PARAMETRIC COST DEPLOYMENT

by

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ABSTRACT

Parametric cost analysis is a mathematical approach to estimating cost. Parametric cost analysis uses non-cost parameters, such as quality characteristics, to estimate the cost to bring forth, sustain, and retire a product. This paper reviews parametric cost analysis and shows how it can be used within the cost deployment process.

INTRODUCTION

Cost is the measure in monetary units of the work associated with human endeavor (Putnam, 1978; Dean, 1995a). Current resource expenditure level is the measure in monetary units of the power associated with human endeavor. Value is an energy potential that drives consumer decisions (Shillito and De Marle; 1992) and value is the measure of consumer choice (Barnard and Wallace, 1994). The primary coordinates of value appear to be quality and cost (Dean, 1995b). Market timing is also important but can also be viewed as the dynamic nature of quality. Quality is defined by customer desires. Quality function deployment (QFD) is a process by which one can deploy quality into the product; into the system to bring forth, sustain, and retire the product; and into the enterprise as a whole (Dean, 1995c). Within QFD, we deploy quality to ensure that the customer gets what is desired. But what about cost?

From physics, we know that work and energy have the same units. Thus, by analogy, cost, as measured by work, and value, as an energy potential, have the same units. From the perspective of an individual, cost is a measure of value in that a consumer is willing to trade money for value. From the perspective of a project, a project is driven by value, which is potential energy. As time proceeds, the cost of a project grows and the residual value to be realized decreases. This model is a direct analog of the law of conservation of energy in physics. This analogy equates value with potential energy and cost with kinetic energy. If too much cost is incurred relative to the initial value of the project, measured in terms of what the customer is willing to spend, then the residual value at the end of the project is negative. Both the individual and project models explain why it is so important to deploy cost while deploying quality. However, to deploy cost we must consciously design for cost (Dean and Unal, 1991; Dean and Unal, 1992). Simply put, cost deployment is a means of designing for cost.

This paper assumes a basic understanding of QFD (Akao, 1990) and cost deployment (Maekawa, 1990). It describes parametric cost analysis (Dean, 1995d) and shows how parametric cost analysis fits within the cost deployment process.

COST DEPLOYMENT

Although there are other scenarios available for cost deployment, the following has been chosen for this paper to simplify the presentation of a relatively new concept.

The basic concept underlying cost deployment to date is to match value with cost. Suppose that we have a system with known parts. If we can determine the importance of parts by some evaluation process, see below, and the cost of those parts, we can then divide the importance of each part by the total importance to obtain the relative importance for each part. We can also divide the cost of each part by the total cost to obtain the relative cost of each part. If we plot relative importance versus relative cost as in figure (1), then the line drawn at forty-five degrees indicates the location of all points for which relative cost is equal to relative value. This indicates that cost and quality are in balance (Shillito and De Marle; 1992). We now plot a point for each part on this graph with its associated relative cost and relative importance as coordinates. If the point for a part is significantly below the line, then that part has far too much cost for the importance. It is, thus, a candidate for cost reduction and is chosen for detailed value engineering. This chart is called the value graph.
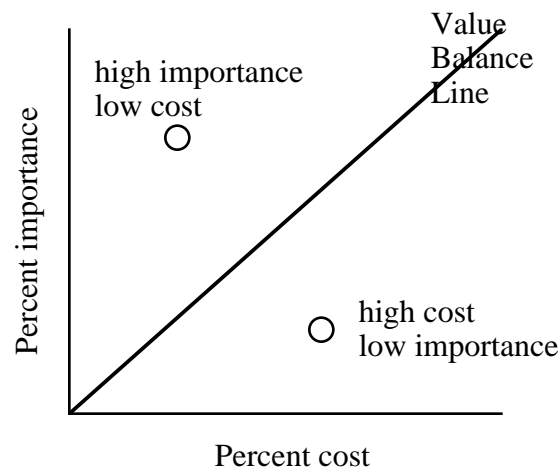

Figure 1. The Value Graph

QFD provides a natural framework for obtaining the importance of a part. This can be seen in figure (2), which follows the standard system engineering decomposition (Blanchard and Fabrycky, 1981). Referring to the matrix of matrices in King (1989), the customer demand versus quality characteristic matrix (A1) transforms customer importance into quality characteristic importance. The quality characteristic versus function matrix (A2) transforms quality characteristic importance into function importance. The function versus mechanism matrix (C2) transforms function importance into mechanism importance. The mechanism versus part matrix (C4) transforms mechanism importance into part importance. The complete process above, thus, transforms customer importance into part importance. We now have a part importance with a direct relation to the customer desires that define the quality of the product.

In the past, cost has typically been determined by tearing down either a company built or a competitive product to obtain detailed cost information from company processes or vendors. This is a detailed cost accounting effort. When complete, there is a cost for each part and a cost database. The cost for each part is then coupled with the importance for each part to provide a value graph. Candidate parts for cost reduction are then chosen from the value graph.
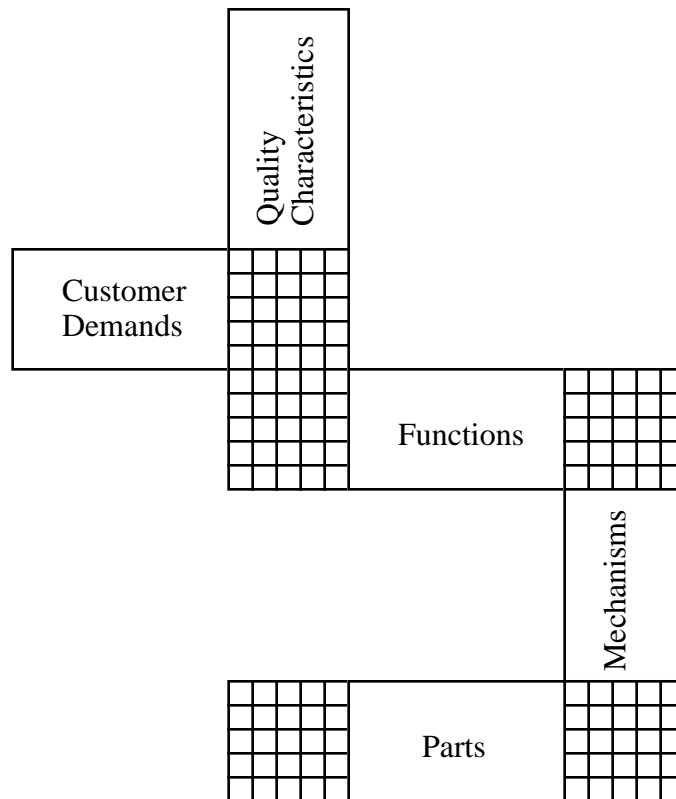
Figure 2. Customer Demand to Part Importance Transformation

When the cost database is coupled with the QFD data base, a very important database emerges. It contains an instance of combined quality and cost data. The evaluation of alternatives for the cost reduction of the selected parts provides additional instances. Multiple instances permit the application of statistical processes to determine equations that can predict cost in terms of quality characteristics. This offers the potential for quality based cost estimating. With this data base we can apply parametric cost analysis toward that target.

PARAMETRIC COST ANALYSIS

Parametric estimating is the generation and application of equations that describe relationships between cost, schedule, and measurable attributes of systems that must be brought forth, sustained, and retired.

Parametric estimating relies on simulation models that are systems of statistically and logically supported equations. The impacts of a product's physical, performance, and programmatic characteristics on cost and schedule are captured by these equations. The output of the models is validated with data from past projects. The object to be estimated is described by choosing specific values for the independent variables in the equation which represent the characteristics of the object. The equations are then used to extrapolate from past and current experience to forecast the cost of future products.

The typical statistical process is to find a value for m parameters $p = (p_1 \ldots p_k)$ such that the cost y can be predicted reasonably well by the equation

$$y = f(x,p) + e$$

where e is the prediction error and $x = (x_1 \ldots x_m)$ is a set of measures of system characteristics that vary over n cases $(y_i \, x_{1i} \ldots x_{mi})$, different for each $i = 1, n$. The above equation is the general form for response surface methodology (Box and Draper, 1987). Thus, from a statistical perspective, parametric cost analysis may be viewed as an application of response surface methodology to the field of cost analysis.

Given that the function f is linear in the parameters p, i. e.

$$y = \sum_{l=1}^{k} p_l \, f_l(x) \ ,$$

one criteria for defining "predicted reasonably well" is least squares (Draper and Smith, 1981) which minimizes the Euclidian distance between the predicted values $(z_1 \ldots z_n)$ and the case values $(y_1 \ldots y_n)$. The equation for calculating the values of these parameters is

$$p = (X' \, X)^{-1} \, X' \, y$$

where X is a matrix with n rows $(f_{1i}(x) \ldots f_{ki}(x))$, X' is its transpose, y is a vector with n rows y_i, and $(X' \, X)^{-1}$ denotes the inverse of the matrix product X' X. Given an arbitrary x, we can then predict the cost y reasonably well using the estimator

$$z = f(x,p).$$

A typical form for parametric cost equations (Dean, Unal, and Moore, 1992) is

$$z = e^{a_0} \, e^{a_i u_i} \ \ldots \ e^{a_r u_i} \, x_1^{b_1} \ \ldots \ x_m^{b_s}$$

where a_i and b_j are coefficients found by using linear least squares, u_i and x_j are statistically significant measures associated with the product, and i and j are indices associated respectively with the variable types u and x. The x_j are typically measures of size, which usually include weight for hardware or the number of lines of code for software. The a_j are generated with the unit binary variables u_i, which indicate class membership, e.g. whether or not an aircraft is a fighter. The coefficient a_0 is the complexity of the base class. The other a_i are the relative complexities of the associated subclasses. Note that if the particular product is not in subclass i, then $u_1 = 0$ and $e^{a_i u_i} = 1$. If the product is in subclass i, then $u_1 = 1$ and $e^{a_i u_i} = e^{a_i}$ modifies the base complexity a_0 to provide the subclass complexity $a_0 + a_i$. This method provides, for example, a means of distinguishing between different manufacturing processes for a given part.

PARAMETRIC COST DEPLOYMENT: STAGE 1

To address parametric cost deployment, assume that the product has been decomposed into mechanisms and parts that perform given product functions. This decomposition is an output of a systems engineering process or a detailed QFD process (Mizuno and Akao, 1994). The sum of the

costs of the mechanisms that provide the function, along with the cost to integrate them, is the cost of the product function (Dean, 1995e). We also assume that a QFD process has been used which maps the quality characteristics to the product functions and to the mechanisms and parts. Finally, we assume that a database exists that includes specific quantities for quality characteristics, mechanism cost, part cost, integration cost, and possibly ancillary size measures, such as associated part weight or the number of lines of code necessary to provide a function implemented in software. Using the database, we can then determine the best parametric equation, given that database, to estimate the cost of any part, mechanism, or function included in the database.

Because integration cost is normally substantial, this cost should also be estimated by a parametric equation. Estimating the integration cost requires inclusion of all quality characteristics within the domain of the integration within the equation determination process.

Suppose that parametric equations have been obtained for parts and their integration into mechanisms. Then, the estimated cost of a mechanism is the sum of these estimated costs. Also, the estimated cost of a function is the sum of the costs of its parts and the integration of these parts into the subsystem which implements the function. The first case is parametric unit cost estimating and the second case is parametric function cost estimating.

Not all product quality characteristics will be statistically significant. In addition, some objects may not have any statistically significant quality characteristics. For these reasons, the initiation of parametric cost deployment should proceed cautiously. Direct estimation of the cost at the mechanism or function level may turn out to be both more economic and more accurate than at the part level. Hence, in moving toward parametric cost deployment, one should start at the highest possible level to test the viability in terms of the specific product or product line.

Note that, given statistically significant parametric cost equations for either the mechanisms and their integration or the functions and their integration, the cost of the total product can be estimated in terms of the quality characteristics. This estimation provides the ability to estimate the cost of quality changes for the total product.

PARAMETRIC COST DEPLOYMENT: STAGE 2

Stage 1 parametric cost deployment as defined above contains a serious flaw. Cost is generated by the system to bring forth, sustain, and retire the product (Dean, 1993a; Dean, 1993b). It is the bringing forth, sustaining, and retiring of the product that costs. The work of human endeavor necessary to bring forth the product is the cost expressed in monetary units. That cost is then allocated to the product on a per unit basis. Thus, product cost is largely driven by the process to bring forth the product. Hence, the quality characteristics of that process should be included in the database and should be used to obtain the parametric cost equations. Stage 2 parametric cost deployment includes these quality characteristics as well.

The PRICE H™ cost model (Anon., 1993) has been one of the most commercially successful cost models for estimating hardware cost during the last 15 years. Development cost is estimated from variables such as a scale of engineering complexity, the amount of prototype support required, the percent of new design required, the difficulty of the integration, the number of prototypes required, and other variables. Most of these inputs reflect the development process. Production cost is estimated with input variables that include the difficulty of machining, the part tolerances required, the assembly tolerances required, the number of parts, the number of production units, and other variables. Most of these inputs characterize the production process. Thus, most of these inputs are quality characteristics of the system to bring forth the product. They are not quality characteristics of the product.

Personal estimating experience indicates that approximately 80 percent of the leverage to reduce cost is within the process to bring forth the product. The remaining 20 percent has to do with product quality characteristics.

Note that the binary variables, u_i, as defined above for parametric cost analysis, become important in describing the discrete decisions required to design the process to bring forth the system. They can be used to distinguish between types of design tools used, types of analyses performed, manufacturing processes, testing methods, management styles, etc. These types of variables can be large cost drivers! Of course, to be incorporated into the cost equations, they must be a part of the database.

To get the full effect of cost drivers, stage 2 cost deployment must include quality characteristics of the system to bring forth the product, as well as the quality characteristics of the product. Both discrete and continuous quality characteristics may be needed to describe this problem. When the incorporation of quality characteristics from both the product and the system to bring forth the product into cost equations is combined with the use of Taguchi methods, response surface methodology, and continuous optimization methods (Luenberger, 1973; Arora, 1989), stage 2 cost deployment is equipped to seek the minimum cost, subject to the desired quality which is supplied by the customer desire versus quality characteristic (A1), product function versus quality characteristic (B1), mechanisms versus quality characteristic (C3), and parts versus quality characteristic (A4) matrices (King, 1989).

Because of the strong dependence of cost on the nature of the system to bring forth the product, stage 2 parametric cost deployment will be more robust than stage 1 cost deployment.

ISSUES IN PARAMETRIC COST DEPLOYMENT

A major issue in the implementation of parametric cost deployment is the necessity for an accurate and substantial database. Within the American aerospace and defense communities there is a common management belief, that the way to save money on a project is to eliminate the collection of cost and system engineering data. Morrocco (1995) notes that in the proposed production cost reduction of the F-16 fighter plane by Lockheed Martin, "Military specifications would be eliminated, as well as cost accounting, inventory tracking, and other reporting systems that create enormous overhead costs." The belief that all data collection increases total cost is a widely held misunderstanding. In reality, if accomplished in an appropriate manner, the implementation and use of a database can lead to significant reductions in total cost. Parametric cost deployment holds that promise; however, convincing aerospace and defense company management that increased data can lead to lower total cost will be even more difficult than convincing them to use QFD as a standard engineering practice. The commercial world may have a role to play in this regard.

A second major issue in the implementation of parametric cost deployment is shared by virtually any form of cost deployment. Cost is incurred from the system to bring forth the product. To be adequately represented, the database must include quality characteristics from that system. Relatively little awareness, let alone understanding, of that system and its quality characteristics have been demonstrated by American business as a whole.

A third major issue in the implementation of parametric cost deployment is also shared by virtually any form of cost deployment. Cost is a systemic phenomenon that requires the use of a number of matrices within the QFD process. A current American paradigm is that QFD is the house of quality (Hauser and Clausing, 1988). In reality, QFD is far more than the house of quality, it is a holistic engineering process and must be viewed as such for cost deployment to succeed.

The final issue presented here concerns the technical nature of the importance transformation provided by the QFD process. As described above, the process to transform customer demand importance into part or mechanism or function importance is valid only if there is no customer demand versus customer demand correlation or quality characteristic versus quality characteristic correlation. This is rarely true in practice. Research is required in this area.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This paper has described parametric cost analysis and shown that it can be integrated into cost deployment. Two levels of integration are described. The first incorporates quality characteristics of the product. The second, an extension of the first, incorporates, in addition, quality characteristics of the system to bring forth the product.

Attaining the goal of the minimum cost for desired customer quality is a necessity in the current world market. This paper has shown that the concepts of parametric cost analysis and optimization can be integrated into cost deployment to create a process that approaches this goal. This paper proposes a framework for such a combined process which it names parametric cost deployment.

As defined in this paper, parametric cost deployment lacks a direct link by which one can directly calculate a change in cost given the change in customer desire and conversely. As defined in this paper, parametric cost deployment also does not complete the linkage between cost and value as described in the introduction to this paper. These links are necessary for further extensions of cost deployment.

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