A System for Values, Communication, and Leadership in Product Design

Paul D. Collopy
DFM Consulting, Urbana IL 61803-0247

ABSTRACT

Design teams can create a higher performance, more affordable product through a clear and unified set of Design Values. To achieve unity, Design Values must be established, then communicated to the team. Project Management should establish and communicate uniform Values, despite technological and political difficulties, as a matter of good leadership.

INTRODUCTION

In the twenty years following the end of World War II, the discipline of systems engineering was born and matured. Hierarchical specifications of requirements, and traceability between requirements and validation tests has become a way of life, particularly in the aerospace industry. Since the mid-1960’s, however, systems engineering has developed very slowly in theory and methodology.

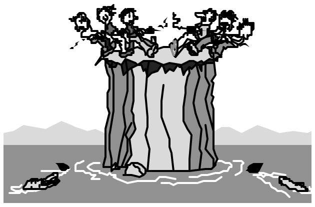
This paper embodies the first new wave in systems engineering in thirty years. It advocates a change from *requirements* to *values*. It demonstrates the benefit of clearly quantified, effectively communicated values to the design of large systems, using military aircraft design as an example. Quantifying values is shown to be an important dimension of project leadership. Communicating values is equally important, and the paper illustrates a system of communicating values down into the design team while simultaneously communicating the design status to management. The result is more control for project managers, more design latitude for individual engineers, and clearer direction for all, leading to a significantly better project.

PROBLEM STATEMENT

Consider the following pair of design decisions, typical of contemporary systems methodology:

1) A senior designer at an aircraft brake division of a major aerospace contractor has devised an innovative solution to a pressing problem -- by utilizing a special alloy in the housing of the brake assembly, she can reduce the assembly weight by 90 pounds. Instead of being 60 pounds over specification, the brake system is now 30 pounds under. The new alloy will increase the manufacturing cost $11,000 per set, but the hydraulics are coming in well under expected cost, so the increase can be afforded.

2) Meanwhile, in southern California, another contractor is wrestling with a similar problem on the same advanced fighter aircraft design. The rudder is turning out to be more expensive than planned. However, the design could be improved by reducing the tolerances and features on the internal ribbing. An engineer projects that this change will reduce the manufacturing cost $10,000, although the weight will increase 190 lbs. Fortunately, the original weight estimate given to the prime contractor was very conservative, so the weight increase is unlikely to draw much attention.



Brake Material	+ $11,000	- 90 lbs.
Rudder	- $10,000	+ 190 lbs.
Net Impact	+ $ 1,000	+ 100 lbs.

Figure 1: Example of Design Discord

The net impact of the two decisions, illustrated in Figure 1, is an aircraft that weighs more and costs more -- clearly a loss. Yet both designers believe they are improving the aircraft. The villain is a process that uses *requirements* not *values*. The aircraft has specified requirements, which are actually limits, on weight and cost (and performance, reliability, etc.). These are budgeted among component systems, so that each has a limit on key figures of merit. We can visualize this as a design space (Figure 2). Every possible design can be plotted as a point in the design space, for example, by plotting weight and cost. This paper uses weight and cost as dimensions for the design space, because two dimensional spaces are easy to visualize. Real product design spaces have many dimensions and are hard to visualize, but are manageable with simple computer tools.

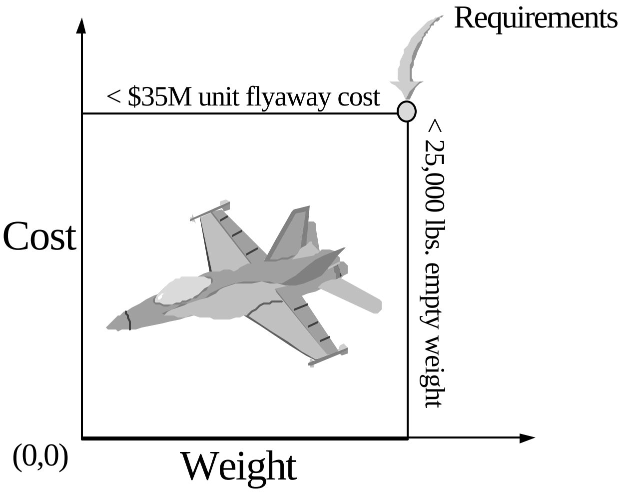


Figure 2: Design Space Defined by Requirements

According to Figure 2, specifications require the aircraft design to lie within the square. However, they give no indication as to where in the square the design should be, or any way to compare one point in the square to any other point. Of course, designers understand that less weight is better and less cost is better, but the specification provides no guidance to compare two points, one of which is lower cost and the other lower weight.

The other key problem with specifications is that the best design must be known (or guessed) in advance, so that the square can include it with very few other feasible designs. There are two dangers to avoid in writing specifications. The first is that, if the square includes too many feasible designs, the engineers may select a poor design, yet it still meets specifications. (Remember that the specifications do not provide designers the insight to distinguish good designs from poor designs, only out of spec designs from in spec designs.) The second danger is that the best design may lie outside the square. Since design of large systems is a constructive process, there is usually no way to describe the best design in advance. Thus, enlightened programs like the Joint Strike Fighter avoid as long as possible specifying requirements, so that engineers can work in the largest possible design space.

PROPOSED SOLUTION

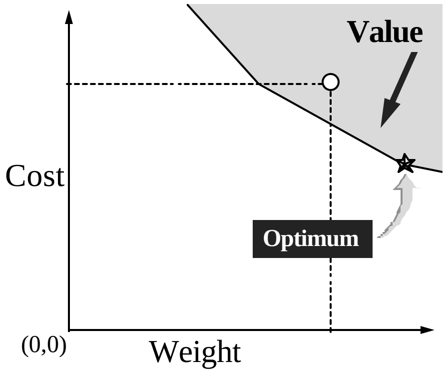


Figure 3: Design Space Defined by Values and Technology

Figure 3 shows an alternative way for project leadership to provide guidance to the design team without eliminating possible designs. This guidance is in the form of a quantitative function, called a *value function*, that combines all the figures of merit that describe the design (for example, the items in the first column of Figure 4) into a single score, the *design value*. The value function in figure 3 might be

$$Design\_Value = 95 - \frac{Flyaway\_Cost}{\$500,000} - \frac{Empty\_Weight}{1000\,lbs.}$$

The value function can be used to compare any two designs -- the design with the higher value is presumed to be better. Notice that the units of design value are unimportant. Since the number is only used for comparison, any convenient units can be used. The value arrow in Figure 3 is the gradient of the value function: a vector formed by the partial derivative of design value with respect to weight and design value with respect to cost. The arrow points in the direction in which value increases most rapidly.

FROM WHERE DO VALUE FUNCTIONS COME? - Value functions are numerical models of customer (operator) needs in comparison to resource availability. They are generated by analyses of needs, economic assessments, and, in the end, project leadership choices. Tools like Quality Function Deployment (QFD) can help to model customer needs, as can life cycle cost analyses. Enterprise economic models can address resource availability in private industry; budget projections help fill this role in government. In the end, however, models can seldom complete the picture. Project leadership must make a call on crucial high-level tradeoffs. We will see that the value function is the most essential communication to the design team as to how the product should be designed. To avoid committing to a value function is the leadership equivalent of a general in the field who confesses to his brigade, “I am not sure whether the enemy is massing to the north or to the east, so each of you just head off whichever way you think is best.”

The lower boundary of the shaded region in Figure 3 is a product of the design team, not project leadership. It represents technological capability, that is, what designs are really possible. In the illustration, we can see that the best design is in the corner labeled with the star. In practice, solutions are not so simple. Not only do real design spaces have many dimensions, but also real design teams cannot explicitly represent the limits of technology in the design space. Individual designers know the limits when they bump against them, but often cannot predict them in advance.

However, given the value function, they can search through possible design options until they hit limits, always moving in the direction of better designs.

	Status	Gradient	Value
Lethality	1.7	188	320
Survivability	0.4	485	194
Weight	28,000	-0.00057	-16
Flyaway Cost	26.3	-3.42	-90
Maintenance Cost	738	-0.0407	-30
Reliability	11	-1.45	-16
Safety	0.03	-733	-22
Tooling Cost	438	-0.0164	-7
Program Risk	20%	-235	-47
Development Time	6.2	-22.9	-142
Development Cost	3.00	-17	-51
Design Value			93

Figure 4: Tracking value during system design

Figure 4 suggests how designers perform this search. The left column identifies the figures of merit used to assess the design. (Each should also have units identified.) The next column is the current value of that figure of merit. The third column contains the partial derivatives that make up the gradient of the value function. The last (right) column is the product of the status (column 2) and the gradient (column 3). Design options can be compared by their impact on the sum of the right column. Whichever option yields the highest sum when its status is multiplied by the gradient is the superior option.

The power of this method is that, in a large project,

- The gradient of the value function can be translated into the relevant figures of merit for each component,
- Each component can track its design progress separately, and
- These same tracking charts can communicate progress back to project leadership (in a manner very similar to requirement hierarchies and status today).

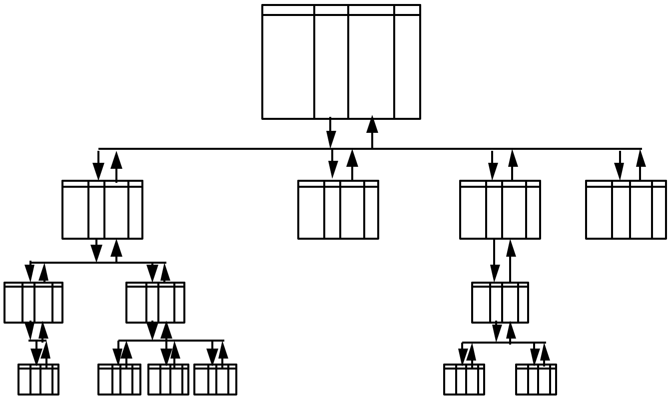


Figure 5: Tracking Charts: A channel of communication

In other words, tracking charts are a two-way communication channel between project leadership and individual designers, communicating design values downward and design status upward (Figure 5).

Figure 6, below, illustrates the tracking sheet that might be used for an individual component, derived from the system tracking sheet in Figure 4. The individual components correspond to the bottom row on Figure 5.

Engine Compressor

	Status	**Gradient**	**Value**
Efficiency	85%	150,000	127,500
Weight	700	-130	-91,000
Manufacturing Cost	700	-1	-700
Maintenance Cost	500	-0.5	-250
Reliability	1500	2.3	3,450
Safety	0.15	-15,500	-2,325
Tooling	2.8	-3	-8
Development Time	3.4	-6	-20
Development Cost	25	-3	-75
Design Value			**36,571**

Figure 6: Component tracking sheet

WHAT ABOUT THE ASPECTS OF A DESIGN THAT CANNOT BE QUANTIFIED, SUCH AS AESTHETICS? - Aspects that cannot be quantified are hard to communicate to component designers under any system, so they tend to not play a part in low level design decisions. This method allows designers to use the figures of merit that are available to them to make design choices that are consistent with the overall program direction.

Recall the two designers in the example at the beginning of the paper. If the leadership of the aircraft design project had communicated to them a common value function, only one of the changes could have been made. The result would have

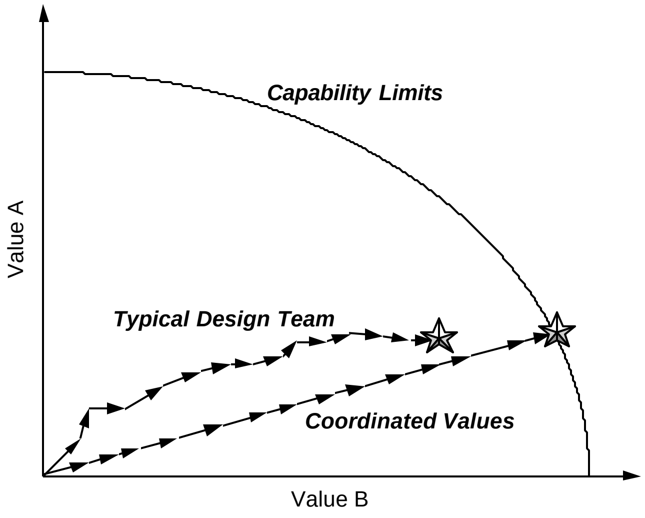


Figure 7: Qualitative results of design with coordinated values: Reaching the limits of the teams capability

been a net improvement, as opposed to the net increase in weight and cost -- all because of leadership, and communication of values.

CONCLUSION

The potential exists today for substantial improvement in the results of large design projects through a simple system of values, leadership, and communication. In private industry, this methodology can dramatically increase the profit yield from new products and place them in a stronger position in the market. For public programs, the result is more value for the taxpayer, better contractor management and more potent and capable systems.

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The author can be reached for comment at (888) 643-4393 or by email at paul@dfmconsulting.com