Pre-Milestone-A Decision-Making: Can We Cost Capabilities?

Abstract

The issue of early, rigorous evaluation of program costs for use in early decision-making is becoming more important as defense funding comes under greater scrutiny. Often at this point in the life cycle, a requirement or desired capability is known, but the manifestation of the solution is unknown or described only at a high level. Can capabilities and little more be used to produce a cost estimate? If so, how can we link the proposed solution to existing system data if only a particular solution's general capability set is known?

This work submits that better strategic decisions within fiscal constraints could be made if rough order of magnitude (ROM) estimates were available for proposed materiel or non-materiel solutions, based on that solution's capability set. This project further proposes the use of a knowledge base to provide support for these estimates; our research team has developed what is known as the Capabilities Knowledge Base (CKB). By mapping a proposed solution to relevant data points, one can use the data and tools available through the CKB to produce a ROM cost estimate. The estimate itself may be developed using a wide spectrum of techniques, including the baseline methodologies proposed by this research effort.

I. Informed Decision-Making and the Concept Decision Experiment

According to Department of Defense (DoD) guidance dated June 19, 2006, the [2006] Quadrenniel Defense Review (QDR) report called upon senior departmental leaders to “better integrate the processes that define needed capabilities, identify solutions and allocate resources to acquire them in order to enable corporate decision-making that cuts across traditional stovepipes”. In response to this directive, DoD leaders are evaluating a new early lifecycle decision-making framework that includes a Concept Decision (CD) Review (supported by an Evaluation of Alternatives or EoA). The CD Process has been set forth as a way to combine requirements, capabilities portfolio evaluation, and resource allocation considerations in the pursuit of joint, efficient, and well-informed decision-making early in the acquisition life cycle. The Concept Decision will either replace or occur in conjunction with Milestone A to decide which of the prospective solutions provided by the EoA will best enhance overall US defense capability while balancing priorities of cost, schedule, and risk management.

The issue of early and rigorous evaluation of program costs becomes more and more important as defense funding becomes more scrutinized. Clearly, decision-makers need high-fidelity cost information at this key decision point, but more often than not, it is scant. Providing reliable, useful cost estimates very early in the acquisition life cycle is challenging for several reasons. Often at this point in the life cycle, a requirement or desired capability is known, but the manifestation of the solution is unknown or described only at a high level. This is certainly a challenge, given that defense cost estimating is usually performed given a detailed system description. In addition, given the changing face of the battlefield and warfare, proposed solutions are often unlike anything presently in existence.

II. Pre-Milestone-A Cost Estimating

As any cost estimator can confirm, there exists a spectrum of situations in which a cost estimate may be prepared. One extreme is creating a cost estimate in a situation where there is very little information about the item being estimated and no supporting data. The other extreme is when the entity being estimated is fully understood, and all data exists to estimate the cost exactly. In this case, the data are actual costs after the item has been developed, constructed, or bought.

As we progress from the point of no information to the point of perfect information, our cost estimating methodology changes to suit the information climate. For instance, when information about the item or service is higher-level and/or data is not readily available, cost estimators tend to rely upon analogies and parametric methods to produce their estimate. However, as we move toward the right, estimates tend to utilize more “data-hungry” methodologies such as engineering builds and projections using actual costs to date. It is also clear to the casual observer that as we move along the spectrum from left to right, we may expect for our estimate to be more reliable and closer to the actual cost at project or acquisition completion.

The pre-Milestone-A costing environment is particularly challenging. This is the stage in which information is often extremely scarce. *Figure 2* illustrates the “sub-spectrum” of the cost estimating spectrum described above. Even within the Pre-Milestone-A timeframe, a range of information climates might exist.

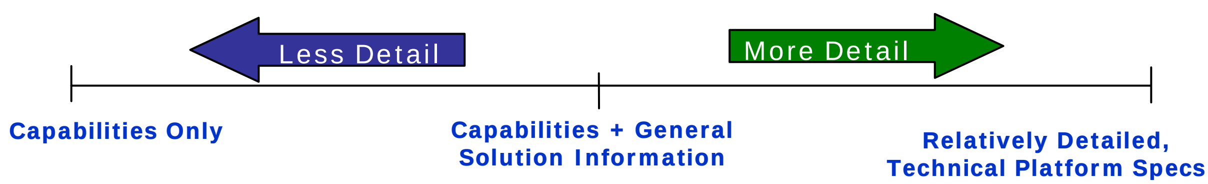

Figure 2: Spectrum of Information Availability at Milestone A

Depending upon the situation, there may be one or many proposed solutions to a set of capability gaps before Milestone A. These solutions could be a materiel system such as a vehicle or software package, or it could be a non-materiel solution, such as a policy change or a training curriculum change. As one can see in *Figure 2,* the information regarding the proposed solution(s) could range from simply the desired capability expressed in very qualitative terms to a relatively detailed, well-developed concept with some technical platform specifications. The most commonly-occurring scenario, however, is nearer to the middle where there exists high-level capabilities information along with some very general solution information.

Since every cost estimate of an item or project must be based on some type of past experience, pre-Milestone-A cost estimating is no exception. How can we link the proposed solution to existing systems (our past experience) if we know only a particular solution’s general capability set? Can capabilities alone be used to produce a cost estimate? If so, could that cost estimate be used in decision-making with any degree of confidence?

Suppose we made the assumption that a system’s capabilities have a relationship to its cost. To the casual observer, this assumption seems rather logical. If we buy something that can do more, do it quicker, or do it better, then it should cost more. However, one can identify situations in which this assumption might not hold; if a particular computer technology is maturing at an accelerated rate, the cost to acquire that capability might not be correlated to the cost of acquiring a similar capability five years ago. Yet, even this example has a relationship between capability and cost upon closer inspection; to arrive at an acceptable cost estimate one must understand the rate of technology maturation (and this maturity information may or may not be available to the analyst). The question at hand, however, is whether or not capabilities can predict cost within some acceptable level of percentage error to provide decision makers with data that helps avoid decisions that would yield negative future cost effects. In theory, these decisions could be avoided if a rough order of magnitude (ROM) estimate is available that is based on the proposed materiel solution's set of capabilities.

III. Early Cost Estimating: Approaches and Algorithms

The early cost team at ODASA-CE is currently tackling the challenging pre-Milestone-A costing environment. Our approach includes the use of a knowledge base that records current system cost information and capabilities. By using the relevant entities extracted from the CKB, a ROM cost estimate may be developed using a wide spectrum of techniques.

Numerous costing approaches are being examined and developed as this project evolves. It is important to emphasize that cost estimates at this point in the life cycle are highly situation-specific, and thus methodologies under development are only recommended strategies. The analyst's judgment is key. Therefore, the team at ODASA-CE is developing what are called "baseline" or "recommended" methodologies---in essence, a starting point for a would-be early cost estimate builder. It is understood that the analyst will begin with one of these baselines and then use any additional data or information about the solution to further refine the estimate. Our longer term vision includes providing suggestions/recommendations for how to incorporate this additional information.

IV. Bin and Bump Up

One of the most basic techniques that the team is proposing is commonly referred to as the "Bin-and-Bump-Up" approach. Consider the following scenario. A proposed materiel solution is approaching its Concept Decision Review and will address three capability gaps. The analyst will assign a relative importance to each of these capabilities. Suppose one or two of the capabilities are more urgent or have more drastic consequences if not filled. As shown in *Figure 3a,* each capability C_i (where *i* ranges between 1 and *n*) is given a corresponding weight w_i. *Figure 3b* shows the weights for our three-capability example.

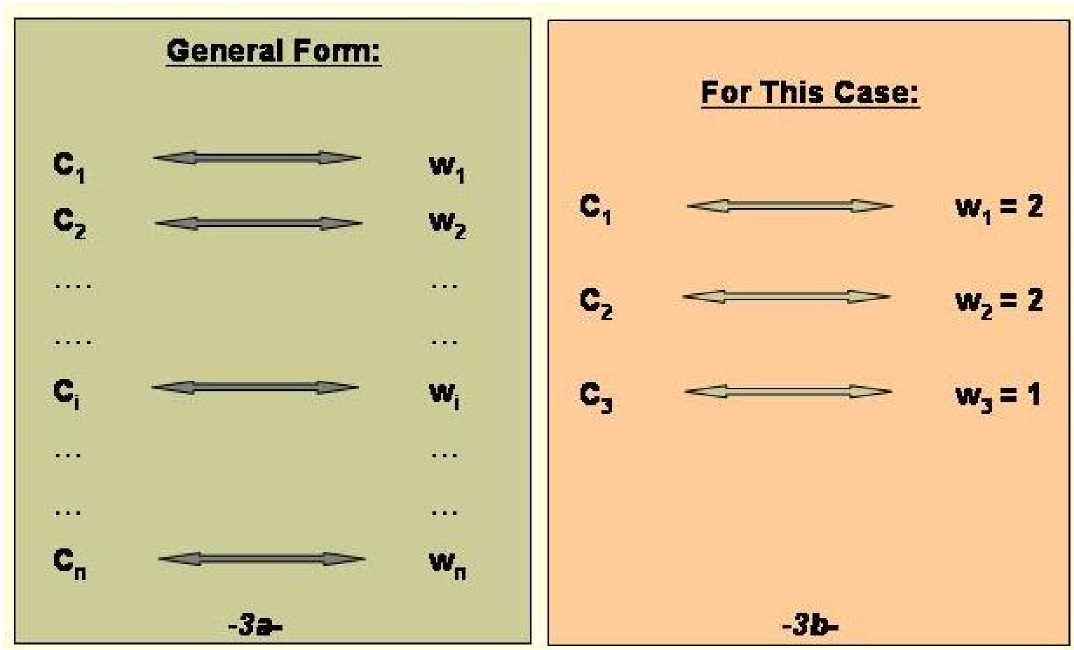

Figure 3: Bin and Bump-Up Weight Assignments

Now, let us further suppose that the analyst defines a set of bins into which each capability may be placed. One natural set that an analyst might select is the three-bin set containing "high", "medium", and "low". By allocating to these bins, correlations among various sets of capabilities can more readily be defined. A natural way of representing the correlations between bins is with a correlation matrix. After the capabilities have been dispersed into bins, then such a correlation matrix can be constructed. *Figure 4* shows a general case correlation matrix for *m* bins. The matrix is populated with correlation coefficients $X_{i,j}$, where *i* and *j* index the bins.

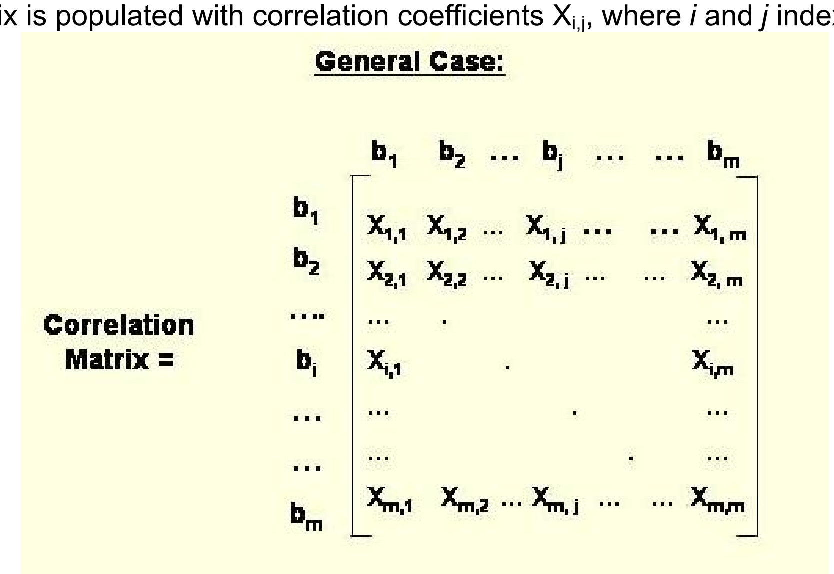

Figure 4: Correlation Matrix for the General Case

In addition, *Figure 5* is an example correlation matrix, which is the one we will use for this example case.

For This Example:

$$
\begin{array}{c} \\ \text{High} \\ \text{Med} \\ \text{Low} \end{array}
\begin{array}{c} \begin{array}{ccc} \text{High} & \text{Med} & \text{Low} \end{array} \\ \begin{bmatrix} X_{H,H} & X_{H,M} & X_{H,L} \\ X_{M,H} & X_{M,M} & X_{M,L} \\ X_{L,H} & X_{L,M} & X_{L,L} \end{bmatrix} \end{array}
=
\begin{array}{c} \\ \text{High} \\ \text{Med} \\ \text{Low} \end{array}
\begin{array}{c} \begin{array}{ccc} \text{High} & \text{Med} & \text{Low} \end{array} \\ \begin{bmatrix} 3 & 2 & 2 \\ 2 & 2 & 1 \\ 2 & 1 & 1 \end{bmatrix} \end{array}
$$

Figure 5: Correlation Matrix for the Example Case

Next, each capability must be put into the most appropriate bin. For this example, we will place capabilities one (C_1) and two (C_2) into the high bin, and we will place capability three (C_3) into the low bin. The medium bin remains empty for this example. Once the correlation matrix has been defined and populated, the analyst can proceed by using the weights (resulting from combinations of individual capability weights with relevant values from the correlation matrix) to assign significance values to each of the relevant current and/or historical system data points. *Figure 6* illustrates how the capability weights and correlation matrix convert to system weights.

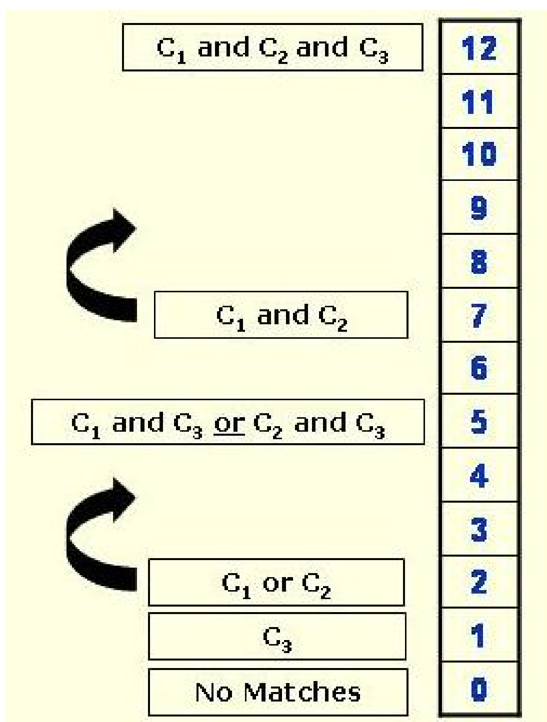

Figure 6: "Bin-and-Bump-Up" Example Configuration

As is illustrated above, the capability weights give the system weight if a current or historical system has only that capability in common with the proposed materiel solution. If two capabilities match, then the analyst adds the correlation coefficient belonging to the pair to their summed capability weights. *Figure 7* gives an example of this calculation for the case when the current system matches C_1 and C_3 of the proposed solution.

$$C_i + C_j = w_i + w_j + X_{i,j}$$

$$\Downarrow$$

$$C_1 + C_3 = w_H + w_L + X_{H,L}$$

$$\Downarrow$$

$$C_1 + C_3 = 2 + 1 + 2 = 5$$

Figure 7: Example "Bin-and-Bump-Up" Calculation for the Two Match Case

Figure 8 shows a similar calculation for the case in which there are three capability matches.

$$C_i + C_j + C_k = w_i + w_j + w_k + X_{i,j} + X_{j,k} + X_{i,k}$$

$$\Downarrow$$

$$C_1 + C_2 + C_3 = w_1 + w_2 + w_3 + X_{1,2} + X_{2,3} + X_{1,3}$$

$$\Downarrow$$

$$C_1 + C_2 + C_3 = 2 + 2 + 1 + 3 + 2 + 2 = 12$$

Figure 8: Example "Bin-and-Bump-Up" Calculation for the Three Match Case

Each of the relevant current systems is sorted into one of the bins shown alongside the numerical scale shown in *Figure 6,* according to the number and identity of capabilities that it has in common with the proposed solution. At this point, the analyst can choose to survey the current systems within each bin to determine if one or more are particularly relevant and need to be "bumped up" (as indicated by the arrows within *Figure 6)*. For instance, if within an early descriptive document, more detail is available on the proposed solution that shows that one or more current systems are (more or less) analogous, the analyst may choose to add additional weight to these data points or create a special higher-level bin into which these systems are placed. After all current systems have been appropriately binned, they are summed, normalized to one, and multiplied by their respective system (or sub-system) costs to produce a basic cost estimate for the proposed solution.

Although *Figure 8* gives the most complex calculation for this example, an actual early cost estimate may include more capabilities and more classification bins. This algorithm can be applied to any similarly structured group of capabilities, weights, and correlations, and is easily incorporated into a basic spreadsheet structure. The general formulation for the system weighting calculation is given in *Figure 9.*

$$\sum_{i=1}^{m} C_{\alpha_i} = \sum_{i=1}^{m} w_{\alpha_i} + \sum_{i=2}^{m}\sum_{j=1}^{i-1} X_{\alpha_i \alpha_j}$$

Figure 9: Bin-and-Bump-Up General Formulation

The C_α's in *Figure 9* refer to the capabilities that the proposed solution and the current system have in common. The elements within the summations are not necessarily ordered, but they are converted to an ordered set as indicated by the α term. The corresponding weights and correlation elements are summed to give the weight for a given set of matches.

Clearly, this gives a concrete, reproducible algorithm to binning and weighting combinations of capability matches, but there are many circumstances under which an analyst might choose to change, augment, or adjust this method. This approach is simply one baseline method that could be used as a tool to produce an early cost estimate. Suggestions can be made by the early cost team, but in the end, the analyst must make this determination based on experience, technical expertise, or subject-matter experts' recommendation.

V. Jaccard Indexing and Weighting

Another approach being developed by the early cost team utilizes the Jaccard indexing and weighting method that is well-known within the data-mining community. Because the Jaccard index (also known as the Jaccard similarity coefficient) is a way of comparing the similarity and diversity of sets of binary variables, the strength of this method is that it takes into account capability matches as well as disparities.

To illustrate how this technique functions in general, let us consider two objects with *n* binary attributes each. We can then use the Jaccard index to measure how alike the two objects are. *Figure 10* gives the general formula for the Jaccard similarity coefficient.

$$\frac{M_{11}}{M_{01} + M_{10} + M_{11}}$$

Figure 10: Jaccard Index General Form

M_{11} is the total number of binary attributes that both objects have a value of one (1). M_{01} is the number of attributes where object 1 has a value of zero (0) and object 2 has a value of one. M_{10} is the number of attributes where object 1 has a value of one and object 2 has a value of zero. The Jaccard index result can range from 0 to 1.

Let us apply this to a capability-based cost estimating situation. Consider a proposed materiel solution has a set of capability gaps that it is able to fill. In order to determine which of the current or historical systems are relevant, the Jaccard index between the individual systems and the proposed solution must be calculated. This can be done manually or in an automated way (this automated calculation framework is being developed by the team at ODASA-CE) by comparing the capability set of each current/historical system to the capability set of the proposed solution. After each of these Jaccard indices have been calculated, those that exceed an analyst-set threshold---0.500, for instance---are considered relevant.

To make this approach even more concrete, suppose that a proposed solution has capabilities C_1, C_2, and C_3. *Table 1* below lists current systems, their capabilities, and their Jaccard index scores when compared to the proposed materiel solution.

Systems	C_1	C_2	C_3	C_4	C_5	Jaccard Index
Proposed Materiel Solution	X	X	X			----
Current System 1	X		X	X		0.500
Current System 2	X	X	X			1.000
Current System 3	X					0.333
Current System 4		X	X	X	X	0.400

Table 1: Jaccard Indexing Example

By using the formula given in *Figure 7,* the Jaccard indices can be calculated for each current system, and the resulting values range from 0.333 to 1.000. If the cut-off point for relevant systems is set at 0.500, then it is clear that only systems one and two are relevant to this estimate.

One way to produce a cost estimate for the proposed solution based on this data is to use the Jaccard index itself for each system as a weight. Then, like in the "Bin and Bump Up" algorithm, the weights would be summed, normalized to one, and multiplied by their respective system (or sub-system) costs to produce a basic cost estimate for the proposed solution.

VI. Conclusions and Future Pursuits

In light of the growing defense leadership interest in making better-informed strategic acquisition decisions earlier in the life cycle, research into capability-based cost estimating approaches, tools, and methodologies must continue. The early cost team at ODASA-CE is committed to this pursuit.

In addition to the study of the continually evolving pre-Milestone-A analysis environment, the team is collecting data, developing tools, and acquiring baseline/recommended methodologies to support the early cost estimator. The "Bin and Bump Up" and the "Jaccard Indexing and Weighting" methods are among the methodologies being researched. A long-term goal of the team is to better facilitate these approaches through intuitive toolboxes and automated frameworks that can reduce cycle time for an early cost estimate. Clearly, there is much left to be done as we seek to alter the present cost-estimating paradigm to address a more fiscally-demanding and technically-advanced acquisition environment.

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