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# Toward Affordable Systems

Portfolio Analysis and  
Management for Army Science  
and Technology Programs

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Brian G. Chow, Richard Silbergitt, Scott Hiromoto

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## Summary

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The Army Modernization Plan states:

Historically, almost 70 percent of a system's total costs were incurred once the system had entered the operations and sustainment phase. As a result, decisions made during design and development place an enormous impact on the overall cost, sustainment, and readiness of items introduced into the Army inventory (U.S. Army, 2006, pp. 26–27).

This plan calls for the consideration of the lifecycle cost of a system during its design and development stage. Studies have shown that on average, 85 percent of lifecycle cost decisions have been made by the end of technology development. This fact raises the concern that, after the S&T phase, one cannot change the basic design to significantly reduce a system's lifecycle cost, further emphasizing the need to consider lifecycle cost at an early stage.

The current method used by the Army Deputy Assistant Secretary for Research and Technology to evaluate ATOs does not include lifecycle cost. Thus, the purpose of this study is to develop and demonstrate a method and a model that allow the consideration of lifecycle cost at an early stage of a system's development, so that timely corrective actions can be taken if lifecycle cost moves above an acceptable level. In addition to the incorporation of lifecycle cost, the method is aimed at alleviating the problem of summing or comparing “apples and oranges” that often occurs when ranking S&T projects. Typical schemes used in the Army S&T community for selecting or ranking S&T (or other) projects sum an individual project's contributions to meeting several different future capability requirements. This traditional approach to ranking runs the risk of having projects scored high and selected for continued funding, even though their high scores may all come from meeting the same FOC requirements. A portfolio of such highly ranked projects can leave the requirements unmet for the rest of the equally important FOCs.

In addition to introducing a new method, the study also demonstrates how input parameters, including cost components, can be estimated. However, the Army S&T and acquisition community will very likely have much better data and can more easily

and accurately make cost estimates. Readers who do not desire to use our cost estimation approaches may still find our analytic framework necessary in dealing with the aforementioned shortfalls currently encountered.

This study takes advantage of the RAND PortMan research and development (R&D) portfolio analysis and management method, which has been under development and improvement since 2002. In addition to consideration of lifecycle cost and insistence on meeting all FOC requirements individually, we have developed a linear programming model for selecting an optimized portfolio of ATOs that can meet all the FOC requirements at the lowest total remaining lifecycle cost.<sup>1</sup>

## Method and Model

The genesis of this method is the RAND PortMan R&D portfolio analysis and management method, which is based on the determination of an expected value (EV) of R&D projects and portfolios. While the previous versions of PortMan, developed for the U.S. Department of Energy and used for Navy applied research programs, allowed detailed comparisons of R&D projects and provided guidance for the portfolio manager relevant to how to manage the R&D portfolio to maximize EV, investment strategy decisions were based on EV alone, with cost considerations based on the EV analysis introduced *ex post facto*.

In this monograph, we describe a variant of PortMan that uses a linear programming model to select a portfolio that consists of ATOs, the highest priority Army S&T projects. This portfolio satisfies the Army's FOC requirements designated for this group of ATOs to meet, while yielding the lowest total remaining lifecycle cost for all the systems developed from the selected ATOs. Our model includes two classes of constraints. First, all individual FOC requirements must be fully met. Second, the total remaining S&T budget<sup>2</sup> for the selected ATOs must not exceed a given budgeted amount that the Army can afford or is willing to pay. As a key application of this model, the budgeted amount was varied to study the relationship between the "affordable" total remaining S&T budget and the "affordable" total remaining lifecycle cost of the systems deployed. The result is that, in some cases, the Army may want to increase the total remaining S&T budget in order to significantly lower the total remaining lifecycle cost. Because the total remaining S&T budget is only a small portion of the total

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<sup>1</sup> Total remaining lifecycle cost is (1) the future lifecycle cost that still has to be paid in order to complete the selected ATOs and to develop and demonstrate the new systems derived from the ATOs and (2) the cost difference between (a) acquiring units of these new systems over a 20-year acquisition period and in operating and maintaining them over their lifetimes and (b) those of the legacy systems. The total does not include past lifecycle cost, which is already spent and should not enter into future decisions.

<sup>2</sup> Total remaining S&T budget is the future S&T budget required to complete the S&T projects (ATOs) selected for the portfolio. It is part of the total remaining lifecycle cost.

remaining lifecycle cost, some S&T projects, although they have high remaining S&T cost, can yield systems that are significantly cheaper to develop, demonstrate, acquire, operate, and maintain—thus lowering the total remaining lifecycle cost far more than the increase in the total remaining S&T budget required to fund these projects.

## Inputs to the Linear Programming Model

The linear programming model used here requires two inputs: (1) the EV of the ATOs and (2) the remaining lifecycle cost of the systems that will be developed from the ATOs. The data that we used to estimate the EVs of the ATOs were derived from the 2006 Defense Technology Objectives (DTOs), which were the latest available during the time of our study. DTOs are updated regularly on the Web by the Director of Defense Research and Engineering. All of the ATOs we chose for this example application of our method and model were also DTOs. We selected ATOs that are also DTOs for this study because more data are available on DTOs.

We have developed an approach called “gap space coverage” to make EV estimates of how well each ATO could meet FOC sub-requirements defined by the U.S. Army’s Training and Doctrine Command. This approach is based on the multiplication of three factors: (1) how many situations encountered by warfighters to which the system derived from the ATO can make a contribution, (2) the size of the gap space in an FOC that the system can help fill, and (3) the size of the contribution that the system can make to filling the gaps.<sup>3</sup>

To estimate remaining lifecycle cost, we started with the remaining S&T cost from the DTO data sheets. We then estimated the System Development and Demonstration cost from the same costs of comparable existing systems. Finally, we added the marginal cost over the legacy system, which is the cost of the new system minus that of the existing system it replaces. This cost has three components: (1) acquisition, (2) upgrade, and (3) operating and maintenance.

## Applications to S&T Portfolio Management

For the demonstration of our method and model, we chose the 29 Army ATOs that are DTOs (as mentioned above). Since these ATOs are only a small subset of the 172

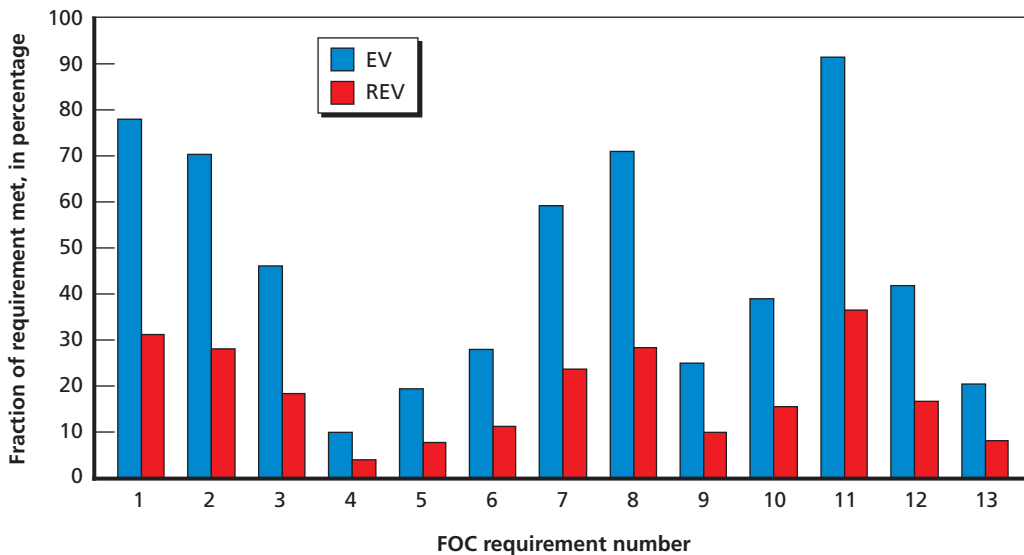
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<sup>3</sup> However, it should be emphasized that this study focused on methodology development. To demonstrate the methodology, we took a retrospective look at how well a small subset of the 2005 ATO projects could meet a hypothetical set of gaps, which we assumed occurred in every FOC requirement and sub-requirement. In other words, the study did not use data on real capability gaps and provided no information on how well the Army S&T portfolio meets the actual gaps. Moreover, since the ATOs were evaluated against hypothetical gaps, one should not draw any conclusions about the merits or drawbacks of any specific S&T project discussed in this study in meeting real Army capability gaps.

existing ATOs, one should not expect this subset to meet 100 percent of each of the FOC requirements. Based on a rough linear approximation, we assume that these 29 ATOs should be required to meet their fair share of 17 percent (i.e.,  $29 \div 172$ ) of the requirements (required expected value [REV]). In fact, as shown by the blue bars in Figure S.1, these 29 ATOs together have the potential to meet on average 46 percent of the FOC requirements, well exceeding their 17 percent “fair share,” which would have been achieved at 37 percent (i.e.,  $17 \div 46$ ) of the actually achievable 46 percent. In this study, the 37 percent is rounded to 40 percent, which is then used as the FOC requirement level that any portfolio of ATOs selected from the 29 ATOs is asked to meet. Additionally, if the systems derived from all 29 ATOs were fielded, they would produce extra capabilities above the capability requirements, as indicated by the red bars in Figure S.1. The difference between the blue and red bars indicates the depth of the ATO pool.

To rank the existing ATOs according to their importance in meeting FOC requirements, we defined the blue bars in Figure S.1 as the achievable EVs that all 29 ATOs together can attain. We then applied our linear programming model to select a subset of these 29 ATOs that meets the REVs, so that the total remaining lifecycle cost is minimized. Results are shown in Figure S.2, where the reference requirement (RR) is 40 percent of achievable EVs. Because the future Army budget for total remaining lifecycle cost and the future strategic environment are uncertain, the requirement may turn out to be higher or lower than the reference. For example, slower economic

**Figure S.1**  
Achievable and Required Expected Value for 29 ATOs





ranked high and protected. Since 1988, the annual defense budget has fluctuated 29 percent above and 21 percent below the average. Because we use a weapon deployment period of 20 years, the uncertainty in a budget and a requirement averaging over a 20-year period is likely to be smaller than the annual uncertainty, and we assume it to be 20 percent. At the reference requirement of 40 percent, this represents a potential range of 32 percent up to 48 percent. The question can therefore be stated as follows:

Given a reference requirement of 40 percent, when the FOC requirements are set at 0.8 (i.e., 32 percent), 0.9 (36 percent), 1 (40 percent), 1.1 (44 percent), and 1.2 (48 percent) of the reference requirement, which ATOs are selected most often for these five cases in order to yield the least total remaining lifecycle cost?<sup>4</sup>

Those ATOs selected most often are most important because no matter what the future will be, they are needed to result in the lowest total remaining lifecycle cost.

In Figure S.2, a green cell indicates that an ATO was selected under the particular FOC requirement. A red cell indicates that the ATO was not selected. ATOs 1, 5, 15, 16, 19, 20, 23, 25, 26, and 29 are always selected under every requirement level. They are the highest ranking ATOs and should be best protected in the event of a budget cut. ATO 10 is selected twice, while ATOs 4, 13, 21, and 27 are selected once. These ATOs are still needed in some future possible requirement levels. In order to meet the requirements at all levels at the lowest total remaining lifecycle cost, as the second- and third-ranked ATOs they should be protected as well. The rest of the 29 ATOs are never selected. In this study, all ATOs are assumed to be successfully completed if they are funded until completion. This assumption implies that there is no need for any backup ATOs, since the selected ATOs will not fail. In our ongoing work, all ATOs are assumed to have a possibility of failure, and we examine the possibility of ATOs that are never selected here serving as backup in the event that the selected ones fail.

We have conducted two sensitivity tests. The first one looks at a future in which the Army requirements are more uncertain. The model shows which additional ATOs should be funded to completion in order to be able to meet a wider range of future requirements. The second one studies whether rougher-grain cost data (grouping our costs in dollars into seven levels) would lead to different model results. We found that the project selection is identical to that in Figure S.2. This suggests the usefulness of a much quicker and easier Delphi method<sup>5</sup> for cost estimation.

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<sup>4</sup> The reference requirement refers to the 13 REVs (red bars) in Figure S.1. At 0.8RR, we mean that all 13 individual requirements are reduced by 20 percent or set at 80 percent of the reference REVs.

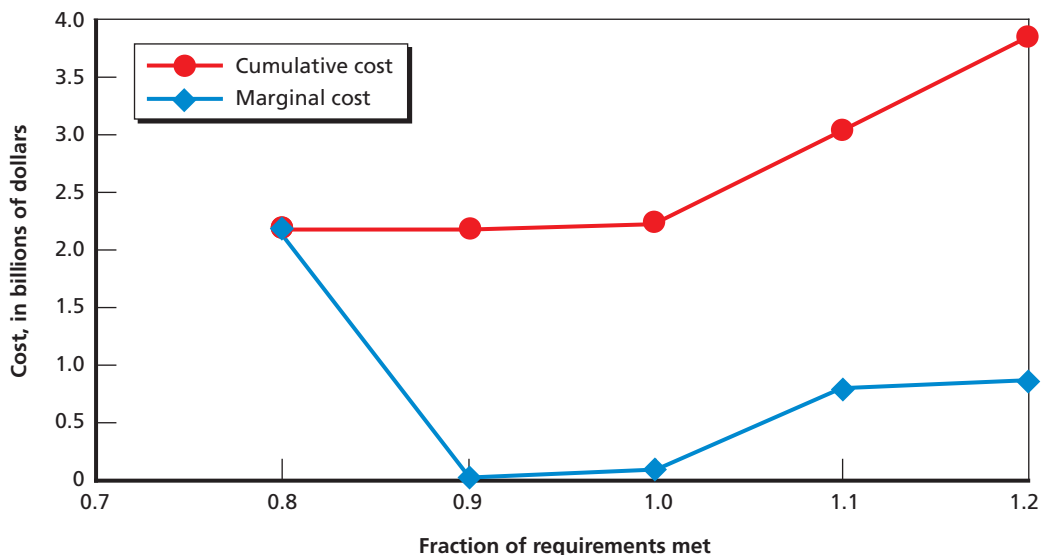
<sup>5</sup> The *Delphi method* uses a panel of experts to answer questionnaires or to grade parameters in two or more rounds. After each round, an anonymous summary of the experts' answers from the previous round is provided to all participants, who are encouraged to revise their earlier individual answers in view of the group's answers.

Our model demonstrates that the total remaining lifecycle cost required to meet marginal increases in FOC requirements is non-linear. The blue line in Figure S.3 shows the marginal cost to meet FOC requirements at four 10-percent increments. It takes \$2.1 billion to meet 0.8RR (i.e., the first 80 percent of the reference requirement). However, the cost allocated to meet 0.8RR also meets the next 10 percentage points of the requirement (0.9RR), representing a marginal cost of zero dollars. As the requirement increases at equal 10-percent increments from 0.9RR to RR to 1.1RR and 1.2RR, marginal increases in total remaining lifecycle cost are \$53 million, \$780 million, and \$830 million, respectively—in a non-linear fashion.

This non-linearity in meeting the four 10-percent increments from 0.8RR to 1.2RR is due to the complicated interplay of two factors. First, all else being equal, the model selects ATOs that can develop systems to meet the requirements most cheaply. Second, adding an additional ATO can sometimes meet requirements in larger chunks than the 10-percent increment. For example, the group of ATOs selected by the model to fulfill the first 80 percent of the reference requirement also fulfills the first 90 percent of the requirement without needing any additional ATO or funding.

Acquisition planners need to pay attention to this non-linearity of cost when they are asked to estimate the change in total remaining lifecycle cost to meet increased or decreased FOC requirements. A good decision hinges on knowing not only the change of requirement, but also the change in lifecycle cost to meet the changed requirement.

**Figure S.3**  
Remaining Lifecycle Cost for Four 10-Percent Increases in Requirements



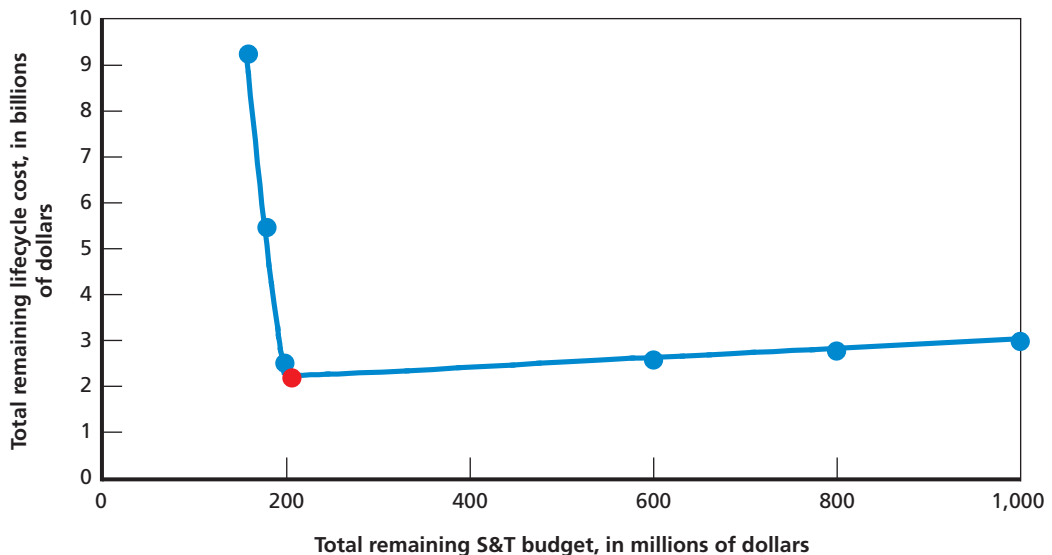
For example, if the additional lifecycle cost to meet a large increase in FOC requirements is low, acquisition planners are more justified in seeking the added funds. On the other hand, if only a small savings in lifecycle cost would result from a large reduction in FOC requirements, the acquisition planners also need to make this situation known to the Army's senior leadership so that the same message can be conveyed to the Secretary of Defense and the legislators in order to avoid a large reduction in the requirements.

Our model also allows examination of the important relationship between the total remaining S&T budget and the total remaining lifecycle cost. Figure S.4 shows this relationship, where the total remaining S&T budget is that required to complete the ATO projects in the portfolio selected to meet all individual FOC requirements (the red bars in Figure S.1) at the lowest total remaining lifecycle cost. In this case, the model selects 11 of the 29 ATOs, with a total remaining S&T budget of \$206 million and total remaining lifecycle cost of \$2.2 billion. Figure S.4 shows that the total remaining lifecycle cost increases sharply if the total remaining S&T budget is reduced from \$206 million only slightly. The cause for this sharp rise is that a smaller total remaining S&T budget forces one to choose cheaper ATOs, although these ATOs would develop systems that are a lot more expensive to field and operate, and they consequently increase the total remaining lifecycle cost sharply. For example, when the total remaining S&T budget is limited to \$159 million, the total remaining lifecycle cost rises from \$2.2 billion to \$9.2 billion. In other words, in our demonstration case, saving \$47 million in remaining S&T funds in the near term would cause the Army to pay \$7 billion more in total remaining lifecycle cost in the long term. This drastic outcome results from the fact that the total remaining S&T budget is typically a very small fraction of the total remaining lifecycle cost. Our model demonstrates the existence of an optimal level of the total remaining S&T budget, and the importance of maintaining the budget at this optimal level. Such a curve (as in Figure S.4) would provide the Army with an important guidance in the proper allocation of funds between total remaining S&T activities and other expenditures, such as procurement of weapon systems.

Above we illustrated only some of the applications of our method and model. The following is a much more complete list:

- Determination of the extent to which the FOC requirements would be met if all existing ATOs were completed and their systems fielded. This allows the Army to trace the impact of ATOs on FOCs.
- Identification and introduction of new ATOs for which existing ATOs leave gaps in meeting FOC requirements.
- Determination of the subset of existing ATOs that can meet all individual FOC requirements at the lowest total remaining lifecycle cost. This determination is of particular interest to the Assistant Secretary of the Army for Acquisition, Logis-

**Figure S.4**  
**Existence of an Optimal S&T Budget**



RAND MG761-S.4

tics, and Technology and the Army Vice Chief of Staff, who co-chair the S&T advisory group that provides the final approval of S&T programs.

- Determination of the extent to which each of the individual FOC requirements is exceeded. This provides a safety margin beyond that already embedded in the requirement. The Army—in particular its Training and Doctrine Command; the Assistant Deputy Chief of Staff for Programs (Force Development); and the Army’s Research, Development and Engineering Command—need to know in which individual FOC requirements these extra safety margins will occur, because these are the requirements for which the Army can have extra capabilities without the need to develop additional costly ATOs and systems.
- Determination of the optimal distribution of funds across FOC requirements. We also found that distributing S&T funds and/or acquisition and operating funds evenly among individual FOC requirements is unlikely to be the least expensive way to meet FOC requirements.
- Determination of which set of ATOs should be ranked high and be protected from budgetary cuts. This set can yield the lowest total remaining lifecycle cost over a range of uncertain future requirements.
- Identification of cost and performance factors that prevent specific ATOs from being ranked higher in importance. Understanding these factors is useful to individual ATO program managers as they develop cost and performance targets.

The model determines the specific cost and contribution that an ATO needs to attain to move to a higher rank.

- Determination of the optimal level of the total remaining S&T budget to meet all of the individual FOC requirements at the lowest total remaining lifecycle cost. The non-linearity in the relationship between the total remaining S&T budget and the total remaining lifecycle cost makes this information critically important as the Army's leadership balances overall Army resource demands. We have found in our example demonstration that even a small cut in the total remaining S&T budget can lead to lifecycle costs in later years that are an order of magnitude or two larger than that of the cut. Also, in our example, a modest increase in the Army total remaining S&T budget can lead to a much larger savings in total remaining lifecycle cost.

## Recommendations

During this study, we developed a method and model that factors in lifecycle costs and meets the conditions of all individual FOC requirements. We also demonstrated how this method and model can be applied to designing, funding, and managing the Army's S&T portfolio so as to meet all the Army's FOC requirements at the lowest total remaining lifecycle cost. The next step is to apply the method and model to real-life cases. We recommend three action items for such applications:

1. The Army S&T community sets up a pilot program between the Warfighting Technical Council and the offices in charge of Army Technology Objectives to test the practicality and usefulness of our iterative procedure for better estimating an ATO's contributions to individual FOC requirements and its derived system's lifecycle cost. This pilot program, if successful, will be an important step toward the goal of meeting future capabilities at the lowest cost.
2. The Army S&T community sets up a pilot program to carry out the method, model, and estimation procedures proposed in this monograph. The pilot program can be based on all of the existing ATOs and should include the eight applications suggested in the previous section, plus the use of the much simpler Delphi method for estimation of rough cost levels. The use of a Delphi method may lead to a wider adoption of our model by various agencies in the S&T and acquisition community.
3. Since the method and model developed here are applicable to the portfolio management of Army programs at other than the S&T stage, the Army may want to apply the approach to, for example, the selection and management of its programs in the System Development and Demonstration stage. Other services and the U.S. Department of Defense (DoD) may wish to test our approach as

well, since they also need to consider individual capability requirements and the lifecycle costs of their programs at an early developmental stage.

In an ongoing follow-on study, we are expanding our method to incorporate uncertainties in S&T project successes with the objective of making the model a better reflection of the uncertain future. The ongoing study examines the impacts of uncertainties on such issues as the selection of ATOs that can meet FOC requirements over a wide range of uncertain futures. In other words, we want to describe how to select a portfolio of ATOs that is robust against uncertainties.

We believe that not only the Army but also the other services and DoD as a whole need to consider lifecycle cost at an early stage in the development of weapon and other systems in order to allow adjustments, where necessary, to achieve affordable systems that meet all individual capability requirements.