to Cost

The IDtC methodology can easily be applied within any organization for IDtC leads to process improvement, attention to the cost/performance/schedule relationship, and high quality end results. IDtC enables IPTs to work together in achieving program goals to optimize the best combination of cost, schedule, and performance. IDtC provides the right tools with proven capabilities to ensure team success. The result is control over the acquisition process leading to satisfaction for the customer, the developer, and the supporter.

CONCLUSION

Given that cost, schedule, and performance are of equal value in meeting the demands of the current market place with new products, parametric estimating is the most viable approach to meeting the cost requirements of the triad. Parametric estimating is faster, cheaper, and of equal or better accuracy when compared to other cost estimating techniques. The cost analyst is not the only one, however, with a stake in the cost estimating process. In today's business environment, the engineer must also play an active and decisive role. Luckily, with current automated approaches to engineering design and cost estimating, these two can be married in an environment where the engineer can get instant feedback on cost and schedule implications as alternative designs are explored. Thus Integrated Design to Cost is a reality.

REFERENCES

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