Evaluating Affordability Initiatives

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In today's defense acquisition climate, the affordability of weapons system development is an important consideration. One way defense contractors are approaching affordability is by introducing "affordability initiatives" into their program development plans. The Laboratory worked with the Joint Strike Fighter Program Office's Advanced Cost Estimating Integrated Product Team to develop a method to assess these initiatives. The process focused on evaluating the risks of each initiative, with results providing inputs to government cost estimating models. (Keywords: Affordability analysis, Cost estimation, Joint acquisition program, Joint Strike Fighter, Risk analysis.)

INTRODUCTION

The goal of the Joint Strike Fighter (JSF) Program is to develop an affordable strike aircraft for the U.S. Air Force, U.S. Navy, U.S. Marine Corps, and U.K. Royal Navy. Currently, two competing contractor teams are developing Preferred Weapon System Concepts. In each concept, the JSF Program Office has encouraged "affordability initiatives," i.e., product and process improvements that are significant departures from current practices and primarily intended to generate cost savings. Challenges facing the JSF Program Office include measuring the impact of each initiative on program life-cycle costs and assessing the degree of risk associated with new processes and procedures. The Program Office's Advanced Cost Estimating (ACE) Integrated Product Team (IPT) collaborated with APL and MCR Federal, Inc., to develop and apply a systematic methodology to meet these challenges.

During the program's Concept Demonstration Phase, the methodology has been carefully applied by the APL/Program Office team to estimate the impacts of these initiatives and to track and judge their progress. As the JSF Program moves toward its Production Phase, APL will continue to work with the Program Office to adapt and develop methods that will provide more realistic cost estimates and concomitant increased insight into system design trade-off and programmatic decisions. The method presented here has advantages over previous practices and meets the current requirements of the ACE IPT. However, the evaluation process is still evolving; the method is continually reviewed, assessed, and revised to ensure its relevance. The Laboratory has worked with the ACE IPT throughout the process to adapt the methodology to best suit their requirements. This article describes the formulation, development, theory, implementation, and adjustment of the process with which the JSF Program Office is evaluating and "valuing" each contractor's affordability initiatives.

Because affordability analyses require a much broader view than traditional cost estimating offers, they must be based on the combined judgment of personnel representing many different areas of expertise. APL provided the right combination of technical and practical experience to merge the various inputs into coherent presentations, facilitate discussions and assessments of issues, and apply results to government cost estimation models.

THE JSF PROGRAM AND GOALS

The JSF Program is defining the next generation of strike aircraft. Three variants are planned: (1) a conventional take-off and landing variant, (2) an aircraft carrier-based variant, and (3) a short take-off, vertical landing variant. Applying a strategy/task/technology process, the program integrates users and developers to define affordable, effective solutions.

Between 1994 and 1996, the JSF Program Office identified design characteristics, specified support and training concepts, and defined comprehensive plans for flight and ground demonstrations. An important result of this phase was the determination that a high degree of airframe and system commonality was possible and could lead to significant reductions in production and life-cycle costs. A summary of the JSF Program through this phase was presented in a previous issue of the *Technical Digest*.[1]

In November 1996, the Concept Demonstration Phase of the JSF Program began. Two contracts were awarded, one to Boeing and one to Lockheed-Martin, to demonstrate their respective concepts. Figure 1 illustrates each contractor's current Preferred Weapon System Concept. After the selection of the best concept in FY2001, the Engineering and Manufacturing Development Phase will begin. As concept demonstration proceeds, the JSF Program Office will require a means to independently assess the programmatic and technical impacts of the proposed affordability initiatives.

Affordability Initiatives

Contractor-proposed improvements may be characterized as either product or process improvements. Product improvements adapt new manufacturing methods or materials to enhance the final product and usually require commitment early during the aircraft's design. Process improvements involve changes in detailed production plans and workflow. A full understanding of the impact of these improvements requires an extensive analysis of processes, equipment, machines, and personnel skills.

Figure 1. Concepts of the JSF Weapon System developed by Boeing (top) and Lockheed-Martin (bottom).

Boeing and Lockheed-Martin have proposed both product and process improvements. Some reflect the current momentum of change within the aerospace industry and can be accounted for in historical trends and traditional cost estimating models. Others are substantial departures from past practices, bolder proposals that purport to significantly reduce development, production, and operational costs. The latter group best fits the term affordability initiatives.

To capture industry trends, early top-down cost estimates have typically been based on historical data from a range of similar programs. However, because of the nature of these bolder initiatives and the early stage of the JSF Program, typical cost estimating relationships that are built using data from historic tactical aircraft programs fail to adequately capture their value. To properly assess them, a new procedure was needed, one that would provide a systematic evaluation of significant departures from traditional practices but would remain compatible with traditional cost estimation methods and structure. Since development of the JSF aircraft will evolve over several years, the process also had to allow for periodic review and reassessment of the initiatives.

Assessment Methodology

The analysis process (Fig. 2) was designed to elicit objective assessments from government subject-matter experts, to document their rationale and areas of concern, and to maintain fairness and consistency. It combines the judgments of subject-matter experts with formal analytical reviews and provides a means for inputting these judgments into the traditional cost estimation tool used by the JSF Program Office. Throughout each cycle, consistency checks are used to evaluate the reasonableness of the results. Because of the competitive nature of this phase of the program, one requirement has been to ensure the protection of each contractor's proprietary information. For this reason, each initiative was analyzed independently, and results were published separately.

The evaluation process logically divides into two aspects: an assessment of likelihood or probability of success (P_s) and an assessment of the value (i.e., dollar savings to the program life cycle) or consequence of success (C_s) to be realized. The use of P_s and C_s was a conscious decision, reflecting the success-oriented nature of contractor plans for each affordability initiative. The risk associated with developing and implementing each initiative was evaluated with the rationale that an examination of risk factors would provide insight into its likelihood of success P_s. For C_s, the contractors' savings claims were subjected to a "reasonableness assessment" since detailed data on which to base estimates of savings were not available at this early stage.

To develop the assessment methodology, the subject-matter experts proceeded in two steps: (1) performing a risk assessment for each initiative and (2) later incorporating risk evaluation into cost models for "valuing." The first step required the development of a risk model, a weighting scheme to evaluate each initiative's P_s, and data collection. The APL Warfare Analysis Laboratory (WAL) provided an open-seminar, group-meeting atmosphere conducive to accomplishing the goals for this analysis. The effort culminated in separate WAL Exercises (WALEXs) with the participation of subject-matter experts drawn from the JSF IPTs to review each contractor's initiatives. Displays allowed a quick review of contractor inputs, other reference materials, and WALEX progress and results. The WAL's Electronic Seminar Support System recorded each participant's comments for additional documentation of results. The WALEXs are detailed later in this article.

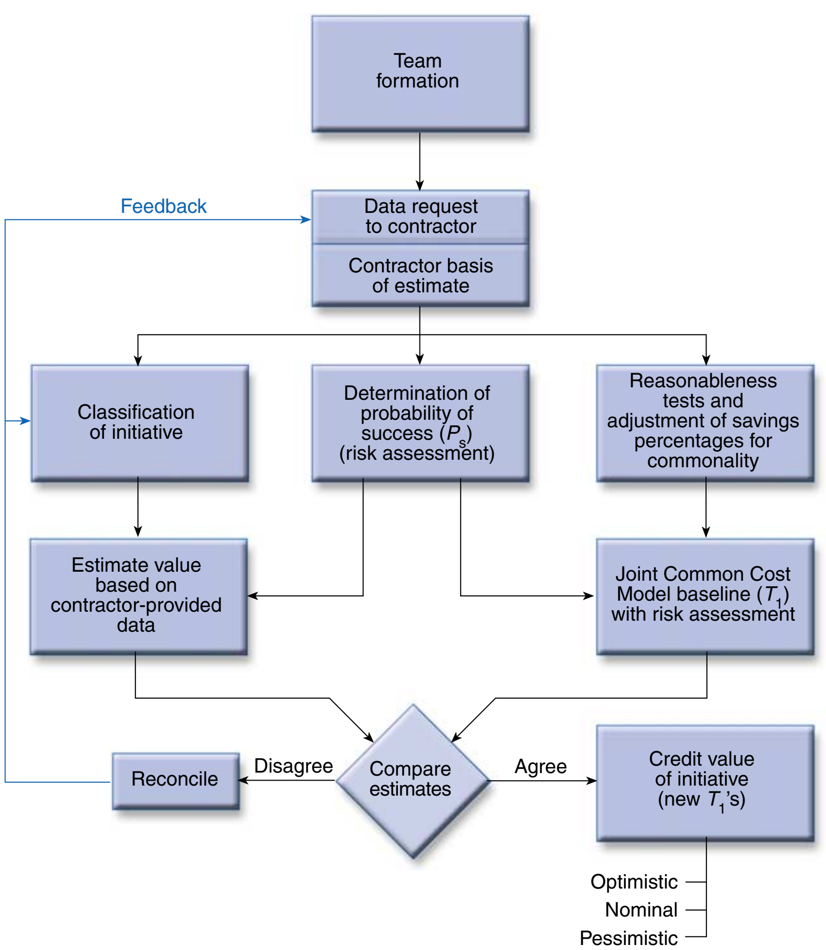

Figure 2. Affordability initiative evaluation process (T_1 = theoretical cost of the first unit.)

DEVELOPING THE MODEL

In September/October 1997, a series of meetings was held for participants during the first round of evaluations. The process developed was a blend of DoD directive requirements, commercial best practices, and innovative ideas for problem solving. Submissions from each contractor provided a baseline. Descriptions of affordability initiatives received "quick-look" reasonableness assessments, and those deemed appropriate were classified into logical groupings. Each initiative was further divided into a risk evaluation (the primary focus of this article) and an assessment of cost implications, to be performed both analytically and via the JSF Program Office's Joint Common Cost Model.

The basic structure of the risk evaluation was adapted from the

Defense Systems ManagementCollege (DSMC) Risk Assessment Model,[2] which divides the overall probability of failure (P_f, the complement of P_s) into three main factors: process maturity, process complexity, and dependency. The first two are further divided into several subfactors, while the dependency factor is intended to account for interrelationships among subfactors. Although the model was a reasonable starting point, and in line with DoD 5000 Series guidance, its detail failed to fully address the needs of the JSF Program (its subfactor category definitions were too general). Since the Program Office must address specific subfactors that focus on airframe materials and manufacturing processes, a more detailed description of subfactors was developed, and specific operational definitions for each were evolved with concurrence of the JSF Airframe Structures and Manufacturing IPTs.

The dependency factor was removed from independent consideration owing to a lack of information regarding either contractor's management structure for their affordability initiatives. However, the resulting process implicitly considered dependency in two ways: (1) overlapping initiatives were identified, and "double-counting" was eliminated during initial classification; and (2) the structure of the algorithm's underlying calculations within the cost model was examined. Thus, the modified risk model used in this assessment had two main branches: maturity and complexity.

Four subfactors covering airframe materials and manufacturing processes were identified as critical within the maturity area: the state of the technology, the design and engineering effort, the manufacturing process, and resource availability. The complexity factor was divided into two subfactors: developmental complexity and implementation complexity. These subfactors represent a further departure from the DSMC risk model, but focus on areas critical to the JSF Program for the success of affordability initiatives.

Once this structure was defined, the most critical phase in developing the process began: establishing operational definitions for each factor and subfactor. This step required the careful translation of qualitative judgments onto a quantitative scale. Significant effort was made to ensure that definitions used for each factor and subfactor were as specific as possible, without being too restrictive. Several meetings with various IPT members were needed to reach final agreement on specific definitions of risk levels for each maturity subfactor. Alternatives for a more objective analysis of the complexity factors were also examined, but later rejected; the lack of detailed contractor input on plans for managing the development and implementation of the initiatives forced reliance on the generic scale of the DSMC model. Tables 1 and 2 list the final definitions for each subfactor. The development of clear operational definitions was extremely important, because a process requiring individual judgments and subjective assessments by a changing group of evaluators can be expected to produce some variability. Although variance can never be completely eliminated, the process discussed here and its documentation provide a means to identify, minimize, and manage uncertainty.

Definitions for maturity factors were considered carefully by IPT members. All scales range from very easy (a known, presently operational technology, design, or process) to extremely difficult (purely theoretical concept or laboratory research yet to be attempted in a production environment). The state-of-technology subfactor measures each initiative in terms of availability and promise of the technology required for success. Ability to attain the required level of technological sophistication within known schedule constraints, as well as hardware and testing maturity, is considered. The focus is on required hardware (or software, if appropriate), independent of its intended use in the production process. Although assessments were performed on a "system" basis, participants were also asked to consider and comment on the technological requirements of key subsystems. The scale ranges from technology that is already operational and deployed to that which still requires significant scientific research.

The design and engineering subfactor measures each initiative in terms of difficulty in advancing the state of the art to that required for the JSF Program. Thus, design and engineering focuses on implementation, separate from technology. For example, an item previously engineered and production-qualified may require extensive form, fit, and function changes or modifications for JSF application. Key subsystems are also considered. The scale ranges from off-the-shelf items meeting all requirements to ones requiring new, breakthrough design or engineering efforts.

The manufacturing process subfactor measures each initiative in terms of the process capability needed to produce required quantities for the JSF Program. Process attributes considered are metrics such as number of allowable defects, yield or throughput requirements, tolerance or precision requirements, overall process capability to be maintained, and allowable failure rates. Evaluation includes assessment of advances required to move from current to proposed manufacturing and assembly processes. The scale ranges from an existing demonstrated process that satisfies all key attributes to one that exceeds the state of the art for at least one key attribute.

The resource availability subfactor grades an initiative on the availability of all resource elements necessary for implementation at production quantities and rates specified for the JSF Program. Resources include parts or subassemblies, tools and fixtures, test equipment and facilities, personnel (including their skills and training

Table 1. Definitions of maturity subfactors.

Level	State of technology	Design and engineering	Manufacturing process	Resource availability[a]
A	Initiative presently operational and deployed	"Off-the-shelf" hardware requirements	Existing, demonstrated process	Readily obtainable through at least one source; successful past experience
B	Process in limited operation	Design required; existing components, specs	Modified; within demonstrated norms	All but one resource obtainable from at least one source
C	Process passed acceptance; approved for limited operation	Design required; beyond present specs	New combination of demonstrated processes	All but two resources obtainable from at least one source
D	Process passed qualification tests	Some development effort required	Demonstrated, but one key attribute new	More than two resources obtainable from at least one source
E	Process passed performance tests/in qualification testing	Moderate development effort required	Demonstrated, but two or more new attributes	Only one resource obtainable from at least one source
F	Process feasibility demonstrated	Major development effort required	New process; within state of the art	Resources have been specified
G	Prototype system tested; significant scientific research required	"Breakthrough" development effort required	New process; exceeds state of the art	Resources have not been specified

[a]Resources include tools/fixtures, test equipment, personnel, materials, and facilities.

Table 2. Definitions of complexity subfactors.

Level	Developmental	Implementation
A	Simple	Simple
B	Minor	Minor
C	Moderate	Moderate
D	Significant	Significant
E	Extremely complex	Extremely complex

levels), materials (quantity and quality), production equipment and facilities, and funding. The scale ranges from all required resources being readily available through at least one dependable source to an initiative for which resources have not yet been specified.

GATHERING THE DATA

Once the risk assessment structure was in place, the gathering and organization of initiative-specific data commenced. In early October 1997, each contractor was asked for additional data on selected initiatives. Later that month, fact-finding trips were made to their main facilities. The visiting team included personnel from the JSF Airframe Structures, Manufacturing, and ACE IPTs, plus Defense Contract Management Command plant representatives. Based on initial lists of initiatives and other data provided by the contractors, Program Office IPT leaders chose their most qualified people to participate on these trips. Both visits included briefings by the contractors on proposed initiatives, the bases of their cost and savings estimates, and discussions with technical and managerial representatives. At this stage, the intent was neither to be critical nor skeptical of the contractors' claims, but only to ensure a clear understanding of each proposal. In many cases (but not all), the same IPT representatives visited each contractor for these data gathering meetings, helping to ensure continuity and consistency in evaluation.

As noted earlier, maintaining fair competition between contractors throughout the competition phase is vital to the source selection process, of which this analysis is but one part. Consistency and fairness have been maintained by (1) depending on a core team of individuals throughout the process, (2) evaluating the contractors during the same time frame under the same ground rules, (3) using the same model having a structure that is well known to both contractors, and (4) providing immediate feedback to contractors in the form of "reconciliation" meetings that address differences between contractor and government assessments.

Following data gathering activities, an initial "weeding out" process was completed. Some initiatives were judged infeasible and eliminated from consideration. As described earlier, contractor claims and bases of estimates for those initiatives remaining were carefully examined to eliminate areas of overlap, double counting of savings, or credit for savings already captured by present cost estimating models. The candidate list also incorporated specific requests from several IPTs for coverage of initiatives that did not lend themselves to typical manufacturing direct labor cost reduction. Specifically, the JSF Modeling, Simulation, and Analysis IPT requested that at least one initiative per contractor contain an advanced application of modeling and simulation. After this consolidation process, lists were separated and classified according to manufacturing area, estimated value, and primary areas of savings impact.

At this stage, the classification of initiatives relies primarily on the judgment of subject-matter experts in the study group. In subsequent evaluations, as detailed engineering estimates become available, this judgment will become more quantitative. Assuming that reasonable progress is made (and demonstrated), data updates will increase the confidence of subject-matter experts and improve P_s.

WAL Sessions

The first round of evaluations consisted of two meetings at APL's WAL during November 1997. The objectives were to record the qualitative assessments of subject-matter experts, document areas of concern for attention in follow-on reviews, and combine opinions to develop an estimate of P_s for each initiative. Electronic seminar support facilities in the WAL enable participants' opinions, comments, and votes to be gathered via a network of computer terminals during open discussion of issues. Individual inputs were recorded and preserved for further analysis. The agenda for these meetings included

- Presentation of technical and financial summaries on each initiative, including a contractor-claimed savings estimate and its basis
- Discussion (covering technical and financial issues) of each initiative
- Collection of comments and concerns from each participant
- Evaluation of each initiative's maturity and complexity subfactors, using rating scales previously described
- Comparison (pairwise) of maturity and complexity factors and subfactors for ranking the relative importance of each
- Combination of individual assessments to obtain a "group consensus" for each factor, and computation of a final P_s
- Discussion of any inconsistencies and clarification of disagreements or misunderstandings among participants

Risk Assessments

After review and discussion of an initiative, participants input their qualitative judgments by systematically voting on each maturity and complexity subfactor. The weighted mean of votes, as input into a derived probability distribution function, provided a nominal P_s value for each subfactor. Probability distribution functions were developed on the basis of relative rankings and yielded a highly nonlinear scale that differed from the DSMC method. Nonlinear probability distribution functions afforded preference to "known quantities," in keeping with the JSF Program objective of entering the Engineering and Manufacturing Development Phase in a "low-risk" status. Contractors were not discouraged from proposing new or innovative ideas, but cost savings credit was not given without demonstrated progress toward a reduced risk solution.

During these WALEXs, the immediate display of voting results helped identify areas of disagreement among participants. If required, these were examined and discussed to ensure a full awareness and understanding of all issues. A discussion often resulted in changes of opinions, and participants were allowed to adjust their votes. Although areas of disagreement were revisited in this manner, there was never pressure to force complete consensus. Differences were expected as part of the evaluation process. If consensus was not reached, results were carried through, with each participant's opinion receiving equal weight. These differences made up the "delta" or uncertainty in estimates of probability of success ΔP_s. Areas of controversy were highlighted and will receive special attention in follow-on data requests to contractors and in reevaluation sessions. The ability to do real-time identification and reassessment of controversial issues is a significant strength of the WAL's seminar support tools.

This method has also been adapted for a "paper-copy" variation in which evaluation and voting processes are completed individually or in small groups. The variation was tested when it was inconvenient to bring together the full group of experts for evaluations. Using secure means, reference materials and voting sheets were transmitted to personnel at remote locations for assessments. This mode loses the advantages of real-time discussions and detailed documentation, but has proven an acceptable alternative.

The participants use Team Expert Choice software,[3] which employs the Analytic Hierarchy Process (AHP)

Method[4] to estimate the relative importance of each subfactor. AHP is a well-known and useful tool for problems requiring decision making that involves multiple attributes and uncertainty. It allows evaluators to break the problem down into manageable segments, address specific aspects of each segment, and create a relative ranking scale of the subfactors. Each participant makes pairwise comparisons between all possible combinations of subfactors, and the "weight" of each subfactor's impact on overall P_s is calculated via the AHP method. These weights become coefficients a through f in Eq. 1.

Team Expert Choice combines participants' qualitative judgments into a single matrix representing the group's judgment. Automated computations identify any inconsistencies not apparent by inspection. As part of the procedure, a further detailed analysis was performed to check each participant's consistency. Surprisingly, for such a complex problem, instances of inconsistency proved rare. The P_s value for each subfactor was then weighted using the group's pairwise comparisons (coefficients in Eq. 1). In future evaluations, pairwise comparisons will be re-voted to determine any changes in their relative importance. Thus, P_s is computed as a function of six subfactors:

$$P_s = aP_T + bP_{D\&E} + cP_P + dP_R + eP_D + fP_I \,, \qquad (1)$$

where

P_T = probability of success for the state-of-technology maturity subfactor,
$P_{D\&E}$ = probability of success for the design and engineering maturity subfactor,
P_P = probability of success for the manufacturing process maturity subfactor,
P_R = probability of success for the resource availability maturity subfactor,
P_D = probability of success for the developmental complexity subfactor,
P_I = probability of success for the implementation complexity subfactor,

and, again, the coefficients are associated weight factors determined by AHP pairwise comparisons. This use of AHP is typical of the type of problem for which the process was designed.[5]

The final output of this group decision process is P_s (Eq. 1) and a range of uncertainty ($\pm\Delta P_s$) for each initiative. The determination of ΔP_s is based on the variance of subject-matter experts' voting distributions during the rating of each subfactor. The uncertainty for each subfactor is combined via root sum squares to yield the overall ΔP_s. An assumption of statistical independence among initiatives is reasonable because of the study's preliminary weeding out process.

The JSF Program's Joint Common Cost Model

Once an estimate of P_s for each initiative was developed, the next step was to settle on a dollar value associated with the initiative C_s, i.e., an "expected value" for each initiative. During concept demonstration, aircraft design is in its early stages, and detailed data on processes and parts potentially affected by proposed initiatives are not available. To continue the evaluation process, results of evaluations were incorporated into a parametric cost estimating model called the Joint Common Cost Model (JCCM).

The JCCM was developed by the ACE IPT to estimate the costs of various aspects of the program. Initially, DoD-approved commercial software was used to develop investment estimates. As a further refinement, the ACE Team developed the Excel-based JCCM, which incorporates traditional "cost driver" areas, but also permits isolation of and focus on specific areas of interest and uniqueness to the JSF Program. For example, although initial calculations use traditional cost estimating models built from an approved database, adjustments are made for technical and programmatic factors unique to JSF. Significant attention is given to design commonality among the JSF variants and its effect on affordability. The Work Breakdown Structure (WBS) used to develop baseline cost estimates is shown in Fig. 3. Within the JCCM, each WBS element is modeled individually. Element cost estimates are rolled up into primary WBS areas of the model, which are categorized as airframe, armament, avionics, and propulsion.

JCCM AFFORDABILITY INITIATIVE MODULE DEVELOPMENT

The Affordability Initiative Module was developed for JCCM to permit continuous reassessment of contractor initiatives as they progress through the development cycle. The module can accept new or follow-on initiatives as they become available, and is only limited by constraints of the basic JCCM cost category structure, which is quite extensive. Adjustments to the JCCM baseline separate and track each initiative and incorporate its impact into the overall estimate.

The JCCM also incorporates the latest updates from government-generated weight-and-commonality assessments, based on the latest contractor design information. An applicability matrix allows the distribution of an initiative's percentage savings to appropriate categories of the production labor effort. Currently, these categories include engineering, tooling, quality control, and manufacturing. The manufacturing category is broken down further into fabrication, assembly, mate/splice, and ramp labor.

In initial evaluations, values contained in the applicability matrices were contractor-specified in their

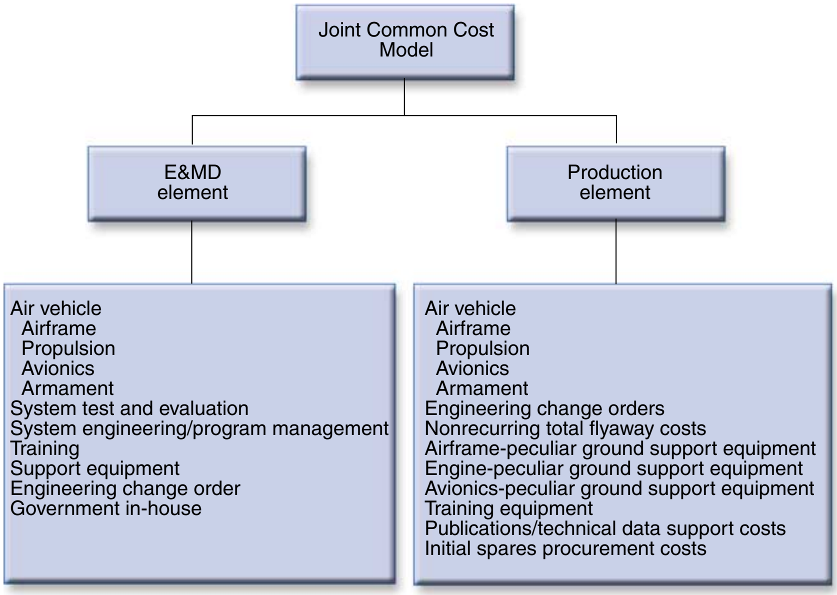

Figure 3. Work Breakdown Structure for the baseline Engineering and Manufacturing Development (E&MD) and Production Phases.

bases of estimates. These categories were later updated on the basis of independent government assessments. Results are summarized as expected values for each affordability initiative.

Because of the risk assessment process, each initiative's P_s carries a degree of uncertainty. The range of uncertainty is used to generate an optimistic and pessimistic value for the initiative's affordability impact by propagating it through JCCM equations.

The Affordability Initiative Module uses P_s and ΔP_s values computed in the risk analysis to compute a set of adjustments to associated T_1 values (theoretical cost, in hours per pound, of the first unit) for each appropriate cost category. In these initial studies, the focus of the effect of affordability initiatives is on T_1. The remaining parameters are held fixed to their nominal values and are therefore constants in this discussion.

T_1 values are calculated using parametric cost estimating relationships for each standard recurring labor category. Initial T_1 values, denoted $T_{1\text{baseline}}$ for each labor category, are based on cost estimating relationships for fighter aircraft development programs of the 1970s through 1990s. (These values must be adjusted to reflect radical changes proposed as affordability initiatives.) Hours-per-pound estimates are multiplied by government weight estimates (AUW, the airframe unit weight) to generate T_1's.

Using a master matrix of on/off "switches," the Affordability Initiative Module allows the evaluation of the impact of each initiative either individually or in any combination of interest. Each initiative's impact is only applied to an appropriate percentage of each aircraft variant's weight using a weighted average of affected aircraft parts. Weights are obtained from the government's assessment of weight and commonality which is performed at the detailed parts level and updated regularly. New values for T_1 and ΔT_1 are used by the JCCM to calculate revised JSF cost estimates. The algorithms and cost estimating relationships in the model, as well as financial and programmatic assumptions, remain unchanged.

The JCCM contains cost estimating relationships of the form

$$\text{Cost} = \text{Rate} \times \text{Hours}, \qquad (2)$$

where Rate is the wrap rate (i.e., applied cost factor) expressed in dollars per hour, and Hours is the amount of labor time associated with a particular element's development or manufacture based on a standard learning/rate curve of the form

$$\text{Hours} = T_1\,(x^b q^r \ldots)\,, \qquad (3)$$

where T_1 is the number of hours required to manufacture parts for the first unit, x is the lot midpoint (with b, a learning or experience factor), q is the lot quantity (with r, a rate factor), and the remaining multipliers (not shown) represent the effect of other technical factors (e.g., low observable requirements).

The impact of an affordability initiative is estimated by multiplying $T_{1\text{baseline}}$ by a term that accounts for the percentage savings claimed by the contractor and the P_s for the initiative. (Contractors have chosen to claim most savings as a percentage reduction from their baseline, i.e., "as is," estimate.) The basic equation for applying the savings is

$$T_1 = T_{1\text{baseline}}[1 - (P_s SW)]\,, \qquad (4)$$

where P_s is probability of success (for development and application of an initiative), S is manufacturing savings (the decimal form of a percentage of the contractor's original claim, $0 \leq S \leq 1$), and W is the applicable weight percentage. Thus if $P_s = 1$, then the entire estimate of manufacturing savings is used, the reduction factor $(1 - P_s S)$ becomes smaller, and T_1 is reduced from its baseline value. If $P_s = 0$, the factor remains 1, none of the savings claimed are accepted, and the baseline is not changed. This form for the equation permits great flexibility. For example, if the contractor modifies an initiative's savings value, adjustment simply requires changing S to the new percentage.

In programming these changes to the model, the concept of applicability was introduced, permitting an initiative's effects to be applied to appropriate sections of the model, as determined by subject-matter experts, and later reviewed and adjusted by other government personnel. The applicability function can also be used to turn on or turn off an initiative's effects, thereby aiding in the analysis of the initiative's marginal impact on the overall cost estimate. Thus, Eq. 4 becomes

$$T_1 = T_{1\text{baseline}}[1 - (P_s SWi)] \,, \tag{4a}$$

where i is the "on/off" switch associated with an initiative.

In its modified form, the JCCM can be used to compute the uncertainty of costs directly related to the uncertainty of input information. The general equation for T_1, as modeled in the JCCM, for any number n of affordability initiatives is

$$T_1 = T_{1\text{baseline}}(1 - P_{s1}S_1)(1 - P_{s2}S_2), \ldots, (1 - P_{sn}S_n), \tag{5}$$

where P_{sn} and S_n are defined as before, and the additional subscript refers to values associated with a particular initiative. The JCCM, as currently modified, permits inclusion of up to 50 initiatives (i.e., $n = 1, 2, 3, \ldots, 50$).

For illustrative purposes, consider the case where only two initiatives are applied, i.e.,

$$T_1 = T_{1\text{baseline}}(1 - P_{s1}S_1)(1 - P_{s2}S_2). \tag{6}$$

Note how each initiative provides a reduction factor to the equation, related to its P_s and its estimated savings. The two probabilities of success, P_{s1} and P_{s2}, also have uncertainty limits, $\pm\Delta P_{s1}$ and $\pm\Delta P_{s2}$, respectively. Therefore, the uncertainty in T_1 due to the assessment process is

$$\Delta T_1 = \{[\Delta P_{s1}(\partial T/\partial P_{s1})]^2 + [\Delta P_{s2}(\partial T_1/\partial P_{s2})]^2\}^{1/2} \,, \tag{7}$$

where

$$\partial T_1/\partial P_{s1} = T_{1\text{baseline}}(-S_1)(1 - P_{s2}S_2), \tag{7a}$$

and

$$\partial T_1/\partial P_{s2} = T_{1\text{baseline}}(-S_2)(1 - P_{s1}S_1). \tag{7b}$$

Equations 7a and 7b calculate partial derivatives of each initiative with respect to its P_s, representing the rate of change in uncertainty of T_1 caused by each initiative. In the JCCM, T_1 values are used to compute labor hours per pound, which are then multiplied by wrap rates to compute estimated costs. Therefore, uncertainty in the cost computation is

$$\Delta\text{Cost} = \text{Rate}[(x^b q^r \ldots)\Delta T_1 \,. \tag{8}$$

Equations for ΔT_1, ΔHours, and ΔCost can be programmed into the JCCM to directly compute the uncertainty of the nominal cost estimate. But rather than create a second copy of the model simply to calculate uncertainty, a more efficient, indirect method using the same calculations as the nominal case was employed. This method has proven more practical for day-to-day use, since many issues addressed by the ACE IPT are short-turnaround and "what if" questions. This method is described next.

For the case of two initiatives, five iterations of the JCCM are required as follows (note that in cases 2–5, the lower and upper bounds for probabilities, 0 and 1, respectively, remain the limits for each calculation).

1. A nominal case where P_{s1} and P_{s2} are specified as the probability of success for each initiative to yield Cost (the nominal value)
2. A case where $(P_{s1} + \Delta P_{s1})$ and P_{s2} are specified as the probability of success for each initiative to yield C_1^+ (the value that reflects the positive influence of ΔP_{s1})
3. A case where $(P_{s1} - \Delta P_{s1})$ and P_{s2} are specified as the probability of success for each initiative to yield C_1^- (the value that reflects the negative influence of ΔP_{s1})
4. A case where P_{s1} and $(P_{s2} + \Delta P_{s2})$ are specified as the probability of success for each initiative to yield C_2^+ (the value that reflects the positive influence of ΔP_{s2})
5. A case where P_{s1} and $(P_{s2} - \Delta P_{s2})$ are specified as the probability of success for each initiative to yield C_2^- (the value that reflects the negative influence of ΔP_{s2})

The combined influence of $\pm\Delta P_{s1}$ and $\pm\Delta P_{s2}$ is summed up by the following:

$$\Delta\text{Cost} = [(C_1^+ - C_1^-)^2 + (C_2^+ - C_2^-)^2\,]^{1/2}. \tag{9}$$

This formula is easily extendible to cases where there are $n > 2$ initiatives. For each additional initiative, after the new baseline (all initiatives) case is established, two additional JCCM cases must be run to develop the uncertainty estimate.

CONCLUSION

A systematic method that uses the opinions of subject-matter experts can be employed to evaluate affordability initiatives. Once initial definitions and ground rules are established, a subjective evaluation by these experts can be conducted expeditiously and converted to an objective measure (P_s) using AHP. Weight factors (relative rankings of each subfactor) must be updated as major maturity and complexity milestones for initiatives are met. Uncertainty that results in the evaluation of P_s can be incorporated into cost models, yielding nominal, pessimistic, and optimistic values for each affordability initiative's impact.

The Affordability Initiatives Assessment Methodology has been employed successfully in face-to-face meetings of subject-matter experts (as in WALEXs), with real-time feedback of results. A paper-copy variation of the method has been successfully employed when WALEX meetings were not practical.

This process forms the basis for future evaluations of JSF affordability initiatives, including those for other life-cycle phases and any newly proposed initiatives. It provides a means for a structured buildup from specific, detailed issues to an overall assessment of each initiative's effect on the JSF cost estimate. It also identifies key factors deserving increased attention as the JSF Program matures. Most importantly, briefings and evaluation sessions brought cost and technical people together, both on government and contractor sides, and combined their inputs to develop documented rationales for alternative courses of action. In the past, this assessment has too often relied on the judgment of one or a few people, often with expertise in only a portion of the full spectrum required.

An initial application of this approach identified opportunities for improvement. Further refinements that evaluate investment requirements, benefit (payoff) potential, and cost estimating relationship sensitivity could supplement this initial approach. Specifically, effects from investments in terms of size and timing, indirect/support labor cost impacts, and impacts on learning curves could be analyzed. Additionally, a risk/management reserve for the largest payoff initiatives could be calculated, and costs to the government of implementing initiatives determined.

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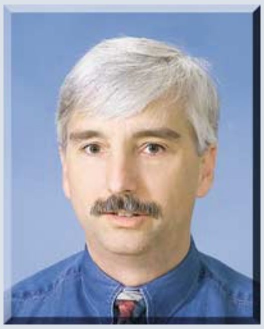

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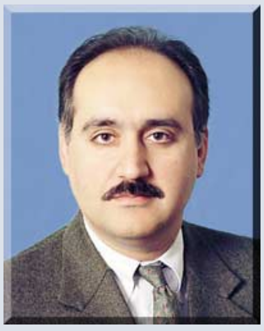

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