Systems Engineering and Program Management

Trends and Costs for Aircraft and Guided Weapons Programs

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Summary

Background

Sound cost estimates are essential to developing good budgets and policy decisions. Some recent RAND studies have looked at estimating techniques for the nonrecurring and recurring flyaway costs of military airframes and engines. This study extends the analysis into what are termed “below-the-line” costs.[1] Below-the-line costs include costs for such items as system test and evaluation, data, special test equipment and tooling, training, operational site activation, industrial facilities, initial spares and repair parts, and systems engineering and program management. These costs are not directly associated with the development or the production of the hardware end item. Nevertheless, they are important cost elements that are necessary for delivery of the complete end item to the government.

RAND began the investigation of below-the-line costs with a study of systems test and evaluation costs (Fox et al., 2004). As a follow-on to that earlier study, this study investigates cost-estimating techniques that can be used to estimate Systems Engineering and

[1] Cost estimates for the Department of Defense are usually structured around the product-centric work breakdown structure described in Military Handbook 881 (Mil-HDBK-881). The handbook provides a framework for categorizing program costs starting with the hardware and software costs directly associated with the end item and adding the below the line costs. Below the line costs derive their name from the fact that they are typically displayed in budget documents and cost estimates as separate cost elements below the hardware cost elements.

Program Management (SE/PM) costs for military aircraft and weapons systems in development and production.

Analysis Approach

Our approach to analyzing SE/PM costs was to first understand the nature of the content of the work that is performed in this area. We define what is involved in the systems engineering and program management disciplines from a general sense of what SE/PM is and describe the iterative process and tools (such as reviews and documents that are developed for a program) that are used in the field. The definition and processes provide a basis for understanding what makes up the scope of the SE/PM effort.

Our next step was to canvas government and industry personnel to learn about the current state of techniques used for estimating SE/PM and to gather data that could be used to investigate various aspects of SE/PM costs. We used a questionnaire, presented in Appendix C, and interviews with both government and contractor personnel to find out how they define SE/PM costs, what techniques they currently use to estimate SE/PM costs, and what they would consider potential cost drivers that could be used for predicting costs. To develop SE/PM cost estimating methods, we collected historical data from several aircraft and missile development and production programs. The data included historical costs, the schedule of major events in the program, and technical information from several aircraft and missile programs. Cost data were collected from a variety of government cost reports and internal contractor accounting reports on programs from the 1960s to today. These data were used to investigate trends in SE/PM costs over time and to generate cost estimating methodologies that cost analysts could use when little program information is available early in the lifecycle of a program.

Our last step was to investigate the effects of new acquisition initiatives on SE/PM costs. The three new acquisition initiatives we investigated were the removal of military specifications and standards, the use of integrated product and process teams, and the relatively new preferred acquisition approach of evolutionary acquisition. Each of these initiatives could affect SE/PM costs. We tried to determine whether the SE/PM costs for these types of programs were different enough from the SE/PM costs for traditional acquisition programs that some adjustment in cost estimating should be made.

Definitions and Methods

One of the complications in developing SE/PM estimates is determining what is included in SE/PM costs. We found that the definition used by the government, as spelled out in (MIL-HDBK-881) and excerpted in Appendix B of this report, covers tasks associated with the "overall planning, directing, and controlling of the definition, development, and production of a system . . . [but] *excludes* systems engineering and program management effort that can be associated specifically with the equipment (hardware/software) element." The exclusionary portion of the definition is difficult to implement because the systems engineering associated with a program is integral to the development of the hardware and software of the system.

When recording SE/PM costs that are incurred, contractors' accounting systems may not consistently address this exclusion in the SE/PM definition. After we interviewed multiple contractors and investigated their detailed internal accounting data, we found their costs under the SE/PM category were not always consistent (see page 54). Some of this difference across contractors was anticipated due to variations in accounting methods. We further found that even within a single company there were differences from one program to another as to what was classified as SE/PM costs (see page 57). Although these differences exist, based on an examination of detailed cost data, we believe that the main cost sub-elements that represent a large portion of the SE/PM costs are classified consistently across contractors and programs (see page 57).

Our discussions with government personnel and contractors revealed a variety of techniques for estimating SE/PM costs. In general, for aircraft programs that are early in their acquisition lifecycle, the government estimates SE/PM using a parametric approach applied at an aggregate level that includes not only the costs of SE/PM, but also includes the costs associated with hardware design. The parametric approaches rely on independent parameters that relate to the overall design of a system (i.e., weight, speed, first flight). This approach is consistent with the task of the government cost estimator—to generate a budget estimate that includes all expected costs, regardless of how they are classified. However, this high level of estimating does not allow for understanding the cost drivers specifically associated with SE/PM and how SE/PM costs are expended through a multiyear development program. This approach also makes it difficult to isolate SE/PM costs for any potential adjustments due to acquisition changes that may have a cost impact. The industry contacts we interviewed used a variety of techniques for developing SE/PM estimates, ranging from “top-down” models to “bottom-up” approaches. The type of model they use generally depends on the desired level of fidelity and level of detail of the estimate and on the maturity of the program. Top-down models typically use parametric approaches similar to those the government uses when little detailed information is known about a program. Bottom-up approaches are used as a program becomes more mature and better information is available that allows more-detailed comparisons with prior experiences.

Because our objective for this study was to develop methodologies that could be used to estimate SE/PM costs directly, we used statistical analysis to develop parametric cost-estimating relationships (CERs) for aircraft and guided weapons programs in development and production. We wanted our resulting estimating methods to utilize parameters directly related to SE/PM costs. Based on our interviews with contractor personnel and on previous cost studies, we generated a list of potential independent variables that could be logically related to SE/PM costs. Using step-wise and ordinary least squares regression analysis, we selected the best CERs most useful to predicting costs.

Finally, to determine if any adjustments to historically based CERs are required to account for new acquisition approaches, we compared the SE/PM cost data from selected sample programs that implemented the new acquisition approaches with the SE/PM cost data for the overall sample of similar programs. We wanted to see what, if any, differences arose in the SE/PM cost for these programs under acquisition reform as compared with other programs to determine if any changes to our estimating methods were necessary to take these new initiatives into account.

Results and Findings

We first examined historical SE/PM costs over time to determine what general cost trends seem to be occurring. As the basis for our quantification of SE/PM development costs, we collected data from a wide assortment of historical efforts including prototype development programs, full development programs, and modification programs. For production analysis, we also used data from several production lots from multiple programs. The data we gathered on aircraft and weapons programs from the 1960s up through recent years showed that SE/PM represents a significant portion of program cost and seems to be on the rise for aircraft development programs (see page 29). For aircraft development programs, SE/PM represents about 12 percent of the total contractor cost. For weapons development programs, the SE/PM percentage of the total cost is even larger—28 percent on average. We found the SE/PM cost split between systems engineering and program management is roughly 50/50 for aircraft programs and 60/40 for weapons programs (see page 34). SE/PM production data for aircraft showed a large amount of variation, while production cost for weapons seemed to more closely follow a traditional cost-improvement curve (also referred to as a learning curve) (see page 36).

Based on our interviews with contractor personnel and a review of prior studies of aircraft and weapons costs, we explored a set of independent variables that we believe could be related to SE/PM cost. Most independent variables fell into three categories: program scope variables, programmatic variables, and physical descriptor variables. Program scope is measured by the cost of the program less SE/PM costs in either development or production. Programmatic variables capture the duration of the effort (in the case of development programs) and quantity of items produced (in the case of production programs). Physical descriptor variables are generally weight based, except in the case of weapons for which diameter was also considered. In addition to these variables, for aircraft in development, we attempted to relate the amount of integration required (as measured by air vehicle cost divided by airframe cost) to the overall SE/PM cost. For weapons in development, we also considered programmatic variables to account for programs that were not traditional engineering and manufacturing development (EMD) programs (i.e., prototype programs or modification programs) and to account for changes over time (based on the contract award year). We were also sensitive to using independent variables that could readily be quantified by a cost analyst early in a program.

We found that for both aircraft and weapons in development, SE/PM costs were most directly related to the overall size of the program (as measured by development cost less SE/PM) (see page 79). In addition, we found that design duration (as measured by months from contract award to first flight) played a role in the SE/PM cost for aircraft development programs (see page 80). In looking at the funding profile of SE/PM costs, we found that about one-third of the total SE/PM cost is expended from contract award to critical design review, the second third of the SE/PM cost is spent from CDR to the first flight date, and the final third is spent from first flight to the end of the program (see page 82). Appendix F details techniques that can be used to time-phase SE/PM development cost estimates.

For both aircraft and weapons, we again determined that scope (as measured by the recurring unit cost of the aircraft or missile) was a significant factor in estimating SE/PM cost in the production phase of the program. In addition, we determined that the cumulative quantity and production rate were related to the unit cost of SE/PM in production (see pages 88 and 105). The ratio of the yearly lot size to the maximum lot size was found to be an independent variable that improved the predictive capability of our estimating equations (see page 93). The cost-improvement slopes, used for projecting yearly SE/PM costs, showed a large variation for aircraft programs, while the slopes for weapons were more tightly grouped (see pages 98 and 111).

Unfortunately, the large degree of variation in the data we used to develop these parametric estimating methods resulted in a large standard error for our estimating equations. We tried to further investigate what might be causing the variation, but were unable to identify any consistent cause. For example, in the case of aircraft production costs, we looked to see whether the high degree of SE/PM cost variability was related to the change in the aircraft model or to the introduction of foreign military sales. These two changes did not align with the fluctuations in the SE/PM cost data (see page 84). For these reasons, we conclude that the CERs we generated are most useful to a cost estimator in the early stages of a program's life cycle, when little is known about the program. When more detailed information is available, other techniques could be applied for developing more-accurate SE/PM estimates. For example, use of a direct-analogy approach in which a well-understood program is compared with a new program can lead to less variation in the final outcome and a better understanding of the specific cost drivers (see page 125).

Finally, we investigated the potential effect that new acquisition approaches, such as decreased use of military specifications and military standards, use of integrated product teams (IPTs), and the use of evolutionary acquisition, would have on SE/PM costs. Because there is not a long history of these types of programs, we compared the SE/PM costs of the few programs that have implemented these changes to the overall population of similar programs. We found that programs that minimized military specifications did not show a significant difference from the overall sample of programs, being within one standard deviation in SE/PM cost from the overall sample average (see page 114). For programs that used IPTs, SE/PM costs were either similar to or slightly higher than SE/PM costs for the overall sample of programs (see page 116). To determine the quantitative effect that evolutionary acquisition (EA) had on SE/PM costs, we analyzed SE/PM costs for a program that concurrently developed multiple variants as a surrogate for an EA program, and we found that it exhibited above-average SE/PM costs (see page 121). In addition, we investigated cost-estimating methodologies employed by one of the first programs to use EA. The cost-estimating technique used by one formally designated evolutionary acquisition program suggests that two areas of SE/PM need to be estimated: the SE/PM cost associated with the specific capability increment or "spiral" and the "overlay" SE/PM cost that is concerned with development and production of the overall program (see page 120).

In conclusion, SE/PM costs are a large portion of the acquisition cost of military aircraft and guided weapons systems. In the case of aircraft, SE/PM costs appear to be rising over time. There are multiple approaches to estimating the cost of SE/PM, and each has advantages and disadvantages. We developed a set of cost-estimating relationships that can be used to specifically estimate the SE/PM cost element for development and production for both aircraft and weapons programs. However, the production CERs we generated were not as good as the development CERs at explaining the variation in the historical data. Finally, we found that implementation of new acquisition approaches had mixed results in changing SE/PM costs.