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An Investigation into Subject Matter Expert Elicitation in Cost Risk Analysis

Christopher W. Miller

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THESIS

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DEPARTMENT OF THE AIR FORCE
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Abstract

This research compares the efficacy of subject matter expert (SME) elicitation methods to other cost estimation methods using a development and production dataset provided by AFLCMC/FZC. First, by using descriptive statistics to evaluate low versus high amount of the respective cost estimation methods by analyzing the means of percent cost growth for both groups. Next, this research involved using a statistics-based approach to investigate whether SME based cost estimating methods have an associated relationship to percent change of Program Acquisition Unit Costs (PAUC), which will be our proxy variable to cost growth. Using a pooled cross-sectional OLS regression analysis model with adjusted R^2 of 0.298, 144 POEs sample for development have statistical evidence to support SME based cost estimates have a positive association with Program Acquisition Unit Cost (PAUC). Lastly, this research critically examines SME elicitation methods used within DoD and provides best practices used by industry and academia when eliciting SMEs that the cost estimating community should consider implementing.

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First and foremost, I want to thank my beautiful wife. She has been my inspiration. Without her, I would never have survived this program. I also want to thank my wonderful daughter, who has been a shining star whenever things were gloomy. I would also like to thank my chair, Dr. Fass, for his guidance and support throughout the course of this thesis effort. And finally, I am grateful for all of my fellow classmates of 20M for their support and encouragement throughout the duration of the program.

Christopher W. Miller

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AN INVESTIGATION INTO SUBJECT MATTER EXPERT ELICITATION IN COST RISK ANALYSIS

I. Introduction

There is no approved solution to any tactical situation. There is only one tactical principle which is not subject to change. It is to use the means at hand to inflict the maximum amount of wound, death, and destruction on the enemy in the minimum amount of time.

– General George S. Patton Jr.

Although extreme, General George S. Patton Jr.'s view on tactics is as insightful today as when he said it. The words "maximum" and "minimum" are subjective in nature. How should these values be measured? How does the likelihood of the different scenarios affect the decision? The Department of Defense (DoD) faces an operational environment that is characterized by uncertainty, complexity, and ambiguity (Williams, 2010).

Because of this uncertain environment, there is inherent subjectivity in the defense acquisition system. For instance, in cost risk analysis, practitioners elicit expert judgments to form subjective probability distributions to model specific work breakdown structure (WBS) elements when objective data sources are unavailable. Cost practitioners model a program's total cost by summing individual WBS elements which can vary widely in uncertainty. Clearly, the elicitation process must be as rigorous and scientific as possible (O'Hagan, 2019), or the overall cost estimate can be inaccurate due to cognitive biases (Kahneman and Tversky, 1974).

Background

The cost-estimation community is in general agreement that objective modeling, like parametric methods, are the most rigorous for quantifying uncertainty when constructing cost estimates, more formally referred to as a cost risk analysis (AF CRUH, 2007) (Galway, 2007) (Mislick and Nussbaum, 2015). A cost risk analysis is the attempt to evaluate and quantify the inherent uncertainty in a cost estimate (Galway, 2007). When relevant historical and/or empirical data are not available to a cost estimating practitioner, alternate methodologies must be applied to complete a cost estimate. Often, subject matter experts (SMEs) are asked to provide a plausible range for uncertainty in cost estimates. This methodology is commonly referred to as Subject Matter Expert (SME) elicitation, or expert judgment.

The SME elicitation method is applied either because not enough time or resources are available at the time information is needed for the cost estimate, or because it provides an adequate level of detail for the particular purpose of the cost estimate (AF CRUH, 2007) (Arena *et al.*, 2006). However, without appropriate guidance by a cost estimating practitioner, as the facilitator of the elicitation process, experts may fall victim to cognitive or motivational biases (AF CRUH, 2007) (Kahneman and Tversky, 1974). These biases can result in inaccuracies in the cost estimation model.

Problem Statement

As the United States Air Force (USAF) cost-estimation community continues to make use of SMEs, an analysis reviewing the value of current guidance needs to be accomplished. While research related to modeling uncertainty distributions (Smith, 2008), creating reasonable percentile bounds (Capen, 1975), and combining multiple independent experts' inputs has been explored (Coleman *et al.*, 2010), little research has been attempted to compare the efficacy of the SME elicitation method to other cost estimation methodologies relative to cost estimation. Additionally, it is unclear whether DoD guidance related to the use of SME elicitation matches the best practices used in industry and academia.

One way to compare the quality of cost estimation methods is to examine changes from the programmatic baseline, for example, by measuring cost growth. Program managers and commanders within DoD tend to use the terms "cost overrun" and "cost growth" interchangeably when discussing the performance of their acquisition programs. However, these terms have very different meanings. *Cost overrun* is the amount by which a contractor exceeds the estimated cost and/or final ceiling of the contract (Defense Acquisition University, 2015). *Cost growth* is defined as the difference between the original baseline program cost estimate and the estimate at complete (Porter *et al.*, 2009).

Current DoD and USAF's policies provide a few rules of thumb to guide cost estimators when eliciting subject matter experts (JA CSRUH, 2014, P. ii). However, these policies do not include guidance for cost estimators and subject matter experts in the avoidance of common cognitive biases or the accuracy of the estimates themselves. Therefore, the purpose of this research is to determine the accuracy and validity of expert judgement methods in the USAF cost-estimation community relative to other cost estimation methodologies, and to determine if there are best practices outside of the DoD that should be considered for immediate implementation.

Research Questions

The following research questions are investigated:

1. What heuristics does the DoD cost-estimation community use to reduce uncertainty, complexity, and ambiguity when using subject matter expert elicitation methods?
2. What heuristics are used in other disciplines that the Air Force cost-estimation community should consider implementing?
3. Is there an associated relationship between the percentage of Subject Matter Expert (SME) based cost estimating method to cost growth for Program Office Estimates (POEs) during the development and/ or production phases of a program's life cycle?

4. Does cost growth tend to be higher for Subject Matter Expert (SME) based estimates than analogy or more objective based cost estimating methods during the development and/ or production phases of a program's life cycle?

Research Focus

One of six centers under the Air Force Materiel Command (AFMC) Major Command (MAJCOM), Air Force Life Cycle Management Center (AFLCMC), is the single center responsible for total life cycle management of Air Force weapon systems. Data for this research was obtained directly from the individual program offices from the Cost and economics division of AFLCMC (Valentine, 2019). The data from the program offices include all the uncertainty metrics employed by cost estimators in their respective annual program office estimates (POEs) among other high-ticket items, which were briefed in slide form to the AFLCMC Cost Division located at Wright Patterson Air Force Base, Ohio. A unique byproduct from the slides is data on the breakout of cost estimating methods used to build 704 POEs. The advantages of using POEs from AFLCMC are they are centrally located and easily accessible for reviewers.

Model and Implications

This exploratory research uses a statistics-based approach to investigate if SME based cost estimating methods have an associated relationship to Program Acquisition Unit Costs (PAUC), which will be our proxy variable to measure cost growth. To conduct the statistical inferences, a separate multiple linear regression analysis model is applied for the development and for the production phases of the life cycle. The method that will be used is the ordinary least squares (OLS) method.

As previously mentioned, cost estimating practitioners elicit expert judgements to form subjective probability distributions to model the cost of specific WBS elements when objective sources are unavailable. This study first attempts to characterize how the DoD cost community accounts for cognitive or motivational biases when eliciting SMEs. Then, it explores how academia and industry account for these biases. Finally, it attempts to answer the remaining research questions through descriptive statistics and regression models.

Unfortunately, without appropriate guidance from the cost practitioner (as the facilitator of the elicitation process), experts may fall victim to cognitive or motivational biases, resulting in overly optimistic (or pessimistic) inputs to cost estimation models. By researching different SME elicitation methods within academia and industry, and by testing AFLCMC empirical data, this research may result in a deeper understanding of best practices, and allow for meaningful policy recommendations for practitioners.

Summary

This exploratory research will identify the processes and procedures that are outlined in the AF and DoD guidance when performing subjective cost risk and uncertainty in support of life cycle cost estimates for major defense acquisition programs (MDAPs). Chapter II, the literature review, will examine best practices, approved methods, and reporting requirements when conducting a subjective cost risk and uncertainty analysis. Chapter II will also investigate SME elicitation techniques recommend for use by industry and/ or academia. Chapter III, the methodology description, will explain how the data were gathered, and describe the methodology that was used for the analysis. The purpose of this chapter is to provide the reader with an overview of the methods taken in order for another researcher to replicate the process to achieve similar results. Chapter IV will contain the results and implications from the statistical analyses.

Finally, Chapter V will conclude the thesis, applying the results to the research questions, recommending best practices, and suggesting possible future research opportunities.

II. Literature Review

Chapter Overview

The purpose of this chapter is to provide a review of peer-reviewed literature on methods for managing subjective uncertainty and to investigate the comparison of DoD policies to industries best practices. The literature on elicitation is extensive in fields that include statistics, psychology, management science, economics, and environmental science (O'Hagan, 2019, P. 69). This literature review focuses on three key areas: 1) the relevance of subject matter expert (SME) elicitation in the cost estimating field within the DoD, 2) the importance of correctly facilitating the elicitation of SMEs' uncertainty distributions in cost estimates, and 3) the recommended best practices that the government and industry uses to capture subjective uncertainty for cost modeling. The following sections will provide a brief description of the extensive literature that was reviewed to conduct the analysis. This chapter provides the foundation upon which subsequent chapters will be built.

Under USC Title 10 Section 2432, the Secretary of Defense is required by law to report full life cycle cost for each Major Defense Acquisition Program (MDAP) (Selected Acquisition Reports, 10 C.F.R. § 2432, 2019). To fulfill this requirement, the Department of Defense (DoD) forecasts its expenditures numerous years into the future for the MDAP's Life Cycle Cost Estimate (LLCE) based on information available at the time. An important element of that forecast is the estimated cost of MDAPs. However, estimates are just that—estimates—not firm calculations of future expenditures. A cost practitioner has a range of methods, formally known as cost methodologies, available when estimating the cost work breakdown structure (WBS) elements of a MDAP. The methods typically used by the cost estimating community are outlined in the 2008 edition of the Air Force Cost Analysis Handbook (AFCAH). This handbook includes the best practices used when conducting the analogy/factor, parametric, engineering build-up, and SME elicitation methods along with some of the limitations (AFCAH, 2008, P. 3-1).

In 1974, Nobel Laureate Daniel Kahneman and Professor Amos Tversky started the revolutionary study of Behavioral Economics. They proposed that when facing numerous sensory inputs, it is natural to reduce complexity via the use of *heuristics*, also known as best practices. In general, these heuristics are quite useful, but sometimes they lead to severe and systematic errors, commonly referred to as *biases* (Kahneman and Tversky, 1974).

Kahneman describes two systems of how human behavior is determined under decision making. He famously notes: "*System 1* (automatic thinking) operates automatically and quickly, with little or no effort and no sense of voluntary control", and *System 2* (conscious thinking) "allocates attention to the effortful mental activities that demand it, including complex computations" (Kahneman, 2011, P. 20-21). When eliciting judgments from SMEs, Kahneman would highly encourage a process to hone in on System 2, or conscious thinking by SMEs. It is important for the cost estimating practitioner to understand common biases, whether cognitive or motivational, to better facilitate the elicitation process from SMEs.

Cost Estimating Methodologies

"The essential characteristics of a good cost estimate are *completeness*, *reasonableness*, *credibility*, and *analytic defensibility* (Mislick and Nussbaum, 2015, P. 13)." Balancing these four characteristics requires that the cost estimate reflects the current conditions, while also accounting for likely future processes and/or improvements (Mislick and Nussbaum, 2015). When using the different methodologies of cost estimation, it is foundational for cost estimating practitioners to first understand the advantages and disadvantages each method brings forth to the cost estimate.

An advantage of using the analogy and/ or factor method is that this method is difficult to refute when there is a strong similarity between the two systems being estimated. Cost estimating practitioners depend on input from program engineers and manufacturing analysts to: 1) identify historical programs which are similar to the new program, 2) select the best analogies between the old and new programs, 3) properly adjust the analogies for differences between the old and new programs (normally by applying a factor), and 4) check the reasonableness of the analogy estimates (AFCAH, 2008, P. 3-32). These four elements are key to a good cost estimate when using the analogy/factor method, and if done incorrectly, the cost estimate may no longer be the analytically defensible or credible.

The advantages of the use of parametric methods are: 1) it can be easily adjusted by modifying input parameters, 2) it provides objective measures of estimating validity, 3) it provides statistical information for estimating uncertainty/risk analysis, and 4) it does not require analysts to have technical expertise to apply parametric cost estimation methods (AFCAH, 2008, P. 3-34). Once established, the cost estimating practitioner assumes that the historical pattern will hold in the future, so cost is treated as a dependent variable, and it is a function of physical and/ or performance characteristics, which are also known as explanatory variables (Mislick and Nussbaum, 2015, p. 50). A disadvantage of parametric methods is that it can creates a “black box” process wherein cost estimating practitioners may not be able to break an estimate into its component costs (AFCAH, 2008, p. 3-34). In this case, the cost estimating practitioner must understand what is being modeled. At the aggregate level the estimate maybe analytically defensible, however, if components cannot be broken up individually, the estimate will lose credibility if the parametric modeling techniques is improperly used.

The engineering build-up (actuals) method is a "bottom-up" application of labor and material costs, in which many detailed estimates are summed together to form the total cost estimate. A key characteristic to this method is that it is what people outside the cost estimating community believe is the best cost estimating approach due to its detail (Mislick and Nussbaum, 2015, p. 51). The downside to this estimation method is the estimate is both data and labor intensive, and this method is also prone to double counting and omissions of lower level WBS elements (AFCAH, 2008, p. 3-30).

A method commonly related to the engineering build-up method is estimating a program by an earned value management (EVM) analysis approach. An EVM analysis is normally conducted later in the life cycle of a MDAP which uses the past program specific cost to project future costs for the same program (Valentine, 2019). These two sub-categories of engineering build-up are important to distinguish because the method is dependent on where in the acquisition life cycle a given program is. For the purposes of this thesis, these will be treated as separate cost estimating methods for both development and production datasets.

The final cost estimating method is known as subject matter expert (SME) elicitation, commonly referred to expert judgement in the literature. It is important to note, "Putting odds on uncertain events or ranges on uncertain qualities is not a skill that arises automatically from experience and intuition… researchers discovered that assessing uncertainty is a general skill that can be taught with a measurable improvement" (Hubbard, 2011, p. 94-95).

The advantages of using the SME elicitation methods are: 1) it uses SME experiences to develop an estimate when detailed and/ or historical data are not available and/ or relevant, 2) it is especially useful for filling holes in data that is used to drive other estimation methods, and 3) it provides crosschecks for other estimating methods (AFCAH, 2008, p. 3-30). Like the other cost estimation methods, there are downsides to this method as well. The disadvantages of using SME elicitation include: 1) the estimate's credibility depends on the SME's credibility, 2) the documentation of SME recommendation and decision process is the only assurance for the estimate, 3) interviewing SMEs can be time-consuming, 4) SME judgement may contain biases, and 5) SMEs may not have detailed databases of historical efforts to inform their opinions (AFCAH, 2008, p. 3-30).

Figure 1 depicts when different cost estimating methods are commonly applied relative to the Department of Defense (DoD) Program Phase Life Cycle Structure. It helps give an idea of the appropriate time to apply particular techniques and could be applied to non-DoD programs as well. At the beginning of a program, during the concept and design phases, there is more emphasis on using analogy and parametric methods. In these early phases, gross estimates are the norm, as detailed estimates are not usually possible with poor program definition, changing requirements, and scarce cost data. As the program matures, it becomes more defined, additional data are collected, and the estimates get more detailed. Engineering (Build-Up) and Extrapolation from Actuals are used more frequently as the program transitions to Production and Deployment and Operations and Support (O&S) (AFCAH, 2008, P. 3-30).

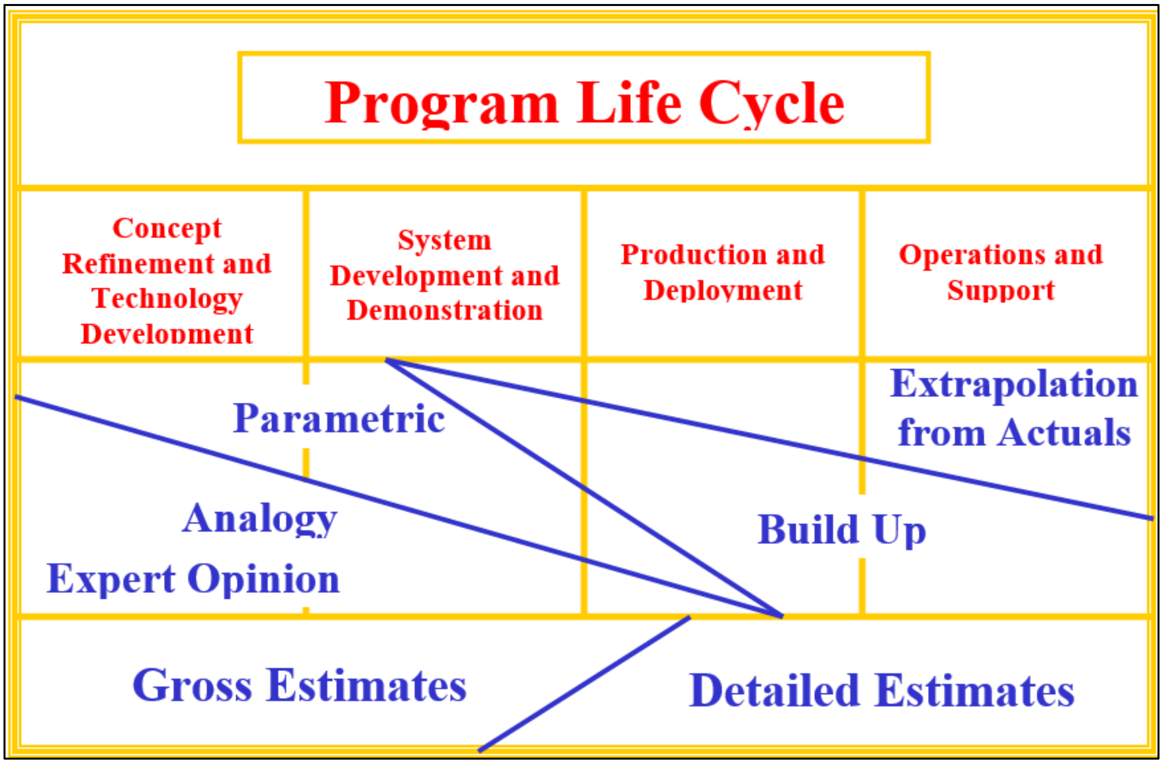


Figure 1. Selection of Methods, (AFCAH, 2007, P. 3-29)

Elements of the Work Breakdown Structure (WBS)

The Work Breakdown Structure (WBS) provides a systematic framework for defense material items within a program and is a critical tool in ensuring all portions of a program is covered. The mandated MIL-STD-881D "offers uniformity in definition and consistency of approach for developing all levels of the WBS" for use by all agencies of the Department of Defense (Department of Defense, 2018, P. iv). The WBS decomposes a project into smaller components for ease of management control, which allows a cost practitioner to develop cost estimation methods at these smaller components. The WBS is best described as "a product-oriented family tree composed of hardware software, services, data, and facilities which results from systems engineering efforts during the development and production of a defense material item" (Mislick and Nussbaum, 2015, P. 53).

The WBS, in general, consists of three primary hierarchical levels, with a fourth and fifth sometimes included in expanded forms (Department of Defense, 2018); for this research data was collected at the level two when comparing the different methodologies used when conducting past POE cost estimates. Level one represents the entire system or material item such as an aircraft, ship, space, or missile system (Mislick and Nussbaum, 2015). The second level of the WBS captures major elements subordinate to the system known as prime mission products which includes hardware and software elements. Level two also includes: integration and assembly, system test and evaluation (ST&E), system engineering/Program management (SE/PM), common support equipment (CSE), peculiar support equipment (PSE), training, data, operational/site activation, and initial spares and repair parts (Department of Defense, 2018). Figure 2 and Figure 3 displays a WBS for a generic aircraft system with varying amounts of detail.

Program WBS		
1	2	3
Aircraft system	Air vehicle	Air frame Propulsion Communications/identification Navigation/guidance Fire control Automatic flight control Central computer Electronic warfare suite Weapon delivery equipment Armament
	System test and evaluation	Development test and evaluation Operational test and evaluation Mockups Fire control Test facilities
	Systems engineering/program management	Systems engineering Program management Integrated logistic support
	Common support equipment training	Maintenance trainers Aircrew training device Training course materails
	Data	Technical publications Engineering data Management data Support data Data depository
	Operational/site activation	Contractor technical support
	Initial spares and repair parts	

Figure 2. Top Level Program WBS (Mislick and Nussbaum, 2015)

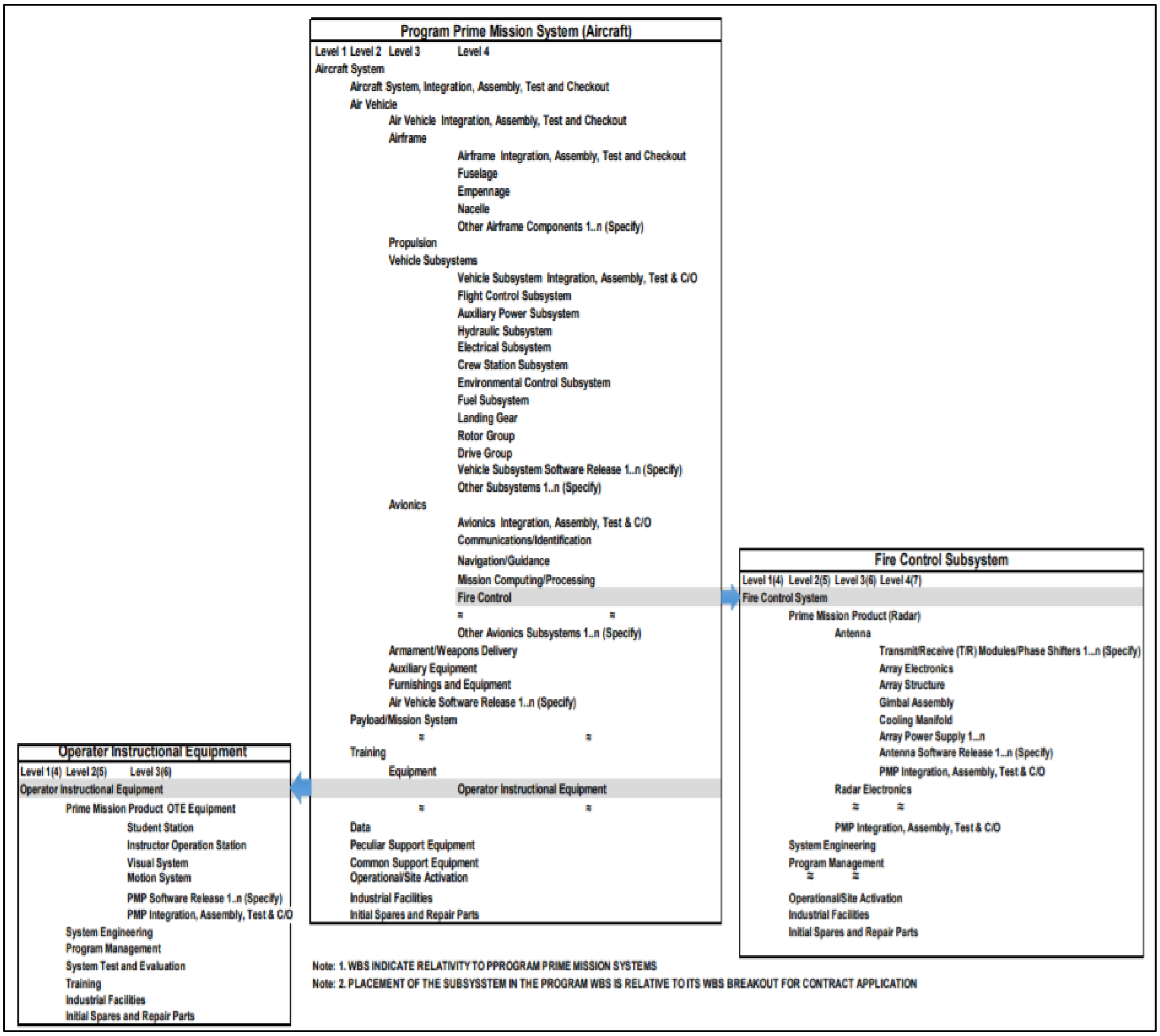


Figure 3. Top Level WBS (MIL-STD-881D, P. 12)

Biases in SME Elicitation

The SME elicitation method used within the DoD represents a SME's "degree of belief" in the form of a probability distribution as previously mentioned (O'Hagan, 2019). Bias occurs when expressions of the experts' thinking do not match their actual thinking at the time of the elicitation, and the experts' estimates do not follow normative statistical or logical rules (Meyer *et al.*, 2001). These biases may cause the expert to consistently underestimate or overestimate a requirement across multiple estimates, resulting in entire product portfolios that are underfunded or overfunded, and a well-trained cost practitioner can assist in preventing common pitfalls described in the literature (AF CRUH, 2007) (JA CSRUH, 2014). Sources of bias can be a person's needs (motivational bias) or thoughts process (cognitive bias) for the estimate (Meyer *et al.*, 2001).

"The ground-breaking research of Tversky and Kahneman (1974) set in motion the heuristics and biases research program, the underlying principle of which is that people's judgments are often made on the basis of heuristics (systematic best practices as related to the Air Force), which are quick, short-cut reasoning processes" (O'Hagan, 2019, P. 70). Kahneman (2011) stresses that rigorous critical thinking happens when we consciously slow down the process, taking time to think about the full situation. See Table 1 for the common biases published in the JA CSRUH and AF CRUH as related to subjective uncertainty.

Table 1. Common SME Biases (JA CSRUH, 2014, P. 29)

Motivational Bias	Cognitive Bias
Social pressure (face-to-face)	Representativeness (small-sample)
Impression (not face-to-face)	Availability (most recent)
Group Think	Anchoring and Adjustment
Wishful thinking	Inconsistency (opinion changes over time)
Career goals	Relating to irrelevant analogies
Misunderstanding	Underestimation
Project Advocacy	
Competitive Pressures	

The complete list of biases associated with behavioral economics is extensive, so a subset of the most commonly cited examples in the literature will be reviewed. The "Subjective Uncertainty within the DoD" section will critically analyze the two handbooks' best practices when conducting SME elicitation, to review what action(s) are recommended to combat these common biases.

Anchoring bias is defined as an individual's failure to sufficiently adjust from his or her first impression in solving a problem—the individual anchors to the first impression. Research has shown that on average, individuals tend to make insufficient adjustments to the initial basis, resulting in the response being "anchored" to the basis (Kahneman and Tversky, 1974). As a result, when using an analogy as basis for an estimate, the expert may fail to fully adjust for the change in complexity between the historical analogy and the new effort. Sometimes this bias is explained in terms of Bayes theorem as the failure to adjust a judgment considering new information as in updating one's prior (Meyer *et al.*, 2001).

Availability bias affects an individual's ability to accurately estimate frequencies and to recall other aspects relevant to the WBS cost estimate. Consequently, experts may base their advice on the information that is easiest to recall, rather than considering the full range of observations and experience (Meyer *et al.*, 2001). Using a systematic discourse to identify a recognized likelihood during the elicitation process will allow the expert to reflect on the possibility of an event occurring "X" percent, i.e. 20% of the time, rather than allowing the expert to only reflect on familiar or recent events that are easy to recall. Encouraging the SME to think of reasons why the range could be larger, especially in the upper direction, is a best practice identified that should minimize and hopefully eliminate the availability bias from occurring.

The next bias is the *wishful thinking bias,* also referred to as the overconfidence bias in the behavioral economics field. This bias stems from the idea that individuals assess that they are better than the average practitioner in their field and less likely to experience negative events or outcomes. These individuals will focus on what can "go right" in a project, while believing that nothing could "go wrong." Studies show that practitioners (and even experts) use incorrect assumptions that lead to not truly identifying all possible outcomes to their probability distributions (Coleman, 2010). Often, this is driven by a false sense of control over events. As a result, experts who have succumbed to wishful thinking bias will consistently underestimate task completion times and costs, even when presented with information demonstrating that many similar tasks have run over both schedule and budget (Flyvbjerg, 2011). Optimism can lead directly to overconfidence by SMEs, who may assume their point estimate to be a better and more reliable estimate than is justified.

Subjective Uncertainty within the DoD

Cost estimation is partly science, art, and judgment and employs inter-disciplinary quantitative and qualitative analysis techniques or practices (Mislick and Nussbaum, 2015, P. xiii). There are two foundational handbooks that inform the Air Force's cost estimating community as it attempts to quantify risk and uncertainty for cost estimates. The two handbooks are the United States Air Force Cost Risk and Uncertainty Analysis Handbook (AF CRUH) and the Joint Agency Cost Schedule Risk and Uncertainty Handbook (JA CSRUH). It is important to note that the Joint guide was published in 2014, which supersedes the Air Force's guide that was published in 2007. Tecolote Research, Inc., under the sponsorship of the Air Force Cost Analysis Agency, developed the initial AF CRUH in April 2007 (AF CRUH, 2007, P. ii). Both handbooks will be reviewed because some of the data that has been gathered does occur prior to 2007.

The overarching purpose of the handbooks is to describe acceptable best practices to model uncertainty in order to quantify cost risk (AF CRUH, 2007) (JA CSRUH, 2014). The JA CSRUH is a cross-agency guide designed to assist DoD analysts in applying risk and uncertainty within cost estimates, and has been endorsed for the use by the Departments of Navy, Army and

Air Force, the missile Defense Agency (MDA), and NASA (JA CSRUH, 2014). The main goal of both handbooks is, "to define and clearly present simple, well-defined cost risk and uncertainty analysis processes that are repeatable, defendable, and easily understood" (JA CSRUH, 2014, P. 1).

Both handbooks address subjective uncertainty methods, often applied to WBS elements for which historical or relevant data is not available. In these cases, cost estimating practitioners generally turn to expert judgement or knowledge that is possessed by engineers, managers, and other subject matter experts (SMEs) to inform a subjective probability distribution related to the cost of the WBS element. This process is called "elicitation." The two handbooks describe best practices to model cost estimate uncertainty in order to calculate and report cost risk to decision makers and Congress (AF CRUH, 2007, p.1). These recommendations are quite useful because they create consistent rules of engagement (ROEs), but sometimes they can lead to systematic biases (AF CRUH, 2007) (Kahneman and Tversky, 1974).

The AF CRUH has seven steps and the JA CSRUH has nine steps for the best practices when eliciting SMEs. Table 2 depicts a summary of how the two handbooks differ.

Table 2. AF CRUH v. JA CSRUH

Brief Description of Step	JA SCRUH	AF CRUH
Have historical minimum, maximum, and averages on hand	1	not included
Use multiple experts	2	1
Ask the expert for an upper and lower value	3	2
Encourage a dialog to identify various possible outcomes	4	3

Seek the most-likely value near the end of the step for discussion	5	4
Select a distribution	6	5
Treat the SMEs input as the 70% interval	7	6
Crosscheck information and challenge SMEs against historical experience	8	7
Iterate the evolving conclusions with the experts as needed	9	not included

The JA CSRUH first advises the cost estimator to have historical minimum, maximum, and averages on hand. This information will be used for talking points as the interview develops to provide further context to the conversation. This information should not be used to "bludgeon" the expert, but should be used to challenge or support estimates during the elicitation process. Both guides recommend not initially sharing the historical minimum, maximum, and averages with the expert to avoid unintended "anchoring."

The next seven steps are identical in both handbooks. After the estimator has the historical minimum, maximum, and averages on hand, if applicable, the handbooks both recommend using multiple experts. In general, cost estimating practitioners are required to model the uncertainty ranges given by the multiple SMEs into a single probability distribution which combines the knowledge of the experts. However, both the AF CRUH and JA CRSUH fail to recommend a methodology to use when combining information for multiple SMEs. The lack of information could be detrimental to a cost analyst that is new to the field of government cost estimating.

A key finding in a 2007 RAND study was the DoD's "elicitation methodologies are largely ad hoc, in that they are seldom based on or derived from references to the elicitation literature" (Galway, 2007, P. 12). Establishing clear and concise rules of engagement (ROEs) within the JA CRSUH would combat the inconsistent practices when conducting elicitation from multiple experts. Next, we will discuss some of the commonly used techniques prescribed through researched or commonly used techniques by the DoD when using multiple experts.

One technique studied by a Coleman (2010) at the Naval Postgraduate School (NPS) is called "conflation." For this technique, a cost practitioner uses a distribution with the mean of experts' most likely values while using the lowest low and the highest high as end points to create the absolute range of possible outcomes that will be modeled in the cost estimate (Coleman, 2010). Another common technique for using multiple experts not prescribed by the JA CSRUH but commonly used within DoD is the Delphi Method (Meyer *et al.*, 2001), which attempts to avoid the "groupthink" bias.

Irving Janis, the late Yale social psychologist famously noted:

> The more amiability and esprit de corps among members of a policy-making ingroup, the greater is the danger that independent critical thinking will be replaced by groupthink. ... The social constraint consists of the members' strong wish to preserve the harmony of the group, which inclines them to avoid creating any discordant arguments or schisms. (Janis, 1991, p. 237)

Janis was convinced that the concurrence-seeking tendency of close-knit groups can cause these groups to make inferior decisions (Janis, 1991, p. 238).

The Delphi Method is a technique often used to limit the biasing effects of interaction such as the *"groupthink" bias*. In a Delphi study, the experts do not interact with one another and only interact with the moderator in a limited way. The experts, in isolation from one another, give their judgments and, in some cases, their reasons for making these judgments. The moderator collects these judgments, makes the judgments anonymous, distributes these judgments to the individual experts, and allows each of them to revise their previous judgments. This process can be repeated for as many times as desired (e.g., until consensus is achieved) (Dalkey, 1969, p.37). Individuals are more prone to groupthink if they have a strong desire to remain a member, if they are satisfied with the group, if the group is cohesive, and if they are not a natural leader in the group (Meyer *et al.*, 2001). There are many techniques in the literature that could be used when using multiple experts for SME elicitation. The cost estimating community "must stop viewing elicitation as an ad hoc art, and instead adopt a more structured, scientific process" (Brown, 2019, p. 3)

After eliciting multiple experts, the next step recommended by the AF CRUH and JA CSRUH is to ask the expert for an upper and lower value, and to encourage discussion related to why the range could be larger, especially in the upper direction. After the range is established, the cost estimator should ask the expert to identify the value that has "a one in five chance of being lower or the value that has one in five chance of being exceeded." (JA CSRUH, 2014, P. 29) (AF CRUH, 2007, p. 15). The handbooks note that such a dialog makes the participants determine not only the bounds but also their interpretation of the probability distribution that is being developed. As the facilitator at this step, it is important to have the SME reflect on all of the possible outcomes for the modeled WBS element. People in general tend to assess only highly salient events from memory (Kahneman and Tversky, 1974, P. 8), but it is important for the cost practitioner to elicit the SME's absolute range of possible outcomes or the information received is subject to the availability bias.

Once the range of the uncertainty distribution is defined, the next step is to elicit the most likely value from the interview with the SME, and to use the guidance in the JA CSRUH (2014, p. 29) to select a distribution shape, depicted in Table 3.

Table 3. Recommended Uncertainty Distributions (JA CSRUH, 2014, P. 14)

Distribution	Typical Application	Knowledge of Mode	Number of Parameters Required	Remommended Parameters
Lognormal	Default when no better info. Probability skewed right. Replcate another model result. Power OLS CER uncertainty.	Mean or median known better than the mode	2	Median, high
Log-t	Log-t when < 30 data points		3	Add Degrees of Freedom
Triangular	Expert opinion. Finite min/max. Probabilty reduces towards endpoints. Skew possible. Labor rates. Labor rate adjustments. Factors methods	Good idea	3	Low, mode, and high
BetaPert	Like triangular, but mode is 4 times more important than min or max.	Very good idea	3	Low, mode, and high
Beta	Like triangular, but min/max region known better than mode	Not sure	4	Min, low, high, and max
Normal	Equal chance low/high. Unbounded in either direction. Linear OLS CER uncertainty.	Good idea, but unbounded in either direction	2	Mean/Median/mode and high value
Student's-t	t when < 30 data points		3	Add Degrees of Freedom
Uniform	Equal chance over uncertainty range. Finite min/max.	No idea	2	Low and High
Empirical Fit	Unable to fit a distribution to the data	Not required	N/A	Enter source data and estimated probability for each data point
Note: Low/high are defined with an associated percentile Min/Max are the absolute lower/upper bound (also known as the 0/100)				

In the absence of better information, the cost analyst is to treat the range of the low and high values as a 70-percent interval and use a triangular distribution. For symmetrical distributions, the guidance is to model the low estimate at the 15-percentile and the high estimate at the 85-percentile to form a triangular distribution placing the most likely value at the mode of the distribution (JA CSRUH, 2014). For skewed distributions, both the JA CSRUH and AF CRUH advise the practitioner to skew the bound interpretations to match the ratio of the initial values given by the SME. As shown in Figure 4, the narrower distribution illustrates the distribution shape if the expert bounds are taken as "absolute," which is rarely the case. The recommended practice of adding an additional thirty percent to the distribution enlarges the possible rage for the estimated WBS element (JA CSRUH, 2014, P. 30). The wider distribution depicted in Figure 4 illustrates the true uncertainty distribution that will be used in the cost estimating model and should be interpreted as the true distribution given by the SME. This heuristic is used to correct for the common overconfidence bias from experts. McKenzie (2008) observed that experts' 90% subjective confidence intervals typically contain the true value about 50% of the time, indicating extreme overconfidence.

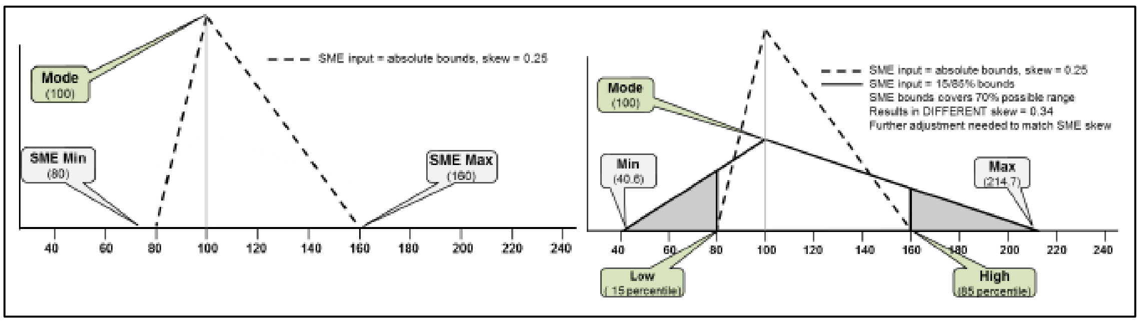


Figure 4. Unadjusted Bound Interpretation on a Tri Dist. (JA CSRUH, 2014, P. 30)

One key question to the JA CSRUH and AF CRUH's best practice is what makes the modeling of the SME's low and high values at the 70-percent interval valid? A source referenced in the handbooks, Capen (1976) found through experimentation that "most people are grossly overconfident … specify uncertainty ranges that are too narrow with respect to their actual knowledge of the variable they are assessing" (p. 4). To add subjectivity to the scenario a technical report by RAND, the researchers recommend to use the "upper and lower values to bound 90 percent of the probability" (Galway, 2007, P. 9). By doing so, the final distribution for the RAND recommendation will be narrower than the what is recommended by the JA CSRUH and AFUHs. Like depicted Figure 4, Figure 5 adjust for the skew of the distribution, but only adds 10 percent of uncertainty to the SME's initial input parameters (Galway, 2007, P. 10). This assumes that SMEs, in general, are capable of systematically identifying 90% of all possible outcomes to model. In Figure 5, the SME's recommend low and high was 300 and 800 respectively with a most-likely value of 400.

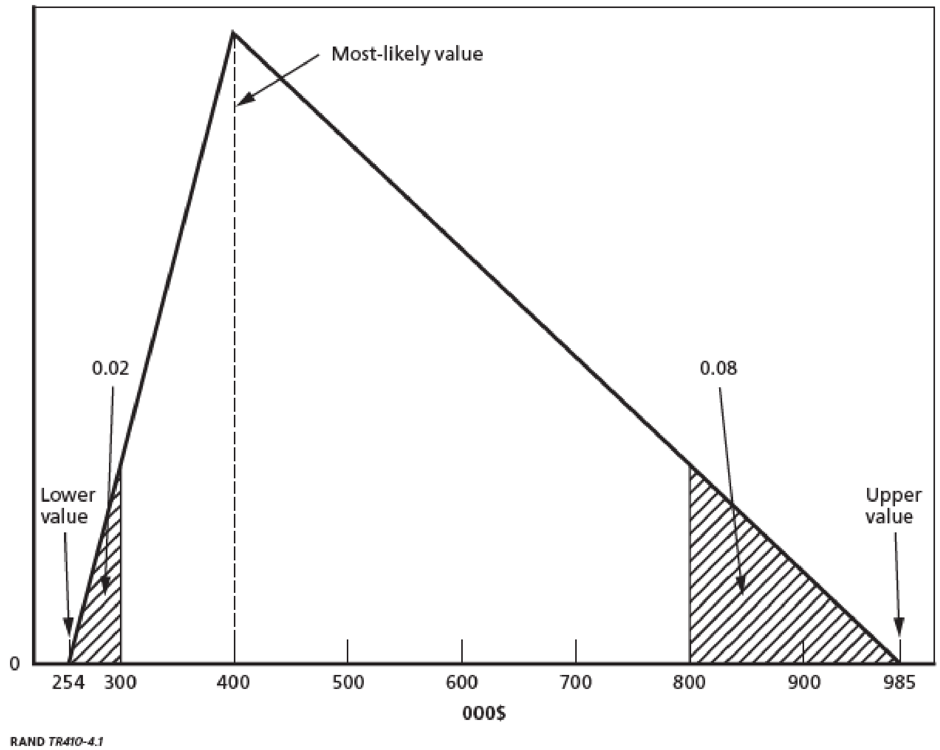


Figure 5. RAND's Fitting an Expanded Triangle Distribution to SME Parameters

The next step recommended by the handbooks is for the cost practitioner to complete crosschecks when appropriate, and challenge experts' inputs against historical experience (JA CSRUH, 2014, P. 30) (AF CRUH, 2007, P. 15). This step is fairly straight forward and situation dependent. The final step recommend by the JA CSRUH is to iterate the evolving conclusions with experts as needed. This could be accomplished by a Delphi study as previously mentioned. However, this step does beg the question: After a cost estimator has submitted the cost estimate, is there a means to update it? Especially if a significant and relevant change in circumstances has occurred such as a requirement change, an unforeseen technical challenge, etc.

Understanding the "how" to manage the SME elicitation process is only the beginning for the cost practitioner. It is arguably more important for the cost practitioner to understand the potential for biased estimates when consulting experts. Brown (2019) points out a fundamental question to consider, "we would not expect an analyst to construct a parametric model without first learning the fundamental of learning regression (in a more general sense, data modeling), so why are expectations any different for elicitation [methods]?" Using expert judgements can be very difficult because the information gathered can have unintentional consequences to the success of the program (AF CRUH, 2007), so understandable methods should be internalized and rigorous guidance should be provided. It is foundational that cost practitioner fully understands how to properly facilitate the interview process when eliciting SMEs for their knowledge for cost modeling, in conjunction with applying heuristics to minimize biases that experts are prone to make when making probabilistic judgments.

Thus far, this chapter has focused on methods for managing subjective uncertainty in the context of the DoD. The remainder of this chapter will focus on methods for managing subjective uncertainty related to private industry to include actuarial work, general insurance, and statistics. A key motivation for this section is to start a discussion related to the applicability of SME elicitation best practices used in industry that could be directly implemented within the DoD. Subjective uncertainty assessments are frequently used within these industries where data is scarce or non-applicable.

Managing Subjective Uncertainty within Industry

Actuaries

A profession that uses subjective uncertainty when making high valued decisions is the actuarial profession. An actuary is a business professional who analyzes the financial consequences of risk by using mathematical, statistics, and financial theory to study uncertain future events. The aim of an actuary, when using subjective methods of estimating risk, is to distinguish between low-quality and high-quality judgments to improve the robustness of the risk estimate. This is done by understanding "the Guess Universe" as shown in Figure 6 (Tredger, 2015).

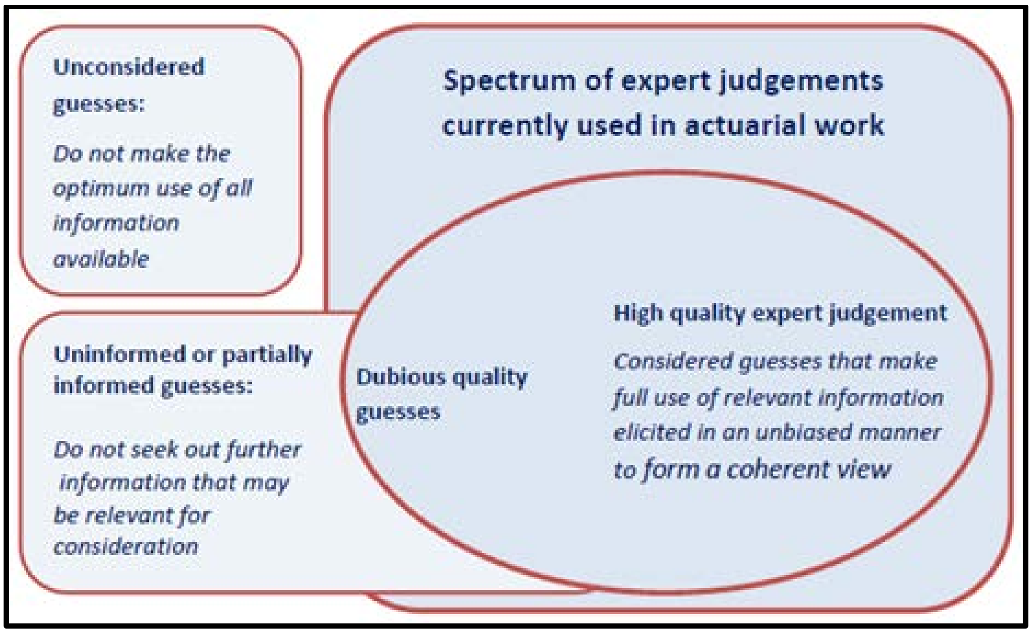


Figure 6. The Guess Universe (Actuary Viewpoint)

The Cambridge Online Dictionary defines guessing as the act of "giving an answer to a particular question when you do not have all the facts and so [you] cannot be certain if you are correct." Therefore, expert judgement would fall into the spectrum depicted in Figure 6. The "Guess Universe" encompasses guesses informed with little knowledge of the situation under consideration from one end of the spectrum to high quality expert judgement at the other (Tredger, 2015).

Within actuarial work, actuaries strive to elicit high quality expert judgements by using relevant information elicited in an unbiased manner to form a coherent view. If done poorly, the credibility of the actuarial worker is on the line. It is important to note that actuaries understand the cognitive and motivational biases that were previously mentioned earlier when discussing the AF CRUH and JA CSRUH. Given the existence of these biases, how do they distinguish between high quality SME elicitation information and just gut feel guesses by the SME? Actuaries combat this dilemma in a three-step approach. The steps include: 1) setting the process of the expert judgement policy, 2) identification of the relevant judgements and updating processes, and 3) identifying the expert (Tredger, 2015).

The DoD fulfills step one with statutory USC Title 10 Section 2432 policy in the supplementary AF CRUH and JA CRSUH handbooks. However, the DoD does not mention guidelines for implementing steps two and three. For the second and third steps actuaries recommend including the following information: 1) date the SME elicitation information was set and subsequently updated, 2) SME owner and experience that qualifies the SME as an expert for that particular scenario, 3) process of peer-review and sign-off, 4) updating process, and 5) identification of materiality (Tredger, 2015).

Two categories are missing from the AF CRUH and JA CRSUH through the actuarial window. First, these handbooks do not provide a way to determine what qualifies a SME as an expert, and second, they do not include an updating process for SME-elicited cost estimates. No documentation of professional qualifications, current position and years employed within the program office, and previous positions held is required for cost estimates in the DoD. A 2006 RAND study advises that "a record of cost estimate accuracy should be tracked and updated periodically" (Arena *et al.*, 2006, p. 98). A formal protocol for updating SME inputs could increase the accuracy and precision of cost estimates, especially prior to cost being realized.

Insurers

Another industry that frequently analyzes subjective uncertainty are insurance companies. The typical duties of these companies are to safeguard their customers' property against the risk of loss, damage, or theft. A well-known insurance company, Lloyd's of London, was founded in the 1600's and is still prevalent today across the world. Lloyd has a team solely dedicated to emerging risks, also described as an issue that is perceived to be potentially significant, but which may not be fully understood, that is updated regularly through conversations with SMEs (Weick *et. al.*, 2012, p. 4). The team also maintains contact with the academic, business, and government communities in efforts to stay current with process and technology improvements (Weick *et. al.*, 2012, p. 4). This team uses heuristics, or best practices, that can be useful within the DoD processes when performing cost estimates.

Several isolated events have caught insurers by surprise but, in general, risk experts are better at identifying risks that are not readily apparent to non-experts (Weick *et. al.*, 2012, P. 8). One important factor that insurers evaluate is the potential dependency of events. Large portfolios can protect insurance companies from major losses if risk is independent, however, if risks are dependent then a single incident can cause large losses (Weick *et. al.*, 2012, P. 9).

This is highly relevant to the DoD for two main reasons. When using the analogy methodology within DoD, what means does the cost estimator have or use to be certain that the analogues program did not have outside events that caused cost growth? The two systems that are being compared could truly be similar, but outside events led to the actual cost of the MDAP. The second factor why dependency is highly relevant to the DoD deals directly with the SME.

One could argue that all SMEs are not created equal. If a cost practitioner researches a performance report of a given SME's inputs, should the cost practitioner adjust the parameters of the cost estimate to reflect SME's performance over time instead of applying the systematic "best practice" of applying 30% to their suggested probability distribution? Although this is more of a rhetorical question, cost estimating practitioners should be aware of the two concepts.

The Lloyd's of London insurance company provides some best practices that could help counteract some of the difficulties associated with SME elicitation within the DoD. Two primary best practice recommendations relate to habitual thinking and missing feedback. These two categories consist of questions the insurer should answer when eliciting information from SMEs. Under the *habitual thinking* category, the questions are: 1) Do established routines miss out on important pieces of information? 2) Do processes lead to habits that prevent people from asking important questions? 3) Have the parameters changed? 4) Do routines no longer cover all angles? (Weick *et. al.*, 2012, P. 10).

Another aspect that is investigated is "missing feedback." This category questions: 1) is there enough information to verify assumptions? 2) How robust is the model? 3) What kind of information would make the model more robust? 4) Can you use auxiliary variables as substitutes for missing information? 5) How does your company feed information back to you? How timely and relevant is the feedback? (Weick *et. al.*, 2012, P. 10). These questions are paramount for insurance companies because they must be mindful of the uncertainties inherent in predicting rare events (Weick *et. al.*, 2012, P. 9) because the credibility of the company is on the line. Although all points are relevant to the DOD, a formal protocol for providing timely feedback to SMEs could make the processes a learning process for the SMEs.

Summary

This review of relevant literature notes that there have been numerous studies performed before ours that help direct our efforts, studies that mainly focus on the concept of developing subjective probability distributions within the DoD, academia and industry. What we have uncovered has shed light on the methods DoD currently employs, and the key considerations within academia and industry through the scope of behavioral economics. With the knowledge researched in this chapter, we are able to confidently identify our starting point of theory and strategy moving forward to our methodology.

One finding is clear after conducting this review; there is very little research linking the efficacy of SME elicitation methods within MDAPs. Academia and industry interpretations and practices have valuable insights in making our processes more robust when eliciting SMEs within the DoD. By reviewing the literature, we now know that there is this need in the community and we can attempt to fill it. We gained the insight into how to structure our methodology, which is covered in the ensuing chapter.

III. Methodology

Chapter Overview

The purpose of this chapter is to describe the procedures used to analyze whether SME based cost estimating is associated with increased cost growth when compared to other cost estimating methods. We use the variable Program Acquisition Unit Costs (PAUC) as a proxy for cost growth. First, the data source, data collection process, data characteristics, and variable identification will be discussed. Next, the steps required for normalization of the dataset will be discussed that were used prior to performing statistical inference tests. Finally, an overview of the model and preliminary statistical tests is described.

Data

Data for this research were obtained directly from the individual program offices within Air Force's Life Cycle Management Center (AFLCMC) and consolidated by AFLCMC/FZC at Wright Patterson AFB, Ohio (Valentine, 2019). The data were included in briefings given to AFLCMC/FZC and then transcribed into a relational database. AFLCMC is one of six centers under Air Force Materiel Command (AFMC) and is the single center responsible for total life cycle management of Air Force weapon systems. The data from the different program offices includes metrics generated by cost estimators in their respective Major Defense Acquisition Program (MDAP) for their annual program office estimates (POEs) submission. A POE is the Program Manager's primary cost estimate of the resources required for his/her program, and is continually updated throughout the life of the program (Mislick and Nussbaum, 2015, P. 44).

In general, the slides include the current status of the program, the current point estimate and risk range for all applicable phases of the program's life cycle, and a description of estimating changes from the previous year. The slides are unique to this analysis because they contain the cost estimating method used at each level two Work Breakdown Structure (WBS) element. The programs are required to disclose their level two WBS elements for the development and production phases of the MDAPs' life cycle as defined in MIL-STD-881-D. Level two elements are the major elements subordinate to the level one major elements (i.e. Aircraft or Information systems), and are prime mission products, which include all hardware and software elements (Department of Defense, 2018). The briefings are required annually and provide an update to the changes in the uncertainty of the program and insight to the overall progress of the respective MDAP. In addition, the briefings are created by the program office cost estimator and program manager who possess first-hand knowledge of their respective programs.

The advantages of using POEs from AFLCMC are that they are centrally located at the AFLCMC/FZC and easily accessible for reviewers. Due to the difficulty in interpretation of subjective documentation provided by the different program offices, the AFLCMC/FZC did not previously transcribe cost estimating methodology information into their database. During this research effort, we updated 6,811 records for 704 POEs (total for development and production) to conduct statistical tests for this thesis.

Due to the non-standardized methods of indicating cost estimating method in the slides, the researchers updated the database using personal judgement, cross-checked with AFLCMC/FZC personnel. The records were updated as rigorously and consistently as possible. A typical POE has an overview slide that provides a level two work breakdown structure with cost estimation method information. A percentage for each method (analogy, factor, engineering build-up, SME elicitation, parametric, and EVM analysis) used was calculated for all POEs. Table 4 depicts an overview slide that provides a level two estimate (dollars in millions).

Table 4. Development Overview Example

Element	Current		% of Total	Methodology	Risk Rating	Risk $	
Software	$	29.7	21%	Parametric	Medium - High	$	5.1
Hardware	$	15.5	11%	Actuals & Analogy	Low	$	1.6
Integration Design	$	10.0	7%	Analogy & Factor	Low	$	1.4
Install/Assembly	$	5.9	4%	Factor	Low	$	0.5
Logistics	$	11.7	8%	Analogy	Medium	$	1.2
ST&E	$	40.1	28%	Actuals & Analogy	Medium - High	$	6.7
Data	$	15.1	11%	Parametric	High	$	2.6
EMD Support	$	6.7	5%	Analogy	Low	$	0.5
OGC	$	7.5	5%	Actuals	N/A	$	-
Program Total	**$**	**142.5**	**100%**			**$**	**19.6**

The majority of this data compiling could be accomplished by reviewing the methodology overview slide. However, when the overview slide language was vague, more information was referenced from backup slides. In addition to the data provided on the overview slide, each level two WBS element was expanded into further detail in subsequent slides. Figure 7 depicts an example of a POE's Integration Design at the level two detailed estimate.

Methodology:

- *SME opinion stated that the integration design effort associated with the CMC would be 20% of the previous AMP effort. Using EVM data from the AMP SDD contract, phased 20% of the effort over the 10 months period of performance.*
- *Kit proofing assumed to be inherent, based on AMP integration efforts*
- *Uncertainty was applied to the 20% factor to capture unknown biases.*

Figure 7. POE Further Detail Example for Level Two "Integration Design"

When two or more cost estimating methods were identified at the level two WBS, whichever method comprised the majority of the estimate was used for the entire total. The use of primary data from program offices is a strength of this analysis.

Dataset Characteristics

The dataset consists of 704 Program Office Estimates (POEs) spanning from 2000 to 2018, representing the majority of MDAPs AFLCMC has in its development and production portfolios. Table 5 and Table 6 depict the yearly POE count by ACAT type for the development and production phases respectively.

Table 5. Program Office Estimates (POEs) by Acquisition Category (Development)

ACAT by Yr	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
I	0	1	1	0	4	5	3	2	2	7	5	8	4	4	7	10	10	9	10	**92**
II	3	1	0	1	2	2	1	1	2	2	5	11	11	4	5	5	9	9	9	**83**
III	0	1	2	5	2	2	3	0	1	5	11	11	10	10	15	16	18	17	25	**154**
Total	**3**	**3**	**3**	**6**	**8**	**9**	**7**	**3**	**5**	**14**	**21**	**30**	**25**	**18**	**27**	**31**	**37**	**35**	**44**	**329**

Table 6. Program Office Estimates (POEs) by Acquisition Category (Production)

ACAT by Yr	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
I	0	1	1	0	4	5	3	2	2	7	5	8	3	4	7	10	10	9	10	**91**
II	3	1	0	1	2	2	1	1	2	2	5	11	11	4	5	5	9	9	9	**83**
III	0	1	2	6	2	4	4	0	4	9	13	16	13	16	21	19	23	19	29	**201**
Total	**3**	**3**	**3**	**7**	**8**	**11**	**8**	**3**	**8**	**18**	**23**	**35**	**27**	**24**	**33**	**34**	**42**	**37**	**48**	**375**

However, only 301 of these POEs will be used for the analysis because the 394 excluded did not have prior year POEs, therefore a cost growth percent could not be calculated for these POEs. Table 7 and Table 8 depict the remaining yearly POEs and ACAT type for the development and production phases respectively for the 310 POEs that have prior year POEs.

Table 7. Remaining POEs by Acquisition Category (Development)

ACAT by Yr	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
I	0	0	0	0	2	0	1	0	1	2	3	4	2	4	6	9	6	7	0	**47**
II	0	0	0	0	0	1	0	0	0	1	4	6	5	3	4	3	5	7	0	**39**
III	0	0	0	1	0	0	0	0	0	2	5	1	3	6	9	11	10	14	0	**62**
Total	**0**	**0**	**0**	**1**	**2**	**1**	**1**	**0**	**1**	**5**	**12**	**11**	**10**	**13**	**19**	**23**	**21**	**28**	**0**	**148**

Table 8. Remaining POEs by Acquisition Category (Production)

ACAT by Yr	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
I	0	0	0	0	2	0	1	0	2	2	3	4	2	4	6	9	6	7	0	**48**
II	0	0	0	0	0	1	0	0	0	1	4	6	5	3	4	3	5	7	0	**39**
III	0	0	0	1	0	0	0	0	1	2	5	2	6	10	11	12	10	15	0	**75**
Total	**0**	**0**	**0**	**1**	**2**	**1**	**1**	**0**	**3**	**5**	**12**	**12**	**13**	**17**	**21**	**24**	**21**	**29**	**0**	**162**

The final data exclusion criteria took place because of incomplete information. The incomplete information criteria meant at the level 2 WBS element; a cost estimating method was not identified in the POE slides. Nine POEs of the remaining 310 POEs met this data exclusion criteria. Four from the development phase, and five from the production phase. Table 9 and Table 10 depict the final POE count used by ACAT type for the development and production phases respectively.

Table 9. Final Data Set by Acquisition Category (Development)

ACAT by Yr	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
I	0	0	0	0	2	0	1	0	1	2	3	4	2	4	6	9	6	7	0	**47**
II	0	0	0	0	0	0	0	0	0	0	4	6	5	3	4	3	5	7	0	**37**
III	0	0	0	1	0	0	0	0	0	1	5	1	3	6	9	11	10	13	0	**60**
Total	**0**	**0**	**0**	**1**	**2**	**0**	**1**	**0**	**1**	**3**	**12**	**11**	**10**	**13**	**19**	**23**	**21**	**27**	**0**	**144**

Table 10. Final Data Set by Acquisition Category (Production)

ACAT by Yr	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
I	0	0	0	0	2	0	1	0	2	2	3	4	2	3	6	8	5	7	0	**45**
II	0	0	0	0	0	1	0	0	0	1	3	6	4	3	4	3	5	7	0	**37**
III	0	0	0	1	0	0	0	0	1	2	5	2	6	10	11	12	10	15	0	**75**
Total	**0**	**0**	**0**	**1**	**2**	**1**	**1**	**0**	**3**	**5**	**11**	**12**	**12**	**16**	**21**	**23**	**20**	**29**	**0**	**157**

The majority of MDAPs in the AFLCMC portfolio of weapon systems are aircraft (see Table 12). The “Other” category consists of MDAPs that are not aircraft such as automated information systems (AISs). Each category represented in Table 11 corresponds to information provided by AFLCMC.

Table 11. Basic Mission Characteristic for Dataset

Basic Mission Characteristics	Development	Production
Bomber	22	23
Fighter	28	27
Helicopter	9	10
Multi-Mission (i.e., Special Operations)	1	1
Other	17	22
Tanker	4	4
Trainer	5	5
Transport (Cargo)	32	39
Unmanned Aerial Vehicle	21	21
VIP Transport	5	5
Total	144	157

Model Development and Diagnostics

To conduct statistical inferences, a separate multiple linear regression analysis model will be applied for the development and for the production phases of the life cycle datasets. The general linear theoretical form of a multiple linear regression can be written as shown in equation 1:

$$y_i = \beta_0 + \beta_1 x_{1,i} + \beta_2 x_{2,i} + \cdots + \beta_k x_{k,i} + \varepsilon_i \qquad (1)$$

Where "*y*" represents the dependent variable, *i*,…, n represent the sample size. β_0, …, β_k are the estimated slope coefficients which provide how much the dependent variable changes when the respective independent variable changes by one unit *ceteris paribus* (all other independent variables being equal), and ε is the error term captures one or a combination of the following: 1) omitted variables, 2) measurement error, 3) incorrect functional form, and/or 4) a random component, (Hilmer, 2014, P. 77).

Equation 1 represents the theoretical linear multiple regression for an entire population. Because it is infeasible to directly observe the entire population, the best we can do is use the sample collected from the AFLCMC/FZC to form an estimated best fit multiple regression empirical model as shown in equation 2:

$$\hat{y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_{1,i} + \hat{\beta}_2 x_{2,i} + \cdots + \hat{\beta}_k x_{k,i} \tag{2}$$

There are numerous ways of developing a best fit empirical model, for the purposes of this thesis, the method that will be used is the ordinary least squares (OLS) method. The goal of this method is to estimate the linear relationship between y and a series of independent variables, x_1, x_2, …, x_k, that best fits the observed sample data by minimizing the sum of squared residual (denoted as e_i) by solving equation 3 (Hilmer, 2014, P. 153):

$$Minimize \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 = \sum_{i=1}^{n} \left(y_i - \hat{\beta}_0 + \hat{\beta}_1 x_{1,i} + \hat{\beta}_2 x_{2,i} + \cdots + \hat{\beta}_k x_{k,i}\right)^2 \tag{3}$$

The initial fitted models will account for all independent variables that are hypothesized to have an association with the dependent variable. A level of significance will be set to at 0.05 for all hypothesis testing. The first statistical measure that will be assessed is F-test. The F-test for the overall significance of the fitted regression model is a test that determines if the coefficients are jointly equal to zero, which is the null hypothesis. A p-value less than or equal to 0.05 for this statistical test would conclude to reject the null hypothesis in favor that at least one of the beta parameters in the fitted model is not equaled to zero.

An independent variable must be less than 0.05 to left in the final fitted model. For the OLS analysis, a backward stepwise procedure will be used to arrive at the final model for development and production phases. All control variables will be left in the model during the backward stepwise analysis. The multiple linear regression model will control for the total number of systems the POE is estimating for (denoted "quantity") and the percentage the POE has realized (denoted "Work Complete %"), in an effort to remove their effects from the dependent variable. The purpose of controlling for the variable, *quantity*, is to account for a potential factor effect of total units estimated. The purpose for the control variable, *Work Complete %*, is to account for the realized costs prior to the POE formulation.

Our development sample includes 144 POEs from 60 MDAPs and our production sample includes 157 POEs from 70 MDAPs. Although a panel regression model was considered prior to running test in the statistical software, our models will employ a pooled cross-sectional regression analysis with a backward regression analysis. Our dataset has a 15-year interval; however, 122 of the 130 MDAPs have observations for four years or less. Table 12 depicts the total amount of MDAPs relative to total amount of years present within the sample, and shows how unbalanced a panel analysis would be for this dataset. For example, 23 development MDAPs have only one observation.

Table 12. MDAPs Years of Data

# of Years	1	2	3	4	5	6	7	Total
Development	23	13	9	10	3	1	1	60
Production	29	15	11	12	2	0	1	70
Total	52	28	20	22	5	1	2	130

Our regression models will include a dummy variable to account for the main effects of the 60 MDAPs for development and 70 for production. This approach does come with some limitations. "Because we assume that the time-invariant component of the error-term is correlated with the independent variables in the population regression model" our model will not be the best linear unbiased estimator (Hilmer, 2014, p. 379). Adjusted R^2 will be used to compare the overall performance of competing multiple regression models.

Once we have the fitted empirical models, we will verify the standard OLS assumptions. First, to assess the assumptions of homoscedasticity and normality of the fitted model's residual, we will conduct a visual test of residual by predicted plot to test for heteroscedasticity. The Shapiro-Wilk (S-W) test will test whether the residuals are normally distributed. Next, to assess for multicollinearity between the predictor variables, we will examine their variance inflation factors. For the multicollinearity test, the VIF score must be below 10 in order for an independent variable to stay in the fitted model.

Dependent Variable

For the purposes of this research, our dependent variable is defined as the absolute value of the Program Acquisition Unit Cost (PAUC) percent change from the prior year's Program Office Estimate (POE), denoted "$|PAUC\%\Delta|$." The Program Acquisition Unit Cost is the total cost of development, production, operating and sustainment (O&S), or military construction (MILCON) divided by the number of units to be procured (Sullivan, 2011, P. 1). For example, the PAUC for development consists of the total development cost divided by the number of units to be procured. The purpose of taking the absolute value of the dependent variable, $PAUC\%\Delta$, is to study the strength of the effect of each individual independent variable by using the standardized beta coefficients in the final fitted models. This can be more informally interpreted as, on a normalized scale for units, which independent variable has the highest effect size on the dependent variable. All dollar amounts are normalized to Base Year (BY) 2019 dollars to account for the effect of inflation.

Independent Variables

We identified six independent variables, summarized in Table 13.

Table 13. Independent (Explanatory) Variables

Variable	Description
%Analogy	Percentage of the POE comprised of the Analogy Cost Estimation Method
%Buildup	Percentage of the POE comprised of the Engineering Build-up Cost Estimation Method
%EVM	Percentage of the POE comprised of the EVM Analysis Cost Estimation Method
%Factor	Percentage of the POE comprised of the Factor Cost Estimation Method
%SME	Percentage of the POE comprised of the SME Elicitation Cost Estimation Method
%Parametric	Percentage of the POE comprised of the Parametric Cost Estimation Method

As previously mentioned, the slides contain how the overall estimate was populated down to the Level two WBS elements. Using this information, a percentage of the cost estimating method for each independent variable in Table 10 was attained for all POEs. Therefore, the possible value of a given variable is zero to one, or 0%-100%, and the sum of the six variables will equal 1, or 100%, for each observation. For example, the POE for program 1 in year 2002 consisted of 22% of the analogy method, 50% of the factor method, and 28% of the parametric method. In this example, % buildup, %EVM, and %SME will have a value of 0% for their variable for this observation.

Summary

Leveraging the research in our literature review, we built a set of independent and control variables that form the backbone of our analysis. This enables us to intelligently defend the use of independent and control variables we hypothesize to have an association with our dependent variable, $|PAUC\%\Delta|$. We outlined our collection of data in order to develop the most robust dataset possible and ensure proper development for future statistical tests. We also provide systematic instructions for the data analysis and model-building process, which enables the process to be reconstructed while also defending our procedures. In Chapter IV, we will put the theory into action to interpret the results of our statistical analysis. In Chapter V we discuss our results and how they answer our research questions, as well as what our recommendations are for using this research and any future research, related to this research, that should be accomplished.

IV. Results and Analysis

Chapter Overview

This chapter presents the results from applying the methodology outlined in Chapter III and is divided into three sections. The first section presents the descriptive statistics for the dependent, independent, and control variables that will be used in the regression model. The second section presents the results of the backwards stepwise regression approach. Finally, the chapter will conclude with limitations of the data and analysis.

Descriptive Statistics

Before performing the backward stepwise regression analysis, a univariate analysis was performed to summarize the individual variables. Table 14 and Table 15 summarize the sample size, median, mean, standard deviation, coefficient of variation, 10% quartile value and 90% quartile value for the development and production datasets respectively. The histogram and full analysis are depicted in Appendix A. A univariate analysis was performed to describe and summarize the data in an effort to find patterns in the data. The descriptive statistics that we would like to highlight are the median, standard deviation, and coefficient of variation. At this time, it is also important to note the percent change from the prior year's Program Office Estimate (POE) variable seems to be high. For this variable, 10 % of the dataset is greater than 36.6% for development (37.2% for production), which seems high for a cost growth proxy, but is our subjective assessment and will not be adjusted for in our regression model. Unfortunately, there is no baseline sample we have to base this on, so future research in this area may be needed – therefore, the characteristics of the data is that 10% of the POEs have a yearly cost growth factor of approximately 37%. The detailed descriptive statistics and histograms for the development and production variables are located in Appendix A.

Table 14. Univariate Analysis (Development)

Variable	n	Median	Mean	Std Dev	10%Q	90%Q
$\|PAUC\%\Delta\|$	144	7.0%	12.5%	15.9%	1.0%	36.6%
%Analogy	144	0.0%	17.3%	27.8%	0.0%	66.0%
%Buildup	144	10.1%	27.3%	33.8%	0.0%	80.3%
%EVM	144	0.0%	24.5%	37.9%	0.0%	93.8%
%Factor	144	13.5%	16.9%	15.6%	1.0%	37.9%
%SME	144	0.0%	7.3%	18.0%	0.0%	27.1%
%Parametric	144	0.0%	6.7%	19.6%	0.0%	24.7%
Quantity	144	2	4	7	1	9
Work Complete %	144	49.2%	46.3%	33.0%	0.5%	92.2%

Table 15. Univariate Summary (Production)

Variable	n	Median	Mean	Std Dev	10%Q	90%Q
$\|PAUC\%\Delta\|$	157	7.7%	13.1%	15.9%	1.1%	37.2%
%Analogy	157	7.1%	20.2%	28.2%	0.0%	76.4%
%Buildup	157	10.3%	30.8%	35.7%	0.0%	87.6%
%EVM	157	0.0%	14.6%	27.9%	0.0%	68.5%
%Factor	157	14.8%	16.3%	12.1%	1.5%	33.8%
%SME	157	0.0%	4.3%	13.5%	0.0%	12.9%
%Parametric	157	0.0%	13.7%	24.8%	0.0%	62.6%
Quantity	157	103	224	373	2	607
Work Complete %	157	0.0%	20.3%	28.2%	0.0%	67.8%

This next section will study the extremes of the six methods by creating two groups to observe their respective means. Group "1" consists of the observations greater than two standard deviations from the mean value for the respective cost estimating method. Group "0" will consist of corresponding observations that contained a value of zero percent. A mean of cost estimating method and percent change from the prior year's Program Office Estimate (POE), denoted "$|PAUC\%\Delta|$" will be evaluated for both groups (see Table 16 and Table 17 for detailed breakout).

Table 16. Descriptive Statistics for Group "0" & "1" – Development

Method	n (0)	n (1)	n (total)	µ (0)	µ (1)	|PAUC %Δ| (0)	|PAUC %Δ| (1)	Δ Cost Growth
%Analogy	75	11	144	0.0%	88.1%	13.7%	9.2%	-4.6%
%Buildup	56	6	144	0.0%	98.5%	12.1%	25.1%	13.0%
%EVM	87	0	144	0.0%	0.0%	13.7%	13.7%	0.0%
%Factor	13	6	144	0.0%	65.7%	13.7%	5.0%	-8.8%
%SME	96	9	144	0.0%	68.7%	12.0%	29.1%	17.1%
%Parametric	113	9	144	0.0%	76.6%	12.7%	7.6%	-5.1%

Table 17. Descriptive Statistics for Group "0" & "1" – Production

Method	n (0)	n (1)	n (total)	µ (0)	µ (1)	|PAUC %Δ| (0)	|PAUC %Δ| (1)	Δ Cost Growth
%Analogy	56	15	157	0.0%	84.2%	14.8%	12.6%	-2.3%
%Buildup	52	0	157	0.0%	0.0%	14.3%	14.3%	0.0%
%EVM	107	13	157	0.0%	85.2%	14.3%	6.6%	-7.7%
%Factor	11	6	157	0.0%	46.8%	16.5%	3.6%	-12.9%
%SME	110	6	157	0.0%	63.2%	14.5%	16.1%	1.6%
%Parametric	93	14	157	0.0%	76.5%	12.4%	19.8%	7.3%

As previously mentioned, the cost-estimation community is in general agreement that objective modeling is the most rigorous for quantifying uncertainty when constructing cost estimates, and we would expect a decrease from the group "0" mean to the group "1" mean value for these methods, and the opposite results for subjective modeling.

Figure 8. $|PAUC\%\Delta|$ vs Group "0" & "1" - Development

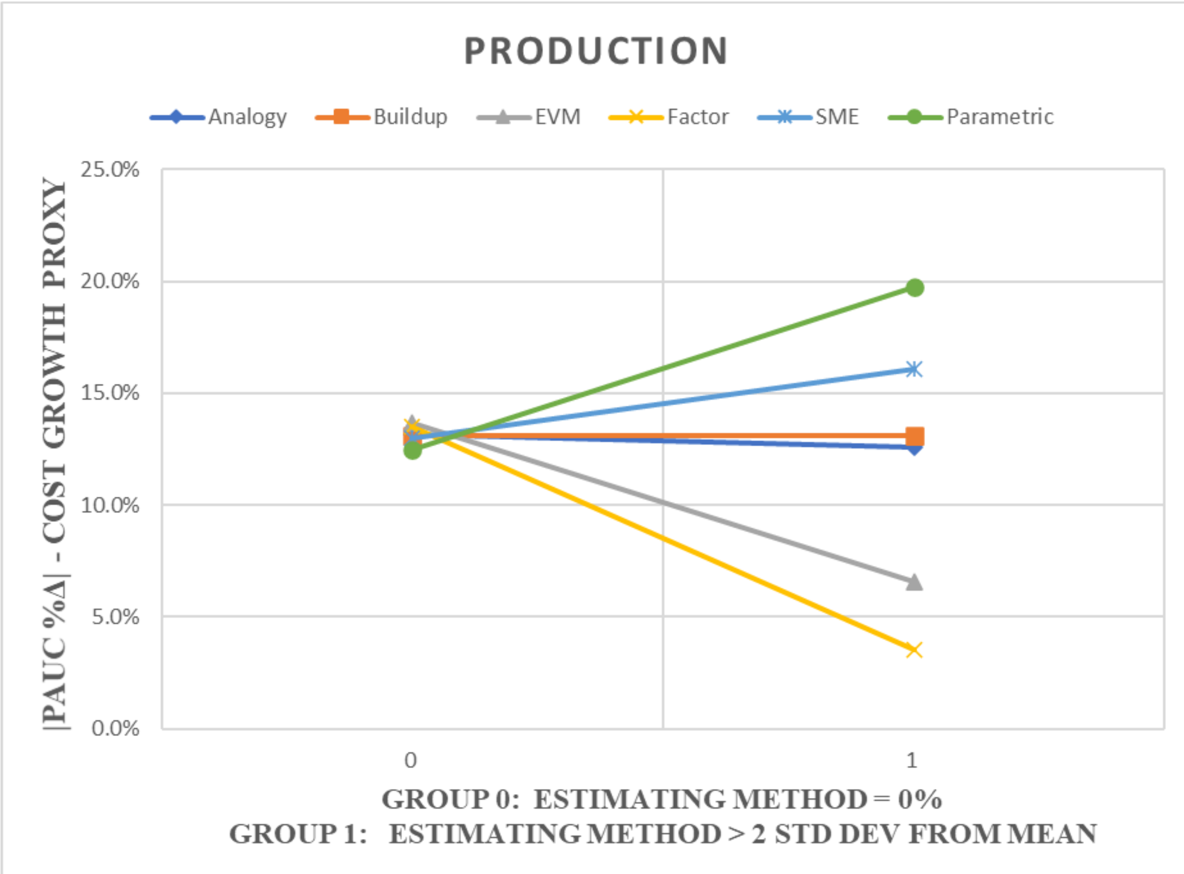


Figure 9. $|PAUC\%\Delta|$ vs Group "0" & "1" - Production

For the %SME elicitation cost estimating method, cost growth changes by 17.1% from the mean value of cost growth for development (depicted in Figure 8) and 1.6% from the mean value for production (depicted in Figure 9) for POEs that contain a high amount of the SME elicitation cost estimating method. Figure 8 and Figure 9 depict the respective $|PAUC\%\Delta|$ for each cost estimating method for the development and production dataset respectively. It is important to note that the trend shows the percentage the point estimate is off on average.

Regression Model

The purpose of this section is to develop an empirical model to study independent variables that have a statistical association with the absolute value of the Program Acquisition Unit Cost (PAUC) percent change from the prior year's Program Office Estimate (POE), denoted "$|PAUC\%\Delta|$" in the AFLCMC's portfolio from 2003 to 2017–thus the dependent variable is $|PAUC\%\Delta|$. First, we theoretically consider the following six independent variables for inclusion in the model: 1) %Analogy, 2) %Buildup, 3) %EVM, 4) %Factor, 5) %SME, and 6) %Parametric while controlling for quantity, the work complete %, and the individual MDAPs as previously mentioned. These variables are summarized in Table 18

Table 18. Variable Descriptions

Variable	Variable Type	Description
$\vert PAUC\%\Delta\vert$	Dependent	Absolute value of the Program Acquisition Unit Cost percent change
%Analogy	Independent	Percentage of the POE comprised of the Analogy Cost Estimation Method
%Buildup	Independent	Percentage of the POE comprised of the Engineering Build-up Cost Estimation Method
%EVM	Independent	Percentage of the POE comprised of the EVM Analysis Cost Estimation Method
%Factor	Independent	Percentage of the POE comprised of the Factor Cost Estimation Method
%SME	Independent	Percentage of the POE comprised of the SME Elicitation Cost Estimation Method
%Parametric	Independent	Percentage of the POE comprised of the Parametric Cost Estimation Method
Quantity	Control	Quantity of systems the POE comprised
Work Complete %	Control	Percentage of the POE completed
Individual MDAPs	Control	Dummy variable for the individual MDAPs

First, we expect objective cost estimating to have a negative association with the $|PAUC\%\Delta|$--as the percentage of objective cost estimating increases thus decreasing cost growth. As previously mentioned, the cost-estimation community is in general agreement that objective modeling, like parametric methods, are the most rigorous for quantifying uncertainty when constructing cost estimates, and are seen as the higher in quality method (AF CRUH, 2007) (Galway, 2007). Next, we expect subjective cost estimating to have a positive association with the $|PAUC\%\Delta|$--as the percentage of subjective cost estimating increases thus increasing cost growth. The engineering build-up variable, denoted *%Buildup*, will be excluded from the initial fitted model, because it has the highest proportion of the estimate on average. One variable has to be removed prior to running a stepwise regression or perfect collinearity will be present in the model which will violate the OLS assumption of no perfect collinearity.

Thus, our initial theoretical model for both development and production are summarized in Equation 4:

$$|PAUC\%\Delta| = f(\%Analogy, \%EVM, \%Factor, \%SME, \%Parametric, Quantity, Work\ Complete\ \%, Individual\ MDAPs) \quad (4)$$

For the research, the additive empirical model will be used as shown in Equation 5 prior to the backwards stepwise regression analysis for development and production:

$$|PAUC\%\Delta| = \beta_0 + \beta_1\%Analogy + \beta_2\%EVM + \beta_3\%Factor + \beta_4\%SME + \beta_5\%Parametric + \beta_6 Quantity + \beta_7 Work\ Complete\ \% + (betas\ for\ the\ Individual\ MDAPs) + \varepsilon \quad (5)$$

As outlined in Chapter 3, OLS regression was used to estimate the beta coefficients using a stepwise regression analysis. The final fitted models are shown in Equation 6 and Equation 7 for development and production respectively. All models for the stepwise analysis are contained in Appendix B.

$$|P\widehat{AUC}\%\Delta| = 0.154 + 0.193\%SME - 0.004Quantity - 0.026Work\ Complete\ \% + \ldots\ betas\ for\ all\ MDAPs \quad (6)$$

$$|P\widehat{AUC}\%\Delta| = 0.133 - 3.93 \times 10^{-5}Quantity + 0.098Work\ Complete\ \% + \ldots\ betas\ for\ all\ MDAPs \quad (7)$$

For this analysis, we are using a level of significance of 0.05. For the final fitted development model, the model results indicate an adjusted $R^2 = 0.297$. Which indicates that 29.7% of the variability is explained by the fitted model. Additionally, the model is statistically significant as the p-value for the F-test is 0.0020-i.e., we reject the null hypothesis and conclude that at least one of the slope coefficients is different than zero. With respect to the individual variables, three of them are statistically significant. See Appendix B for all beta values for MDAPs. Table 19 depicts the steps taken during the reverse stepwise analysis for the development data set models summarizing the F-test values, adjusted R^2 values, degrees of freedom, and respective p-values for the independent variables. The table does not include the p-values of the individual MDAPs, but the values can be seen in Appendix C.

Table 19. Development Dataset Stepwise Analysis Summary

				Development's fitted model p-values						
Model	F-Test	Adjusted R^2	DF Error	%Analogy	%EVM	%Factor	%SME	%Parametric	Quantity	Work Complete %
1	0.0033	0.2948	77	0.266	0.384	0.162	0.205	0.3847	0.972	0.412
2	0.0028	0.2970	78	0.386	0.487	0.142	0.106	*Removed*	0.954	0.458
3	0.0022	0.3015	79	0.510	*Removed*	0.167	0.062	*Removed*	0.988	0.351
4	0.0017	0.3064	80	*Removed*	*Removed*	0.162	0.035	*Removed*	0.936	0.358
5	0.0020	0.2979	81	*Removed*	*Removed*	*Removed*	0.044	*Removed*	0.821	0.726

While controlling for the main effects of the individual (59) MDAPs, the %SME variable is still statistically significant. The beta is positive with a magnitude of 0.193. Five VIF scores are greater than 10 which suggests multicollinearity is present in this fitted model, however, multicollinearity was only present between a few programs and the quantity control variable.

For the final fitted *production* model, the model results indicate an adjusted $R^2 = 0.147$. Which indicates that 14.7% of the variability is explained by the fitted model while taking account for the number of independent and control variables. Additionally, the model is not statistically significant as the p-value for the F-test is 0.0781 we fail to reject the null hypothesis and conclude that all slope coefficients are zero. No other statistical inferences can be made from the fitted production model. Table 20 depicts the steps taken during the reverse stepwise analysis for the production dataset models summarizing the F-test values, adjusted R2 values, degrees of freedom, and respective p-values for the independent variables. The table does not include the p-values of the individual MDAPs, but the values can be seen in Appendix C. It is important to note that none of the independent variables were statistically significant in the Production dataset, which includes %SME.

Table 20. Production Dataset Stepwise Analysis Summary

Model	F-Test	Adjusted R^2	DF Error	Production's fitted model p-values						
				%Analogy	%EVM	%Factor	%SME	%Parametric	Quantity	Work Complete %
1	0.0806	0.1544	80	0.980	0.129	0.106	0.767	0.882	0.793	0.140
2	0.0649	0.1648	81	*Removed*	0.122	0.104	0.766	0.883	0.792	0.137
3	0.0519	0.1747	82	*Removed*	0.097	0.102	0.759	*Removed*	0.793	0.124
4	0.0414	0.1837	83	*Removed*	0.091	0.105	*Removed*	*Removed*	0.789	0.124
5	0.0553	0.1674	84	*Removed*	0.083	*Removed*	*Removed*	*Removed*	0.729	0.233
6	0.0781	0.1470	85	*Removed*	*Removed*	*Removed*	*Removed*	*Removed*	0.735	0.399

Limitations

As with any statistical model, there are limitations to our regression models. First, the database was initially created by POEs produced by cost estimators within an ACAT I, II, or III program office which was then collected by AFLCMC Cost Division. To add another level of complexity, we added the information of cost estimating methods for purposes outlined in this research effort. Although this process was done as carefully as possible, the dataset contained incomplete information. Due to the non-standardized methods of indicating cost estimating method in the slides, the researchers updated the database using personal judgement, cross-checked with AFLCMC/FZC personnel. The records were updated as rigorously and consistently as possible. A typical POE has an overview slide that provides a level two work breakdown structure with cost estimation method information. The benefit of using primary data from the individual program offices far outweigh the cost of this limitation.

As mentioned in the previous chapter, our dataset for both development and production have a cross-sectional component. Our development sample included 144 POEs from 60 MDAPs and our production sample included 157 POEs from 70 MDAPs. Our final model employed a pooled cross-sectional regression analysis, and our VIF score analysis suggests multicollinearity in the model. Because we assumed that the time-invariant component of the error-term is correlated with the independent variables in the population regression model our model will not be the best linear unbiased estimator (Hilmer, 2014, p. 379).

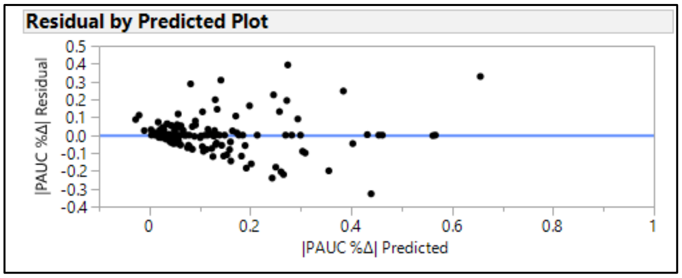


Figure 10. Residual by Predicted Plot (Model 5 – Development)

For the diagnostics tests, the first step is to test the model for constant variance, or homoskedasticity. Figure 10 depicts the residual by predicted plot for the final fitted model with MDAPs main effects included. The figure suggests heteroskedasticity is present in the model, which suggests that there is not constant variance in the model. This may affect the values of the standard errors which in turn may provide inaccurate p-values. The second step is to test the residuals of the fitted model to analyze if they are approximately normally distributed. The Shapiro-Wilk Test provided a p-value of <0.001, therefore we reject the null hypothesis that the residuals are normally distributed. However, the sample size is 144 for this model, so since we have a large sample, we can argue that our statistical inferences are robust to non-normality.

V. Conclusion

Chapter Overview

This chapter summarizes the major findings drawn from the research and analysis conducted in the preceding four chapters. The findings for each research question are also presented and then discussed in the context of relevance and significance to the cost estimating community. We begin by summarizing these findings before we discuss how our research questions have been answered. Finally, the topics of limitations and future research are addressed in this chapter.

Research Questions Answered

SME Elicitation Methods within DoD

The first research question addressed the heuristics that the DoD cost-estimation community uses to reduce uncertainty, complexity, and ambiguity when using subject matter expert elicitation methods. There are two foundational handbooks that inform the Air Force's cost estimating community as it attempts to quantify risk and uncertainty for cost estimates. The two handbooks are the United States Air Force Cost Risk and Uncertainty Analysis Handbook (AF CRUH) and the Joint Agency Cost Schedule Risk and Uncertainty Handbook (JA CSRUH). The heuristics applied can be summarized in nine steps which advises the cost estimator to: 1) have historical minimum, maximum, and averages on hand, 2) use multiple experts, 3) ask the expert for an upper and lower value, 4) encourage a dialog to identify various possible outcomes thus far, 5) seek the most-likely value near the end of the step for discussion, 6) select a distribution, 7) treat the SMEs input as the 70% interval, 8) Crosscheck information and challenge SMEs against historical experience, and 9) Iterate the evolving conclusions with the experts as needed.

SME Elicitation Methods within Academia and Industry

The next research question addresses the concepts and heuristics other disciplines consider when applying subjective uncertainty when using SME elicitation methods. In 1974, Nobel Laureate Daniel Kahneman and Professor Amos Tversky started the revolutionary study of Behavioral Economics. They proposed that when facing numerous sensory inputs, it is natural to reduce complexity via the use of heuristics, also known as best practices. In general, these heuristics are quite useful, but sometimes they lead to severe and systematic errors, commonly referred to as biases. The two disciplines researched for this research effort are actuaries and insurers.

The aim of an actuary, when using subjective methods of estimating risk, is to distinguish between low-quality and high-quality judgments to improve the robustness of the risk estimate. Within actuarial work, actuaries strive to elicit high quality expert judgements by using relevant information elicited in an unbiased manner to form a coherent view. Actuaries combat this dilemma in a three-step approach for high quality expert judgements. The steps include: 1) setting the process of the expert judgement policy, 2) identification of the relevant judgements and updating processes, and 3) identifying the expert. Actuaries dive deeper into stems two and three with these five subprocesses: 1) Identify date the SME elicitation information was set and subsequently updated, 2) SME owner and experience that qualifies the SME as an expert for that particular scenario, 3) process of peer-review and sign-off, 4) updating process, and 5) identification of materiality. If done poorly, the credibility of the actuarial worker is on the line.

Another industry that frequently analyzes subjective uncertainty are insurance companies. Several isolated events have caught insurers by surprise but, in general, risk experts are better at identifying risks that are not readily apparent to non-experts. One important factor that insurers evaluate is the potential dependency of events. Large portfolios can protect insurance companies from major losses if risk is independent, however, if risks are dependent then a single incident can cause large losses. The two primary best practices recommendations by insurers relate to habitual thinking and missing feedback. These two categories consist of questions the insurer should answer when eliciting information from SMEs in efforts of developing high quality, i.e., non-biases subjective probability distributions. These will be outlined in the "Recommendation" section of the chapter.

Empirical Models

The final two research questions are addressed by the pool cross-sectional multiple regression fitted models. As a reminder, the questions are: 1) Is there an associated relationship between the percentage of Subject Matter Expert (SME) based cost estimating method to cost growth for Program Office Estimates (POEs) during the development and/ or production phases of a program's life cycle?; 2) Does cost growth tend to be higher for Subject Matter Expert (SME) based estimates than analogy or more objective based cost estimating methods during the development and/ or production phases of a program's life cycle?

For the final fitted pooled cross-sectional development model, the results indicated an adjusted $R^2 = 0.298$. Which indicates that 29.8% of the variability is explained by the fitted model. Additionally, the overall model is statistically significant as the p-value for the F-test is 0.002-i.e. The model for development controlled for a dummy variable for every MDAP. Interestingly, %SME was still statistically significant with a p-value of 0.044. Suggesting that there is a statistical relationship between the percent SME cost estimating method and the proxy variable for cost growth.

For the final fitted production model, the model results indicated an adjusted $R^2 = 0.147$. Which indicates that only 14.7% of the variability is explained by the fitted model. Additionally, the model was not statistically significant as the p-value for the F-test is 0.0781 we fail to rejected the null hypothesis and concluded that all slope coefficients are zero. No other statistical inferences can be made from the fitted production model. It is important to note that none of the independent variables were statistically significant for the production dataset, which includes the SME elicitation method.

Significance of Results

This research attempts to compare the efficacy of the SME elicitation methods to other cost estimation methodologies using a sample dataset from AFLCMC program office estimates (POEs). Additionally, this research addresses whether DoD guidance related to the use of SME elicitation matches the best practices used in industry and academia. This accomplished by consolidating the heuristics that the DoD cost-estimation community uses to reduce uncertainty, complexity, and ambiguity when using SME elicitation methods, from the governing handbooks, and addresses the concepts and heuristics other disciplines consider when applying subjective uncertainty when using SME elicitation methods. During this research effort, we updated 6,811 records for 704 POEs (includes both development and production phases separate) to conduct statistical tests for this thesis. This information could be useful to the AFLCMC cost estimating community because every level two WBS element has information on what cost estimating method used to develop that cost estimate. As a reminder, this is how we developed the percentage of cost estimating method for a given POE, and is outlined in detail in chapter III

Recommendation

It's easy to claim that the SME elicitation processes within the AF are done poorly, and is in an inferior to other cost estimation methods within the AF. However, this will not be the overarching claim of this thesis. Revisiting this concept from chapter I, the Department of Defense (DoD) faces an operational environment that is characterized by uncertainty, complexity, and ambiguity (Williams, 2010). And we would add with known limited resources. Our recommendation for this thesis is to publish a robust formal method in the cost risk uncertainty handbook to better facilitate the elicitation process from SMEs in efforts to maximize the value of this method. Brown (2019) recommends the Sandford Research Institute (SRI) Elicitation Process model which stresses that documentation is a continual process that takes place throughout each phase of the elicitation. Also, O'Hagan (2019) developed a "SHELF protocol" which requires an experience facilitator to manage the elicitation process to address possible sources of biases in group interactions. Both methods would better facilitate the elicitation process within the cost estimating community.

As previously mentioned, Kahneman elegantly describes two systems of how human behavior is determined under decision making. He famously notes: "System 1 (automatic thinking) operates automatically and quickly, with little or no effort and no sense of voluntary control", and System 2 (conscious thinking) "allocates attention to the effortful mental activities that demand it, including complex computations" (Kahneman, 2011, P. 20-21). When eliciting judgments from SMEs, Kahneman would highly encourage a process to hone in on System 2, or conscious thinking by SMEs, and we would argue that due to the ad hoc nature (Brown, 2019) (Galway, 2007, P. 12) of the current processes we are under a System 1 process as defined by Kahneman.

While reviewing the literature, it was clear that other industries are asking questions like: 1) Do established routines miss out on important pieces of information? 2) Do processes lead to habits that prevent people from asking important questions? 3) Have the parameters changed? 4) Do routines no longer cover all angles? 5) is there enough information to verify assumptions? 6) How robust is the model? 7) What kind of information would make the model more robust? 8) Can you use auxiliary variables as substitutes for missing information? 9) How does your company feed information back to you? These questions were paramount for insurance companies because they must be mindful of the uncertainties inherent in predicting rare events (Weick et. al., 2012, P. 9) because the credibility of the company is on the line. Although all points are relevant to the DOD, a formal protocol for providing timely feedback to SMEs could make the processes a learning process for the SMEs, so further research was done in efforts to find an implementable process for the AF cost estimating community.

Our recommendation for this is a robust formal method called the "SHELF" protocol, or similar concepts that this protocol addresses. This is an implementable protocol that is designed to address and minimize the cognitive and motivational biases that experts are prone to have when making probabilistic judgments (O'Hagan, 2019). The first concept addressed is this idea of training experts in advance of efforts to familiarize the experts with making the necessary probabilistic judgements. This is accomplished by an e-learning course, available to the public, that was developed by the U.S. Office of Naval Research. The second concept addressed under this protocol is called an "evidence dossier" and templates for documentation. The dossier assembles all the most relevant evidence into a single document in a format that is key in combating the availability heuristic. The documentation template would allow a novice cost analyst a checklist of items, so all steps of the SME elicitation process could be reviewed prior to being conducted. Also, this would standardize how the documentation is collected which would satisfy a key finding in a 2007 RAND study (Galway, 2007, P. 12). As previously mentioned, the finding was the DoD's "elicitation methodologies are largely ad hoc, in that they are seldom based on or derived from references to the elicitation literature" (Galway, 2007, P. 12). The final concept that this protocol takes into account is the idea they call a rational impartial observer (RIO). The RIO is a hypothetical person the experts ask, after seeing all of the evidence, listening to other SMEs talk about their individual views; what is the true range of possible outcomes, and what would the shape of this distribution look like when modeling. The SHELF protocol is a robust formal method to theoretically better facilitate the elicitation process with SMEs and is worth the consideration for implementation in the cost estimating community.

Future Research

The ability to expand upon this research is vast. The first section of recommend further research will be viewed from the scope of using the current dataset. The first recommendation for further research is to use the data in a panel regression analysis. The issues and consequences associated with our method, pooled cross-sectional regression analysis, we assumed that the time-variant component of the error-term is correlated with the independent variables in the population regression model. This violates the assumption that the error term is uncorrelated with the independent variables which results in our beta estimates are not the best linear unbiased estimators. The second recommendation is to investigate the dependent variable (denoted "$|PAUC\%\Delta|$" in our research) in efforts to understand this population. Thirty POEs (14 for development and 16 for production) have a value approximately greater than 36.5% (the range is 36.5%- 98.4%). This recommendation is influence by the potential need to investigate omitted variables in our models. These values seem excessive for a cost growth percentage, but we have no context for modeling these values separately.

The next recommendation is outside the scope of our dataset. This recommendation stems from the literature review: “Putting odds on uncertain events or ranges on uncertain qualities is not a skill that arises automatically from experience and intuition… researchers discovered that assessing uncertainty general skill that can be taught with a measurable improvement” (Hubbard, 2011, p. 94-95). We believe an experiment into investigating if SMEs are trainable is completely warranted. Currently, the cost estimating community is recommend to treat a SMEs input as the 70% interval, which assumes, all SMEs are the same and no learning is taking place. Using the SHELF protocol e-learning course could be a source for the “treatment”.

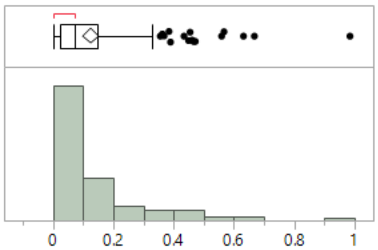
Summary

This research uses a dataset that consists of 704 Program Office Estimates (POEs) representing the majority of MDAPs AFLCMC has in their development and production portfolios. To conduct statistical inferences, a separate multiple linear regression analysis model was applied for the development and production phases of the life cycle datasets. This effort accomplished a meticulous data population for six variables for 704 POEs spanning from 2000 to 2018. This research compared the efficacy of the SME elicitation methods to other cost estimation methodologies using a development and production dataset provided by AFLCMC. Additionally, this research provided best practices used in industry and academia when eliciting SME. This research involved using a statistics-based approach to investigate if SME based cost estimating methods have an associated relationship to Program Acquisition Unit Costs (PAUC), which will be our proxy variable to cost growth. Using a pooled cross-sectional OLS regression analysis model with adjusted R^2 of 0.298 144 POEs sample for development have statistical evidence to support SME based cost estimates have a positive association with Program Acquisition Unit Cost (PAUC), our proxy variable for cost growth.

Appendix A – Univariate Analyses

Dependent Variable

|PAUC %Δ|

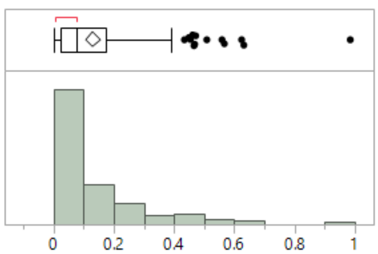


Quantiles		
100.0%	maximum	0.984446253
99.5%		0.984446253
97.5%		0.5911119693
90.0%		0.365720901
75.0%	quartile	0.148514591
50.0%	median	0.0701570775
25.0%	quartile	0.0217632285
10.0%		0.009989711
2.5%		0.0036632043
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	0.1249517
Std Dev	0.1589202
Std Err Mean	0.0132434
Upper 95% Mean	0.1511298
Lower 95% Mean	0.0987737
N	144

Figure 11. $|PAUC\%\Delta|$ Histogram (Development)

|PAUC %Δ|



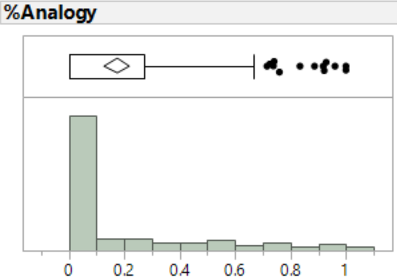
Quantiles		
100.0%	maximum	0.984446253
99.5%		0.984446253
97.5%		0.5697350051
90.0%		0.3717404384
75.0%	quartile	0.1729061395
50.0%	median	0.076807317
25.0%	quartile	0.0251058805
10.0%		0.0108250392
2.5%		0.0039330251
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	0.1309803
Std Dev	0.1588458
Std Err Mean	0.0126773
Upper 95% Mean	0.1560216
Lower 95% Mean	0.1059391
N	157

Figure 12. $|PAUC\%\Delta|$ Histogram (Production)

Independent Variables

%Analogy



Quantiles		
100.0%	maximum	1
99.5%		1
97.5%		0.9405111988
90.0%		0.6599196035
75.0%	quartile	0.2692360485
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	0.1727413
Std Dev	0.2778709
Std Err Mean	0.0231559
Upper 95% Mean	0.2185134
Lower 95% Mean	0.1269692
N	144

Figure 13. %Analogy Histogram (Development)

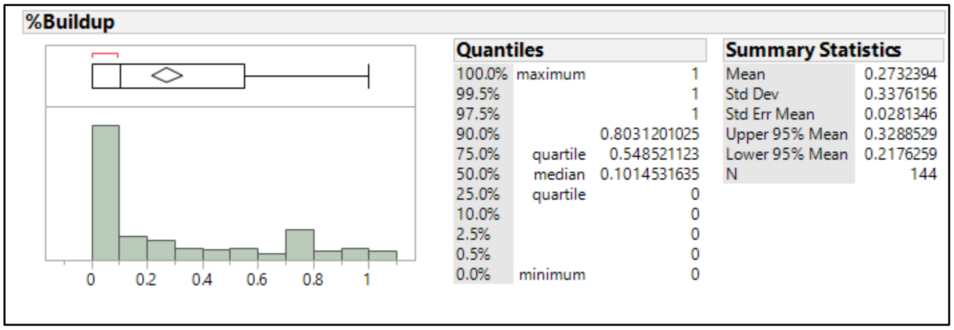


Figure 14. %Buildup Histogram (Development)

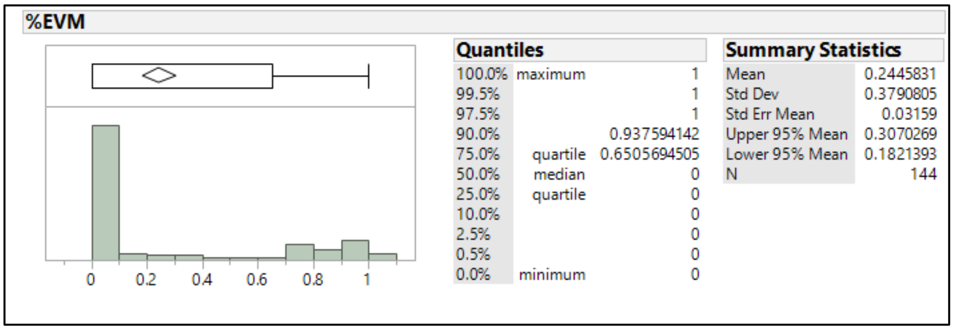


Figure 15. %EVM Histogram (Development)

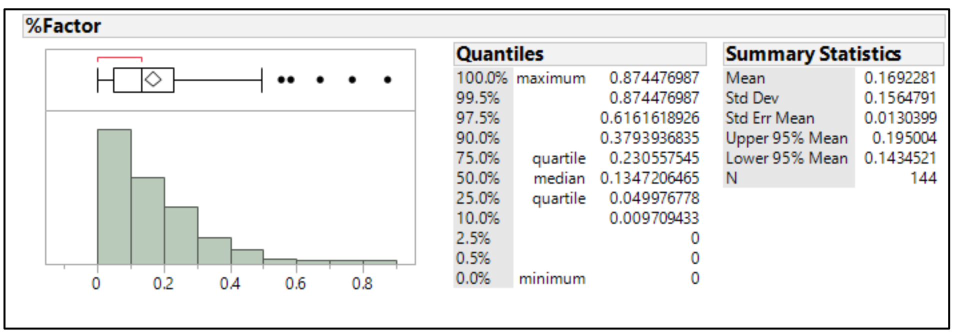


Figure 16. %Factor Histogram (Development)

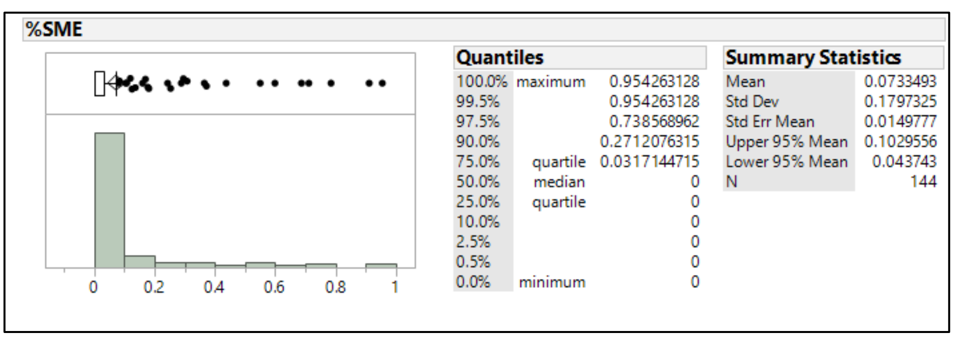
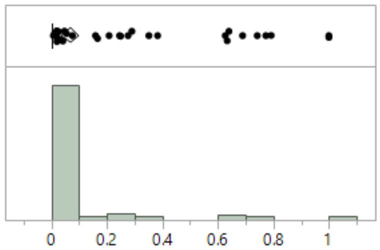


Figure 17. %SME Histogram (Development)

%Parametric



Quantiles

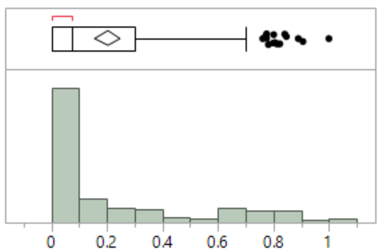
100.0%	maximum	1
99.5%		1
97.5%		0.7800335136
90.0%		0.2471548465
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.0668589
Std Dev	0.1956241
Std Err Mean	0.016302
Upper 95% Mean	0.099083
Lower 95% Mean	0.0346349
N	144

Figure 18. %Parametric Histogram (Development)

%Analogy



Quantiles

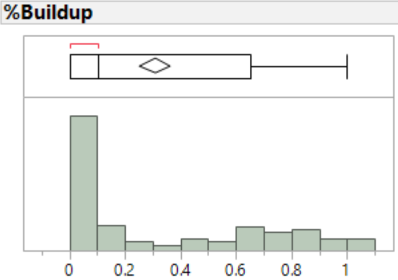
100.0%	maximum	1
99.5%		1
97.5%		0.8905395893
90.0%		0.7636222708
75.0%	quartile	0.3016423785
50.0%	median	0.07131972
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.2019079
Std Dev	0.282141
Std Err Mean	0.0225173
Upper 95% Mean	0.2463861
Lower 95% Mean	0.1574298
N	157

Figure 19. %Analogy Histogram (Production)

%Buildup



Quantiles

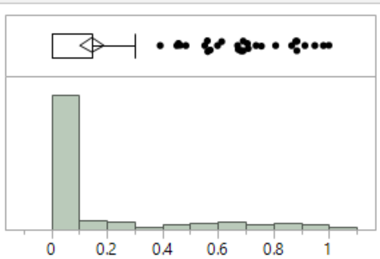
100.0%	maximum	1
99.5%		1
97.5%		1
90.0%		0.8755821466
75.0%	quartile	0.652243116
50.0%	median	0.103380802
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.3082347
Std Dev	0.3570272
Std Err Mean	0.0284939
Upper 95% Mean	0.3645183
Lower 95% Mean	0.2519511
N	157

Figure 20. %Buildup Histogram (Production)

%EVM



Quantiles

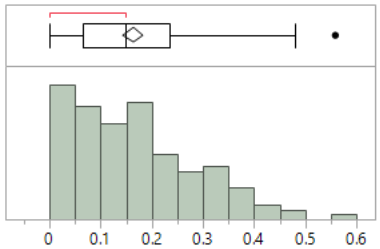
100.0%	maximum	1
99.5%		1
97.5%		0.9154896152
90.0%		0.6849723664
75.0%	quartile	0.147168513
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.1464681
Std Dev	0.2786071
Std Err Mean	0.0222353
Upper 95% Mean	0.1903891
Lower 95% Mean	0.102547
N	157

Figure 21. %EVM Histogram (Production)

%Factor



Quantiles

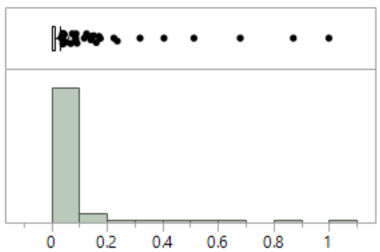
100.0%	maximum	0.558823529
99.5%		0.558823529
97.5%		0.4497516204
90.0%		0.338480731
75.0%	quartile	0.2358108795
50.0%	median	0.147640527
25.0%	quartile	0.0657856605
10.0%		0.015220156
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.1629925
Std Dev	0.1213917
Std Err Mean	0.0096881
Upper 95% Mean	0.1821293
Lower 95% Mean	0.1438557
N	157

Figure 22. %Factor Histogram (Production)

%SME



Quantiles

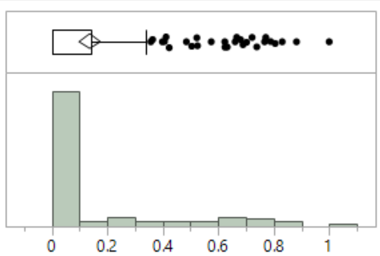
100.0%	maximum	1
99.5%		1
97.5%		0.5217709537
90.0%		0.129038569
75.0%	quartile	0.012838803
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.0429977
Std Dev	0.134952
Std Err Mean	0.0107703
Upper 95% Mean	0.0642722
Lower 95% Mean	0.0217232
N	157

Figure 23. %SME Histogram (Production)

%Parametric



Quantiles

100.0%	maximum	1
99.5%		1
97.5%		0.8064683456
90.0%		0.6255657168
75.0%	quartile	0.1423276125
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

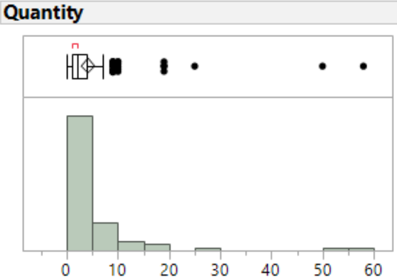
Summary Statistics

Mean	0.1373991
Std Dev	0.2478129
Std Err Mean	0.0197776
Upper 95% Mean	0.1764656
Lower 95% Mean	0.0983326
N	157

Figure 24. %Parametric Histogram (Production)

Control Variables

Quantity



Quantiles

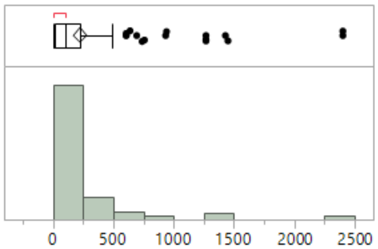
100.0%	maximum	58
99.5%		58
97.5%		21.25
90.0%		9
75.0%	quartile	4
50.0%	median	2
25.0%	quartile	1
10.0%		1
2.5%		0.625
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	4.1527778
Std Dev	7.2684003
Std Err Mean	0.6057
Upper 95% Mean	5.3500603
Lower 95% Mean	2.9554953
N	144

Figure 25. Quantity Histogram (Development)

Quantity



Quantiles

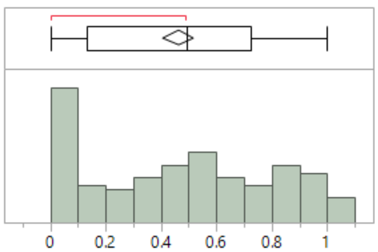
100.0%	maximum	2402
99.5%		2402
97.5%		1430.05
90.0%		607
75.0%	quartile	222
50.0%	median	103
25.0%	quartile	17
10.0%		2
2.5%		1
0.5%		1
0.0%	minimum	1

Summary Statistics

Mean	224.47134
Std Dev	373.44345
Std Err Mean	29.804032
Upper 95% Mean	283.34287
Lower 95% Mean	165.59981
N	157

Figure 26. Quantity Histogram (Production)

Work Complete %



Quantiles

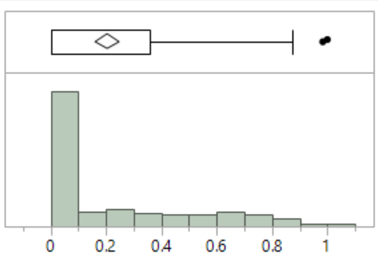
100.0%	maximum	1
99.5%		1
97.5%		1
90.0%		0.921926461
75.0%	quartile	0.7237469113
50.0%	median	0.4923739185
25.0%	quartile	0.1336682995
10.0%		0.0051567065
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.4627215
Std Dev	0.3298213
Std Err Mean	0.0274851
Upper 95% Mean	0.5170511
Lower 95% Mean	0.4083919
N	144

Figure 27. Work Complete % (Production)

Work Complete %



Quantiles

100.0%	maximum	1
99.5%		1
97.5%		0.8658915077
90.0%		0.6779625272
75.0%	quartile	0.3560811555
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.2029455
Std Dev	0.2820428
Std Err Mean	0.0225095
Upper 95% Mean	0.2474081
Lower 95% Mean	0.1584828
N	157

Figure 28. Work Complete % (Production)

Appendix B – Stepwise Models

Figure 29. Model 1 (Development)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.62029
RSquare Adj	0.294824
Root Mean Square Error	0.133453
Mean of Response	0.124952
Observations (or Sum Wgts)	144

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	66	2.2402123	0.033943	1.9059
Error	77	1.3713447	0.017810	Prob > F
C. Total	143	3.6115570		0.0033*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2274722	0.093301	2.44	0.0171*
%Analogy	-0.08083	0.072058	-1.12	0.2655
%EVM	-0.054761	0.06248	-0.88	0.3835
%Factor	-0.213155	0.151089	-1.41	0.1623
%SME	0.1373465	0.10746	1.28	0.2050
%Parametric	-0.083338	0.095322	-0.87	0.3847
Quantity	0.0005844	0.016773	0.03	0.9723
Work Complete %	-0.068743	0.083282	-0.83	0.4117
Program[1]	-0.041114	0.106071	-0.39	0.6994
Program[2]	-0.01817	0.126257	-0.14	0.8859
Program[3]	0.0316197	0.168178	0.19	0.8514
Program[4]	-0.043396	0.154034	-0.28	0.7789
Program[5]	-0.029656	0.149081	-0.20	0.8428
Program[6]	-0.060005	0.077924	-0.77	0.4436
Program[7]	-0.036315	0.123789	-0.29	0.7700
Program[8]	-0.06869	0.077184	-0.89	0.3763
Program[9]	0.1385604	0.089393	1.55	0.1252
Program[10]	-0.010087	0.15355	-0.07	0.9478
Program[11]	-0.05301	0.093624	-0.57	0.5729
Program[12]	0.0180158	0.19581	0.09	0.9269
Program[13]	-0.100113	0.092222	-1.09	0.2811
Program[14]	-0.074947	0.147686	-0.51	0.6133
Program[15]	0.0228894	0.097129	0.24	0.8143
Program[16]	-0.093473	0.113317	-0.82	0.4120
Program[17]	-0.095392	0.158206	-0.60	0.5483
Program[18]	-0.053336	0.098982	-0.54	0.5915
Program[19]	0.1454309	0.112196	1.30	0.1988
Program[20]	0.3483144	0.153741	2.27	0.0263*
Program[21]	0.1984773	0.15215	1.30	0.1960
Program[22]	-0.00742	0.085404	-0.09	0.9310
Program[23]	0.4033775	0.137353	2.94	0.0044*
Program[24]	-0.175901	0.108276	-1.62	0.1083
Program[25]	0.3276364	0.118459	2.77	0.0071*
Program[26]	0.012473	0.101296	0.12	0.9023
Program[27]	-0.066486	0.083673	-0.79	0.4293
Program[28]	-0.036278	0.105616	-0.34	0.7322
Program[29]	-0.008235	0.154914	-0.05	0.9577
Program[30]	-0.055132	0.089008	-0.62	0.5375
Program[31]	-0.051635	0.149488	-0.35	0.7307
Program[32]	0.0759899	0.148913	0.51	0.6113
Program[33]	-0.269976	0.919468	-0.29	0.7698
Program[34]	-0.098955	0.118467	-0.84	0.4061
Program[35]	-0.081909	0.250217	-0.33	0.7443
Program[36]	-0.172012	0.369256	-0.47	0.6426
Program[37]	-0.092287	0.098429	-0.94	0.3514
Program[38]	0.171673	0.171987	1.00	0.3213
Program[39]	-0.013356	0.153309	-0.09	0.9308
Program[40]	-0.095859	0.086116	-1.11	0.2691
Program[41]	-0.120172	0.104131	-1.15	0.2520
Program[42]	0.0114095	0.151899	0.08	0.9403
Program[43]	-0.070652	0.160692	-0.44	0.6614
Program[44]	0.3027363	0.112869	2.68	0.0089*
Program[45]	-0.076145	0.077772	-0.98	0.3306
Program[46]	0.0995634	0.11626	0.86	0.3944
Program[47]	0.1373635	0.169514	0.81	0.4202
Program[48]	-0.123844	0.118619	-1.04	0.2997
Program[49]	-0.069608	0.117117	-0.59	0.5540
Program[50]	0.0978301	0.156271	0.63	0.5331
Program[51]	-0.074584	0.069088	-1.08	0.2837
Program[52]	-0.006066	0.143555	-0.04	0.9664
Program[53]	-0.128234	0.152277	-0.84	0.4023
Program[54]	-0.042533	0.113022	-0.38	0.7077
Program[55]	0.032268	0.779444	0.04	0.9671
Program[56]	0.0491826	0.121824	0.40	0.6875
Program[57]	-0.009023	0.081001	-0.11	0.9116
Program[58]	0.2315268	0.089234	2.59	0.0113*
Program[59]	-0.014354	0.107481	-0.13	0.8941

Figure 30. Model 2 (Development)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.616521
RSquare Adj	0.296954
Root Mean Square Error	0.133251
Mean of Response	0.124952
Observations (or Sum Wgts)	144

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	65	2.2265992	0.034255	1.9292
Error	78	1.3849578	0.017756	Prob > F
C. Total	143	3.6115570		0.0028*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2081108	0.090498	2.30	0.0241*
%Analogy	-0.058792	0.067403	-0.87	0.3858
%EVM	-0.042424	0.060774	-0.70	0.4872
%Factor	-0.223051	0.150437	-1.48	0.1422
%SME	0.1666825	0.101932	1.64	0.1060
Quantity	0.000978	0.016742	0.06	0.9536
Work Complete %	-0.061816	0.082779	-0.75	0.4575
Program[1]	-0.045869	0.105771	-0.43	0.6657
Program[2]	-0.002205	0.12474	-0.02	0.9859
Program[3]	-0.019658	0.157381	-0.12	0.9009
Program[4]	-0.029037	0.152925	-0.19	0.8499
Program[5]	-0.013694	0.147735	-0.09	0.9264
Program[6]	-0.04691	0.076355	-0.61	0.5408
Program[7]	-0.019413	0.122086	-0.16	0.8741
Program[8]	-0.079983	0.07598	-1.05	0.2957
Program[9]	0.1442152	0.089023	1.62	0.1093
Program[10]	0.0029747	0.152591	0.02	0.9845
Program[11]	-0.037802	0.091855	-0.41	0.6818
Program[12]	0.0344437	0.194612	0.18	0.8600
Program[13]	-0.124744	0.087681	-1.42	0.1588
Program[14]	-0.074999	0.147462	-0.51	0.6125
Program[15]	0.0412981	0.094676	0.44	0.6639
Program[16]	-0.079575	0.112027	-0.71	0.4796
Program[17]	-0.094497	0.157964	-0.60	0.5514
Program[18]	-0.04512	0.098386	-0.46	0.6478
Program[19]	0.1460785	0.112024	1.30	0.1961
Program[20]	0.3606702	0.152859	2.36	0.0208*
Program[21]	0.1978248	0.151918	1.30	0.1967
Program[22]	-0.011137	0.085169	-0.13	0.8963
Program[23]	0.3924654	0.136578	2.87	0.0052*
Program[24]	-0.165032	0.107397	-1.54	0.1284
Program[25]	0.3180383	0.117771	2.70	0.0085*
Program[26]	0.0001387	0.100157	0.00	0.9989
Program[27]	-0.058523	0.08305	-0.70	0.4831
Program[28]	-0.030621	0.105258	-0.29	0.7719
Program[29]	0.0030743	0.15414	0.02	0.9841
Program[30]	-0.054766	0.088873	-0.62	0.5395
Program[31]	-0.044387	0.149032	-0.30	0.7666
Program[32]	0.0800994	0.148613	0.54	0.5914
Program[33]	-0.297739	0.91753	-0.32	0.7464
Program[34]	-0.087399	0.117549	-0.74	0.4594
Program[35]	-0.080263	0.249832	-0.32	0.7489
Program[36]	-0.183348	0.368471	-0.50	0.6202
Program[37]	-0.097082	0.098128	-0.99	0.3256
Program[38]	0.1644804	0.17153	0.96	0.3406
Program[39]	-0.020967	0.15283	-0.14	0.8912
Program[40]	-0.099156	0.085903	-1.15	0.2519
Program[41]	-0.110386	0.103371	-1.07	0.2889
Program[42]	0.005934	0.151541	0.04	0.9689
Program[43]	-0.080334	0.160067	-0.50	0.6172
Program[44]	0.3047228	0.112675	2.70	0.0084*
Program[45]	-0.071005	0.077432	-0.92	0.3620
Program[46]	0.1110894	0.115336	0.96	0.3384
Program[47]	0.0729928	0.152459	0.48	0.6334
Program[48]	-0.120001	0.118358	-1.01	0.3138
Program[49]	-0.091411	0.114258	-0.80	0.4261
Program[50]	0.1010752	0.155991	0.65	0.5189
Program[51]	-0.067884	0.068558	-0.99	0.3251
Program[52]	-0.007864	0.143323	-0.05	0.9564
Program[53]	-0.127679	0.152046	-0.84	0.4036
Program[54]	-0.029791	0.111909	-0.27	0.7908
Program[55]	-0.003829	0.777173	-0.00	0.9961
Program[56]	0.0515075	0.121611	0.42	0.6731
Program[57]	-0.001255	0.080391	-0.02	0.9876
Program[58]	0.2437778	0.087994	2.77	0.0070*
Program[59]	-0.007107	0.106999	-0.07	0.9472

Figure 31. Model 3 (Development)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.614125
RSquare Adj	0.301517
Root Mean Square Error	0.132818
Mean of Response	0.124952
Observations (or Sum Wgts)	144

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	64	2.2179470	0.034655	1.9645
Error	79	1.3936099	0.017641	Prob > F
C. Total	143	3.6115570		0.0022*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2027437	0.089877	2.26	0.0269*
%Analogy	-0.041273	0.062353	-0.66	0.5100
%Factor	-0.206756	0.148131	-1.40	0.1667
%SME	0.1854932	0.097986	1.89	0.0620
Quantity	-0.00025	0.016595	-0.02	0.9880
Work Complete %	-0.075244	0.080251	-0.94	0.3513
Program[1]	-0.046873	0.105418	-0.44	0.6578
Program[2]	0.0096399	0.123179	0.08	0.9378
Program[3]	-0.001675	0.154754	-0.01	0.9914
Program[4]	-0.013507	0.150806	-0.09	0.9289
Program[5]	-0.001779	0.146268	-0.01	0.9903
Program[6]	-0.040915	0.075624	-0.54	0.5900
Program[7]	-0.006667	0.12032	-0.06	0.9559
Program[8]	-0.064791	0.07256	-0.89	0.3746
Program[9]	0.1566456	0.086941	1.80	0.0754
Program[10]	0.0074783	0.151959	0.05	0.9609
Program[11]	-0.02982	0.090844	-0.33	0.7436
Program[12]	0.0335492	0.193975	0.17	0.8631
Program[13]	-0.123521	0.087379	-1.41	0.1614
Program[14]	-0.073407	0.146965	-0.50	0.6188
Program[15]	0.0499416	0.093558	0.53	0.5950
Program[16]	-0.066396	0.110066	-0.60	0.5481
Program[17]	-0.119207	0.153446	-0.78	0.4396
Program[18]	-0.044292	0.098059	-0.45	0.6527
Program[19]	0.1230095	0.106691	1.15	0.2524
Program[20]	0.3648817	0.152243	2.40	0.0189*
Program[21]	0.1781295	0.14879	1.20	0.2348
Program[22]	-0.027177	0.081744	-0.33	0.7404
Program[23]	0.3973591	0.135955	2.92	0.0045*
Program[24]	-0.163392	0.107023	-1.53	0.1308
Program[25]	0.3103576	0.116875	2.66	0.0096*
Program[26]	0.0119654	0.098393	0.12	0.9035
Program[27]	-0.064974	0.082266	-0.79	0.4320
Program[28]	-0.031625	0.104906	-0.30	0.7639
Program[29]	-0.006032	0.153088	-0.04	0.9687
Program[30]	-0.071519	0.085293	-0.84	0.4043
Program[31]	-0.05242	0.148104	-0.35	0.7243
Program[32]	0.0767571	0.148054	0.52	0.6056
Program[33]	-0.238613	0.910643	-0.26	0.7940
Program[34]	-0.09629	0.116478	-0.83	0.4109
Program[35]	-0.069439	0.24854	-0.28	0.7807
Program[36]	-0.165451	0.366383	-0.45	0.6528
Program[37]	-0.104419	0.097246	-1.07	0.2862
Program[38]	0.1602252	0.170865	0.94	0.3512
Program[39]	-0.042452	0.149212	-0.28	0.7768
Program[40]	-0.099093	0.085624	-1.16	0.2506
Program[41]	-0.106756	0.102905	-1.04	0.3027
Program[42]	-0.003746	0.150414	-0.02	0.9802
Program[43]	-0.07844	0.159524	-0.49	0.6243
Program[44]	0.2959897	0.111615	2.65	0.0097*
Program[45]	-0.088438	0.073056	-1.21	0.2297
Program[46]	0.1095401	0.11494	0.95	0.3435
Program[47]	0.0795877	0.151671	0.52	0.6012
Program[48]	-0.131372	0.116851	-1.12	0.2643
Program[49]	-0.091971	0.113884	-0.81	0.4218
Program[50]	0.0761627	0.15136	0.50	0.6162
Program[51]	-0.080624	0.065869	-1.22	0.2246
Program[52]	-0.014685	0.142525	-0.10	0.9182
Program[53]	-0.138465	0.150767	-0.92	0.3612
Program[54]	-0.040605	0.110471	-0.37	0.7142
Program[55]	0.0574245	0.769694	0.07	0.9407
Program[56]	0.0358761	0.119143	0.30	0.7641
Program[57]	-0.008575	0.079445	-0.11	0.9143
Program[58]	0.2420425	0.087673	2.76	0.0072*
Program[59]	-0.016424	0.105818	-0.16	0.8770

Figure 32. Model 4 (Development)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.611985
RSquare Adj	0.306423
Root Mean Square Error	0.132351
Mean of Response	0.124952
Observations (or Sum Wgts)	144

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	63	2.2102181	0.035083	2.0028
Error	80	1.4013389	0.017517	Prob > F
C. Total	143	3.6115570		0.0017*

Parameter Estimates

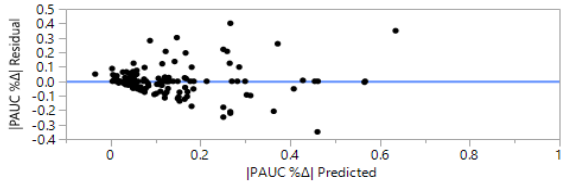
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1847403	0.085362	2.16	0.0334*
%Factor	-0.208542	0.147586	-1.41	0.1615
%SME	0.2025765	0.094194	2.15	0.0345*
Quantity	0.0013222	0.016366	0.08	0.9358
Work Complete %	-0.073864	0.079941	-0.92	0.3583
Program[1]	-0.06421	0.101753	-0.63	0.5298
Program[2]	0.0250933	0.120521	0.21	0.8356
Program[3]	0.0135883	0.152488	0.09	0.9292
Program[4]	0.0020053	0.14845	0.01	0.9893
Program[5]	0.0137029	0.143878	0.10	0.9244
Program[6]	-0.038027	0.075232	-0.51	0.6146
Program[7]	0.0062869	0.1183	0.05	0.9578
Program[8]	-0.055888	0.071051	-0.79	0.4338
Program[9]	0.1583986	0.086595	1.83	0.0711
Program[10]	-0.000575	0.150938	-0.00	0.9970
Program[11]	-0.014771	0.087644	-0.17	0.8666
Program[12]	0.0488649	0.191912	0.25	0.7997
Program[13]	-0.116575	0.086441	-1.35	0.1813
Program[14]	-0.076498	0.146374	-0.52	0.6027
Program[15]	0.0639484	0.090813	0.70	0.4834
Program[16]	-0.050996	0.1072	-0.48	0.6356
Program[17]	-0.103919	0.151164	-0.69	0.4938
Program[18]	-0.031093	0.095672	-0.32	0.7460
Program[19]	0.138204	0.103826	1.33	0.1869
Program[20]	0.3701048	0.151504	2.44	0.0168*
Program[21]	0.1918182	0.146827	1.31	0.1952
Program[22]	-0.02354	0.081273	-0.29	0.7728
Program[23]	0.4056335	0.134903	3.01	0.0035*
Program[24]	-0.153782	0.10566	-1.46	0.1495
Program[25]	0.310811	0.116462	2.67	0.0092*
Program[26]	0.0170904	0.097743	0.17	0.8616
Program[27]	-0.057906	0.081283	-0.71	0.4783
Program[28]	-0.038285	0.104055	-0.37	0.7139
Program[29]	-0.010693	0.152388	-0.07	0.9442
Program[30]	-0.062503	0.083902	-0.74	0.4585
Program[31]	-0.060473	0.147084	-0.41	0.6821
Program[32]	0.0661223	0.146661	0.45	0.6533
Program[33]	-0.328848	0.897214	-0.37	0.7149
Program[34]	-0.080238	0.113524	-0.71	0.4818
Program[35]	-0.101343	0.242964	-0.42	0.6777
Program[36]	-0.205775	0.360012	-0.57	0.5692
Program[37]	-0.111608	0.096298	-1.16	0.2499
Program[38]	0.1481128	0.169284	0.87	0.3842
Program[39]	-0.026686	0.146781	-0.18	0.8562
Program[40]	-0.105454	0.084784	-1.24	0.2172
Program[41]	-0.105777	0.102532	-1.03	0.3053
Program[42]	-0.008645	0.149704	-0.06	0.9541
Program[43]	-0.104599	0.154007	-0.68	0.4990
Program[44]	0.2906421	0.11093	2.62	0.0105*
Program[45]	-0.077905	0.071052	-1.10	0.2762
Program[46]	0.1173795	0.113926	1.03	0.3060
Program[47]	0.0960191	0.149099	0.64	0.5214
Program[48]	-0.120812	0.115349	-1.05	0.2981
Program[49]	-0.094832	0.113401	-0.84	0.4055
Program[50]	0.091753	0.14899	0.62	0.5398
Program[51]	-0.069004	0.063263	-1.09	0.2787
Program[52]	-0.040746	0.136497	-0.30	0.7661
Program[53]	-0.158419	0.147203	-1.08	0.2851
Program[54]	-0.038056	0.110015	-0.35	0.7303
Program[55]	-0.007225	0.760786	-0.01	0.9924
Program[56]	0.045871	0.117766	0.39	0.6979
Program[57]	-0.008894	0.079164	-0.11	0.9108
Program[58]	0.2533772	0.085682	2.96	0.0041*
Program[59]	-0.019188	0.105363	-0.18	0.8560

Figure 33. Model 5 (Development)

Response |PAUC %Δ|

Whole Model

Residual by Predicted Plot



Summary of Fit

RSquare	0.602301
RSquare Adj	0.297889
Root Mean Square Error	0.133163
Mean of Response	0.124952
Observations (or Sum Wgts)	144

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	62	2.1752435	0.035085	1.9786
Error	81	1.4363134	0.017732	Prob > F
C. Total	143	3.6115570		0.0020*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%	Std Beta	VIF
Intercept	0.1541712	0.083081	1.86	0.0671	-0.011135	0.3194771	0	.
%SME	0.1932058	0.094536	2.04	0.0442*	0.005108	0.3813037	0.218508	2.328218
Quantity	-0.003647	0.016082	-0.23	0.8212	-0.035646	0.028351	-0.16682	110.18853
Work Complete %	-0.025621	0.072728	-0.35	0.7255	-0.170326	0.1190837	-0.05317	4.6400983
Program[1]	-0.029288	0.099311	-0.29	0.7688	-0.226886	0.1683102	-0.03082	2.2248108
Program[2]	-0.017993	0.117315	-0.15	0.8785	-0.251413	0.215428	-0.01894	3.1045915
Program[3]	0.0007657	0.153151	0.00	0.9960	-0.303957	0.3054886	0.000697	3.9590553
Program[4]	0.0054452	0.14934	0.04	0.9710	-0.291695	0.302585	0.004957	3.7644637
Program[5]	-0.090684	0.124222	-0.73	0.4675	-0.337846	0.1564781	-0.09544	3.4808942
Program[6]	-0.072282	0.071656	-1.01	0.3161	-0.214856	0.0702911	-0.09295	1.7293414
Program[7]	-0.074023	0.104389	-0.71	0.4803	-0.281725	0.1336782	-0.0779	2.4581383
Program[8]	-0.082966	0.068838	-1.21	0.2316	-0.219932	0.0540001	-0.10669	1.5959874
Program[9]	0.1418102	0.086322	1.64	0.1043	-0.029943	0.313563	0.196545	2.9152586
Program[10]	-0.010342	0.151705	-0.07	0.9458	-0.312186	0.2915027	-0.00941	3.8846165
Program[11]	-0.029354	0.087568	-0.34	0.7383	-0.203587	0.1448789	-0.04068	3.0000609
Program[12]	-0.125145	0.148093	-0.85	0.4006	-0.419805	0.1695138	-0.11393	3.7018715
Program[13]	-0.131329	0.086335	-1.52	0.1321	-0.303108	0.0404493	-0.1941	3.3160529
Program[14]	-0.062227	0.146921	-0.42	0.6730	-0.354554	0.2301004	-0.05665	3.6435067
Program[15]	0.0313487	0.088372	0.35	0.7237	-0.144484	0.2071816	0.03686	2.1990405
Program[16]	-0.084736	0.105148	-0.81	0.4227	-0.293948	0.1244759	-0.09963	3.113193
Program[17]	-0.108325	0.152059	-0.71	0.4783	-0.410875	0.1942244	-0.09861	3.90279
Program[18]	-0.048074	0.095496	-0.50	0.6160	-0.238082	0.1419335	-0.06182	3.0714635
Program[19]	0.1259773	0.104099	1.21	0.2297	-0.081147	0.3331017	0.161999	3.6497664
Program[20]	0.3176625	0.147789	2.15	0.0346*	0.0236093	0.6117156	0.289185	3.6866591
Program[21]	0.1760759	0.147302	1.20	0.2354	-0.117009	0.4691603	0.160291	3.6624103
Program[22]	-0.020906	0.081749	-0.26	0.7988	-0.183562	0.14175	-0.02688	2.2508261
Program[23]	0.4185955	0.135416	3.09	0.0027*	0.1491603	0.6880306	0.38107	3.095208
Program[24]	-0.172535	0.105466	-1.64	0.1057	-0.38238	0.0373104	-0.18158	2.5091328
Program[25]	0.3106339	0.117176	2.65	0.0097*	0.0774904	0.5437774	0.326913	3.0972286
Program[26]	0.018098	0.09834	0.18	0.8544	-0.177567	0.2137629	0.023273	3.2570797
Program[27]	-0.075308	0.080837	-0.93	0.3543	-0.236149	0.0855327	-0.08855	1.8400376
Program[28]	-0.042199	0.104656	-0.40	0.6878	-0.250433	0.1660341	-0.05849	4.2851964
Program[29]	-0.07009	0.147374	-0.48	0.6356	-0.363318	0.2231367	-0.06381	3.6659767
Program[30]	-0.060717	0.084407	-0.72	0.4740	-0.22866	0.1072261	-0.07139	2.0061231
Program[31]	-0.083199	0.147099	-0.57	0.5732	-0.37588	0.2094824	-0.07574	3.6523411
Program[32]	0.0433895	0.14667	0.30	0.7681	-0.248439	0.3352176	0.0395	3.6310799
Program[33]	-0.031819	0.877591	-0.04	0.9712	-1.77795	1.7143126	-0.02897	129.99757
Program[34]	-0.087574	0.114101	-0.77	0.4450	-0.314599	0.1394512	-0.09216	2.9368035
Program[35]	-0.036979	0.240119	-0.15	0.8780	-0.514741	0.4407833	-0.04755	19.41895
Program[36]	-0.091584	0.352976	-0.26	0.7959	-0.793896	0.6107278	-0.08337	21.030098
Program[37]	-0.082222	0.094602	-0.87	0.3873	-0.270452	0.1060067	-0.10573	3.0142283
Program[38]	0.2081401	0.164872	1.26	0.2104	-0.119904	0.5361842	0.189481	4.588236
Program[39]	-0.021549	0.147636	-0.15	0.8843	-0.315298	0.2721998	-0.01962	3.6790284
Program[40]	-0.122022	0.084484	-1.44	0.1525	-0.290119	0.0460741	-0.15691	2.4039196
Program[41]	-0.083374	0.10192	-0.82	0.4157	-0.286163	0.1194152	-0.09803	2.9249757
Program[42]	-0.015788	0.150536	-0.10	0.9167	-0.315308	0.283731	-0.01437	3.8249972
Program[43]	-0.115115	0.154771	-0.74	0.4592	-0.423061	0.1928299	-0.1048	4.043231
Program[44]	0.2811706	0.111407	2.52	0.0136*	0.0595063	0.5028348	0.295905	2.7997413
Program[45]	-0.088568	0.071083	-1.25	0.2164	-0.230001	0.0528649	-0.11389	1.7017781
Program[46]	0.1389326	0.113592	1.22	0.2248	-0.08708	0.3649456	0.146213	2.9106719
Program[47]	0.1315577	0.147864	0.89	0.3763	-0.162646	0.4257611	0.119764	3.6904276
Program[48]	-0.149216	0.114281	-1.31	0.1954	-0.376599	0.078168	-0.15704	2.9460815
Program[49]	-0.108454	0.113684	-0.95	0.3429	-0.334649	0.1177413	-0.11414	2.9153664
Program[50]	0.080862	0.149703	0.54	0.5906	-0.217	0.378724	0.073613	3.7827851
Program[51]	-0.07422	0.063543	-1.17	0.2462	-0.20065	0.0522104	-0.11603	2.0097871
Program[52]	-0.008541	0.135407	-0.06	0.9499	-0.277958	0.2608754	-0.00778	3.0947845
Program[53]	-0.146549	0.147864	-0.99	0.3246	-0.440753	0.1476541	-0.13341	3.6904276
Program[54]	-0.098873	0.101868	-0.97	0.3346	-0.301557	0.103812	-0.11626	2.9219602
Program[55]	0.2521571	0.742836	0.34	0.7351	-1.225854	1.7301685	0.229552	93.140138
Program[56]	0.0320565	0.118079	0.27	0.7867	-0.202885	0.2669977	0.037692	3.926008
Program[57]	-0.006624	0.079633	-0.08	0.9339	-0.165069	0.1518207	-0.00779	1.7856174
Program[58]	0.2361412	0.085329	2.77	0.0070*	0.0663634	0.405919	0.277656	2.0501936
Program[59]	0.002804	0.104847	0.03	0.9787	-0.205808	0.2114162	0.002951	2.4797381

Figure 34. Model 1 (Production)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.566333
RSquare Adj	0.15435
Root Mean Square Error	0.146073
Mean of Response	0.13098
Observations (or Sum Wgts)	157

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	76	2.2291953	0.029332	1.3747
Error	80	1.7069943	0.021337	Prob > F
C. Total	156	3.9361896		0.0806

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0716249	0.062971	1.14	0.2588
%Analogy	0.00188	0.073985	0.03	0.9798
%EVM	-0.131413	0.085669	-1.53	0.1290
%Factor	0.3491083	0.21358	1.63	0.1061
%SME	0.0570796	0.192013	0.30	0.7670
%Parametric	0.0116048	0.077751	0.15	0.8817
Quantity	-3.046e-5	0.000116	-0.26	0.7928
Work Complete %	0.1822429	0.12214	1.49	0.1396
Program[1]	0.013417	0.114796	0.12	0.9073
Program[2]	0.0956492	0.157843	0.61	0.5462
Program[3]	-0.008835	0.108479	-0.08	0.9353
Program[4]	-0.017293	0.15322	-0.11	0.9104
Program[5]	-0.156955	0.15099	-1.04	0.3017
Program[6]	0.0319498	0.150733	0.21	0.8327
Program[7]	-0.132966	0.112809	-1.18	0.2420
Program[8]	-0.135605	0.084306	-1.61	0.1117
Program[9]	-0.149273	0.114587	-1.30	0.1964
Program[10]	-0.139712	0.084276	-1.66	0.1013
Program[11]	0.0389578	0.150307	0.26	0.7962
Program[12]	0.0203414	0.077642	0.26	0.7940
Program[13]	-0.036331	0.151351	-0.24	0.8109
Program[14]	0.0153043	0.188779	0.08	0.9356
Program[15]	0.123365	0.154458	0.80	0.4268
Program[16]	-0.210056	0.211956	-0.99	0.3247
Program[17]	-0.117568	0.088159	-1.33	0.1861
Program[18]	0.0163704	0.152082	0.11	0.9145
Program[19]	0.0609508	0.090646	0.67	0.5033
Program[20]	0.0627182	0.095054	0.66	0.5113
Program[21]	0.1594158	0.099264	1.61	0.1122
Program[22]	-0.052272	0.092705	-0.56	0.5744
Program[23]	-0.087843	0.171452	-0.51	0.6098
Program[24]	-0.051459	0.088305	-0.58	0.5617
Program[25]	0.1551896	0.081812	1.90	0.0614
Program[26]	0.1703732	0.109694	1.55	0.1243
Program[27]	0.0828938	0.15031	0.55	0.5828
Program[28]	-0.043278	0.083893	-0.52	0.6074
Program[29]	0.4276262	0.153486	2.79	0.0067*
Program[30]	-0.174811	0.112917	-1.55	0.1255
Program[31]	0.3873982	0.112531	3.44	0.0009*
Program[32]	-0.035512	0.100868	-0.35	0.7257
Program[33]	-0.089527	0.17712	-0.51	0.6146
Program[34]	-0.080805	0.104671	-0.77	0.4424
Program[35]	-0.012012	0.091943	-0.13	0.8964
Program[36]	-0.090594	0.151796	-0.60	0.5523
Program[37]	-0.092362	0.160732	-0.57	0.5672
Program[38]	-0.12681	0.087875	-1.44	0.1529
Program[39]	-0.042898	0.148971	-0.29	0.7741
Program[40]	0.1344143	0.163707	0.82	0.4140
Program[41]	-0.031668	0.17149	-0.18	0.8540
Program[42]	-0.112524	0.122925	-0.92	0.3627
Program[43]	-0.056859	0.092845	-0.61	0.5420
Program[44]	-0.06073	0.168449	-0.36	0.7194
Program[45]	-0.128964	0.079859	-1.61	0.1103
Program[46]	0.3219246	0.153111	2.10	0.0386*
Program[47]	-0.15093	0.168366	-0.90	0.3727
Program[48]	-0.097504	0.078153	-1.25	0.2158
Program[49]	-0.154056	0.162085	-0.95	0.3447
Program[50]	-0.115145	0.091227	-1.26	0.2106
Program[51]	-0.074925	0.184023	-0.41	0.6850
Program[52]	0.3900747	0.116081	3.36	0.0012*
Program[53]	-0.09182	0.078433	-1.17	0.2452
Program[54]	0.215388	0.117188	1.84	0.0698
Program[55]	0.0922008	0.152121	0.61	0.5462
Program[56]	0.1183398	0.128159	0.92	0.3586
Program[57]	-0.103531	0.124831	-0.83	0.4094
Program[58]	-0.097334	0.1046	-0.93	0.3549
Program[59]	0.0927993	0.162717	0.57	0.5701
Program[60]	-0.051594	0.079942	-0.65	0.5205
Program[61]	-0.011315	0.204081	-0.06	0.9559
Program[62]	0.0047304	0.154102	0.03	0.9756
Program[63]	-0.059228	0.158647	-0.37	0.7099
Program[64]	-0.115597	0.096927	-1.19	0.2365
Program[65]	0.1853104	0.267828	0.69	0.4910
Program[66]	0.0117525	0.114155	0.10	0.9183
Program[67]	-0.008243	0.098585	-0.08	0.9336
Program[68]	0.1885002	0.099124	1.90	0.0608
Program[69]	0.0560134	0.108957	0.51	0.6086

Figure 35. Model 2 (Production)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.56633
RSquare Adj	0.164783
Root Mean Square Error	0.145169
Mean of Response	0.13098
Observations (or Sum Wgts)	157

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	75	2.2291816	0.029722	1.4104
Error	81	1.7070080	0.021074	Prob > F
C. Total	156	3.9361896		0.0649

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0721152	0.059571	1.21	0.2296
%EVM	-0.131726	0.084253	-1.56	0.1218
%Factor	0.3491611	0.212249	1.65	0.1038
%SME	0.0564131	0.189036	0.30	0.7661
%Parametric	0.0111619	0.075302	0.15	0.8825
Quantity	-3.032e-5	0.000115	-0.26	0.7922
Work Complete %	0.1822555	0.121384	1.50	0.1371
Program[1]	0.0139698	0.112018	0.12	0.9011
Program[2]	0.0968256	0.149968	0.65	0.5203
Program[3]	-0.009121	0.107228	-0.09	0.9324
Program[4]	-0.017522	0.152007	-0.12	0.9085
Program[5]	-0.157161	0.149838	-1.05	0.2974
Program[6]	0.0314956	0.148743	0.21	0.8328
Program[7]	-0.132701	0.11163	-1.19	0.2380
Program[8]	-0.135403	0.083409	-1.62	0.1084
Program[9]	-0.149724	0.112504	-1.33	0.1870
Program[10]	-0.139447	0.083108	-1.68	0.0972
Program[11]	0.0389872	0.149373	0.26	0.7948
Program[12]	0.0202557	0.077089	0.26	0.7934
Program[13]	-0.035558	0.147338	-0.24	0.8099
Program[14]	0.0145759	0.185435	0.08	0.9375
Program[15]	0.1231411	0.153252	0.80	0.4240
Program[16]	-0.209972	0.210619	-1.00	0.3218
Program[17]	-0.117829	0.087012	-1.35	0.1794
Program[18]	0.0159851	0.150387	0.11	0.9156
Program[19]	0.0611698	0.089677	0.68	0.4971
Program[20]	0.062394	0.093611	0.67	0.5070
Program[21]	0.1592843	0.098515	1.62	0.1098
Program[22]	-0.052635	0.091028	-0.58	0.5647
Program[23]	-0.08805	0.170198	-0.52	0.6063
Program[24]	-0.051648	0.087448	-0.59	0.5564
Program[25]	0.154823	0.080031	1.93	0.0565
Program[26]	0.1704781	0.108938	1.56	0.1215
Program[27]	0.0829038	0.149379	0.55	0.5804
Program[28]	-0.042599	0.079026	-0.54	0.5913
Program[29]	0.4276049	0.152534	2.80	0.0063*
Program[30]	-0.174723	0.112165	-1.56	0.1232
Program[31]	0.386899	0.110118	3.51	0.0007*
Program[32]	-0.034959	0.097886	-0.36	0.7219
Program[33]	-0.089698	0.175896	-0.51	0.6115
Program[34]	-0.08076	0.104008	-0.78	0.4397
Program[35]	-0.011603	0.089962	-0.13	0.8977
Program[36]	-0.089844	0.147973	-0.61	0.5454
Program[37]	-0.092491	0.159658	-0.58	0.5640
Program[38]	-0.127064	0.086767	-1.46	0.1470
Program[39]	-0.0432	0.147578	-0.29	0.7705
Program[40]	0.1338313	0.161088	0.83	0.4085
Program[41]	-0.030922	0.167913	-0.18	0.8544
Program[42]	-0.112591	0.122136	-0.92	0.3593
Program[43]	-0.056253	0.089166	-0.63	0.5299
Program[44]	-0.060225	0.166237	-0.36	0.7181
Program[45]	-0.129363	0.077817	-1.66	0.1003
Program[46]	0.3219617	0.152156	2.12	0.0374*
Program[47]	-0.15145	0.166084	-0.91	0.3645
Program[48]	-0.097829	0.076624	-1.28	0.2053
Program[49]	-0.15321	0.15764	-0.97	0.3340
Program[50]	-0.115488	0.089663	-1.29	0.2014
Program[51]	-0.075222	0.182516	-0.41	0.6813
Program[52]	0.390277	0.115091	3.39	0.0011*
Program[53]	-0.091563	0.077295	-1.18	0.2396
Program[54]	0.2148958	0.114861	1.87	0.0650
Program[55]	0.0919676	0.150904	0.61	0.5439
Program[56]	0.1180047	0.12669	0.93	0.3544
Program[57]	-0.103483	0.124044	-0.83	0.4066
Program[58]	-0.09759	0.10347	-0.94	0.3484
Program[59]	0.0925325	0.161373	0.57	0.5680
Program[60]	-0.051794	0.079062	-0.66	0.5143
Program[61]	-0.011939	0.201345	-0.06	0.9529
Program[62]	0.0057992	0.147333	0.04	0.9687
Program[63]	-0.059378	0.157557	-0.38	0.7073
Program[64]	-0.115514	0.096272	-1.20	0.2337
Program[65]	0.185293	0.26617	0.70	0.4883
Program[66]	0.0116261	0.113341	0.10	0.9186
Program[67]	-0.007343	0.09142	-0.08	0.9362
Program[68]	0.1887011	0.098197	1.92	0.0582
Program[69]	0.0557181	0.107665	0.52	0.6062

Figure 36. Model 3 (Production)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.566212
RSquare Adj	0.174745
Root Mean Square Error	0.144301
Mean of Response	0.13098
Observations (or Sum Wgts)	157

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	74	2.2287185	0.030118	1.4464
Error	82	1.7074711	0.020823	**Prob > F**
C. Total	156	3.9361896		0.0519

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.073525	0.058455	1.26	0.2120
%EVM	-0.135189	0.080465	-1.68	0.0967
%Factor	0.3490701	0.210978	1.65	0.1018
%SME	0.0578743	0.18765	0.31	0.7585
Quantity	-0.00003	0.000114	-0.26	0.7927
Work Complete %	0.1850566	0.119186	1.55	0.1244
Program[1]	0.0173271	0.109048	0.16	0.8741
Program[2]	0.0954255	0.148775	0.64	0.5230
Program[3]	-0.007858	0.10625	-0.07	0.9412
Program[4]	-0.011876	0.146276	-0.08	0.9355
Program[5]	-0.154328	0.147725	-1.04	0.2992
Program[6]	0.0311873	0.147839	0.21	0.8334
Program[7]	-0.135294	0.109591	-1.23	0.2205
Program[8]	-0.13624	0.08272	-1.65	0.1034
Program[9]	-0.150307	0.111762	-1.34	0.1824
Program[10]	-0.137737	0.081811	-1.68	0.0961
Program[11]	0.0373027	0.148049	0.25	0.8017
Program[12]	0.0199813	0.076606	0.26	0.7949
Program[13]	-0.036967	0.146151	-0.25	0.8010
Program[14]	0.0120672	0.183556	0.07	0.9477
Program[15]	0.1295161	0.146214	0.89	0.3783
Program[16]	-0.213277	0.208183	-1.02	0.3086
Program[17]	-0.115734	0.085342	-1.36	0.1788
Program[18]	0.0142054	0.149011	0.10	0.9243
Program[19]	0.059693	0.088589	0.67	0.5023
Program[20]	0.0633291	0.092839	0.68	0.4971
Program[21]	0.1653946	0.088941	1.86	0.0665
Program[22]	-0.054145	0.089915	-0.60	0.5487
Program[23]	-0.087942	0.169179	-0.52	0.6046
Program[24]	-0.049063	0.08518	-0.58	0.5662
Program[25]	0.1567935	0.078447	2.00	0.0490*
Program[26]	0.1717163	0.107967	1.59	0.1156
Program[27]	0.0865709	0.146435	0.59	0.5560
Program[28]	-0.043057	0.078494	-0.55	0.5848
Program[29]	0.4336189	0.146159	2.97	0.0039*
Program[30]	-0.173812	0.111326	-1.56	0.1223
Program[31]	0.3846196	0.108386	3.55	0.0006*
Program[32]	-0.035275	0.097277	-0.36	0.7178
Program[33]	-0.088873	0.174756	-0.51	0.6124
Program[34]	-0.081874	0.103116	-0.79	0.4295
Program[35]	-0.011304	0.089401	-0.13	0.8997
Program[36]	-0.091254	0.146784	-0.62	0.5359
Program[37]	-0.087173	0.154645	-0.56	0.5745
Program[38]	-0.124459	0.084462	-1.47	0.1444
Program[39]	-0.044693	0.146353	-0.31	0.7609
Program[40]	0.1322394	0.159768	0.83	0.4102
Program[41]	-0.030516	0.166886	-0.18	0.8554
Program[42]	-0.114436	0.120774	-0.95	0.3462
Program[43]	-0.057344	0.08833	-0.65	0.5180
Program[44]	-0.061731	0.164934	-0.37	0.7092
Program[45]	-0.130166	0.077164	-1.69	0.0954
Program[46]	0.328128	0.145484	2.26	0.0268*
Program[47]	-0.152809	0.164839	-0.93	0.3566
Program[48]	-0.099365	0.075466	-1.32	0.1916
Program[49]	-0.156457	0.155176	-1.01	0.3163
Program[50]	-0.116906	0.088618	-1.32	0.1908
Program[51]	-0.075882	0.18137	-0.42	0.6768
Program[52]	0.3887203	0.113925	3.41	0.0010*
Program[53]	-0.093143	0.076099	-1.22	0.2245
Program[54]	0.2134888	0.113783	1.88	0.0642
Program[55]	0.090586	0.149715	0.61	0.5468
Program[56]	0.1163384	0.125435	0.93	0.3564
Program[57]	-0.10486	0.122956	-0.85	0.3962
Program[58]	-0.098706	0.102579	-0.96	0.3388
Program[59]	0.0919273	0.160356	0.57	0.5680
Program[60]	-0.051754	0.078589	-0.66	0.5120
Program[61]	-0.013574	0.199841	-0.07	0.9460
Program[62]	0.0043776	0.146141	0.03	0.9762
Program[63]	-0.059696	0.1566	-0.38	0.7040
Program[64]	-0.116135	0.095605	-1.21	0.2280
Program[65]	0.1820415	0.263678	0.69	0.4919
Program[66]	0.0131646	0.11219	0.12	0.9069
Program[67]	-0.008762	0.090373	-0.10	0.9230
Program[68]	0.1867654	0.096743	1.93	0.0570
Program[69]	0.0559819	0.107007	0.52	0.6023

Figure 37. Model 4 (Production)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.565709
RSquare Adj	0.183742
Root Mean Square Error	0.143512
Mean of Response	0.13098
Observations (or Sum Wgts)	157

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	73	2.2267379	0.030503	1.4810
Error	83	1.7094518	0.020596	Prob > F
C. Total	156	3.9361896		0.0417*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0801886	0.054019	1.48	0.1415
%EVM	-0.136572	0.079901	-1.71	0.0911
%Factor	0.3323586	0.202787	1.64	0.1050
Quantity	-3.04e-5	0.000113	-0.27	0.7893
Work Complete %	0.1841832	0.118501	1.55	0.1239
Program[1]	0.0119439	0.107054	0.11	0.9114
Program[2]	0.0906055	0.147143	0.62	0.5397
Program[3]	-0.011475	0.105024	-0.11	0.9133
Program[4]	-0.015216	0.145077	-0.10	0.9167
Program[5]	-0.148414	0.145675	-1.02	0.3113
Program[6]	0.0264027	0.146219	0.18	0.8571
Program[7]	-0.140342	0.10777	-1.30	0.1964
Program[8]	-0.137526	0.082163	-1.67	0.0979
Program[9]	-0.148739	0.111036	-1.34	0.1840
Program[10]	-0.139598	0.081142	-1.72	0.0891
Program[11]	0.0435687	0.145847	0.30	0.7659
Program[12]	0.021228	0.076081	0.28	0.7809
Program[13]	-0.039942	0.145036	-0.28	0.7837
Program[14]	0.0083111	0.182151	0.05	0.9637
Program[15]	0.1277752	0.145306	0.88	0.3817
Program[16]	-0.16786	0.146352	-1.15	0.2547
Program[17]	-0.120987	0.083168	-1.45	0.1495
Program[18]	0.0246387	0.144327	0.17	0.8649
Program[19]	0.0557555	0.087185	0.64	0.5243
Program[20]	0.0577753	0.090578	0.64	0.5253
Program[21]	0.1605666	0.087074	1.84	0.0687
Program[22]	-0.056128	0.089195	-0.63	0.5309
Program[23]	-0.092312	0.167663	-0.55	0.5834
Program[24]	-0.049183	0.084713	-0.58	0.5631
Program[25]	0.1519928	0.076467	1.99	0.0501
Program[26]	0.1669506	0.106272	1.57	0.1200
Program[27]	0.0844667	0.145477	0.58	0.5631
Program[28]	-0.045861	0.077539	-0.59	0.5558
Program[29]	0.4325375	0.145318	2.98	0.0038*
Program[30]	-0.168024	0.109134	-1.54	0.1275
Program[31]	0.3797412	0.10664	3.56	0.0006*
Program[32]	-0.041409	0.094702	-0.44	0.6631
Program[33]	-0.093165	0.173249	-0.54	0.5922
Program[34]	-0.069024	0.093808	-0.74	0.4639
Program[35]	-0.007304	0.087972	-0.08	0.9340
Program[36]	-0.09311	0.145859	-0.64	0.5250
Program[37]	-0.09228	0.152916	-0.60	0.5478
Program[38]	-0.12559	0.083921	-1.50	0.1383
Program[39]	-0.048592	0.145009	-0.34	0.7384
Program[40]	0.1258086	0.157536	0.80	0.4268
Program[41]	-0.034668	0.165433	-0.21	0.8345
Program[42]	-0.118765	0.1193	-1.00	0.3224
Program[43]	-0.059774	0.087497	-0.68	0.4964
Program[44]	-0.06026	0.163964	-0.37	0.7142
Program[45]	-0.130699	0.076723	-1.70	0.0922
Program[46]	0.3245851	0.144237	2.25	0.0271*
Program[47]	-0.150133	0.16371	-0.92	0.3618
Program[48]	-0.101432	0.074757	-1.36	0.1785
Program[49]	-0.15688	0.154322	-1.02	0.3123
Program[50]	-0.11918	0.087828	-1.36	0.1785
Program[51]	-0.079844	0.179926	-0.44	0.6584
Program[52]	0.3847978	0.112594	3.42	0.0010*
Program[53]	-0.097323	0.074473	-1.31	0.1949
Program[54]	0.2073924	0.11144	1.86	0.0663
Program[55]	0.0895879	0.148862	0.60	0.5489
Program[56]	0.1113936	0.123726	0.90	0.3706
Program[57]	-0.100866	0.121604	-0.83	0.4092
Program[58]	-0.097098	0.101886	-0.95	0.3434
Program[59]	0.088516	0.1591	0.56	0.5795
Program[60]	-0.053911	0.077849	-0.69	0.4906
Program[61]	-0.017385	0.198368	-0.09	0.9304
Program[62]	0.0004062	0.144777	0.00	0.9978
Program[63]	-0.045599	0.148962	-0.31	0.7603
Program[64]	-0.116705	0.095065	-1.23	0.2231
Program[65]	0.2337384	0.202429	1.15	0.2515
Program[66]	0.0110895	0.111376	0.10	0.9209
Program[67]	-0.010465	0.089711	-0.12	0.9074
Program[68]	0.197768	0.089434	2.21	0.0298*
Program[69]	0.0552046	0.106392	0.52	0.6052

Figure 38. Model 5 (Production)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.551654
RSquare Adj	0.167357
Root Mean Square Error	0.144946
Mean of Response	0.13098
Observations (or Sum Wgts)	157

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	72	2.1714139	0.030159	1.4355
Error	84	1.7647757	0.021009	Prob > F
C. Total	156	3.9361896		0.0553

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.1449911	0.037174	3.90	0.0002*
%EVM	-0.141571	0.08064	-1.76	0.0828
Quantity	-3.971e-5	0.000114	-0.35	0.7294
Work Complete %	0.1399193	0.116535	1.20	0.2333
Program[1]	-0.026474	0.105499	-0.25	0.8025
Program[2]	0.0624694	0.147597	0.42	0.6732
Program[3]	-0.03107	0.105383	-0.29	0.7689
Program[4]	-0.013756	0.146523	-0.09	0.9254
Program[5]	-0.126508	0.146509	-0.86	0.3903
Program[6]	-0.003528	0.146523	-0.02	0.9808
Program[7]	-0.161582	0.108056	-1.50	0.1386
Program[8]	-0.093729	0.078472	-1.19	0.2357
Program[9]	-0.095258	0.107193	-0.89	0.3767
Program[10]	-0.108554	0.079689	-1.36	0.1768
Program[11]	0.0334862	0.147172	0.23	0.8206
Program[12]	0.0029568	0.076011	0.04	0.9691
Program[13]	-0.031188	0.146385	-0.21	0.8318
Program[14]	0.0125887	0.183951	0.07	0.9456
Program[15]	0.1616355	0.145266	1.11	0.2690
Program[16]	-0.188155	0.147283	-1.28	0.2049
Program[17]	-0.148116	0.082318	-1.80	0.0756
Program[18]	0.0417334	0.145387	0.29	0.7748
Program[19]	0.0312856	0.086755	0.36	0.7193
Program[20]	0.0286823	0.089709	0.32	0.7500
Program[21]	0.132628	0.086242	1.54	0.1278
Program[22]	-0.089439	0.087716	-1.02	0.3108
Program[23]	-0.108359	0.169048	-0.64	0.5233
Program[24]	0.0114011	0.076984	0.15	0.8826
Program[25]	0.1238201	0.075254	1.65	0.1036
Program[26]	0.1361433	0.105641	1.29	0.2010
Program[27]	0.1185696	0.145419	0.82	0.4172
Program[28]	-0.032766	0.077897	-0.42	0.6751
Program[29]	0.425854	0.146712	2.90	0.0047*
Program[30]	-0.121459	0.106423	-1.14	0.2570
Program[31]	0.3588693	0.106934	3.36	0.0012*
Program[32]	-0.079398	0.092738	-0.86	0.3943
Program[33]	-0.100929	0.174914	-0.58	0.5655
Program[34]	-0.016747	0.089099	-0.19	0.8514
Program[35]	-0.009571	0.08884	-0.11	0.9145
Program[36]	-0.062036	0.146066	-0.42	0.6721
Program[37]	-0.11383	0.153871	-0.74	0.4615
Program[38]	-0.109773	0.084197	-1.30	0.1959
Program[39]	-0.057438	0.146355	-0.39	0.6957
Program[40]	0.067468	0.154994	0.44	0.6645
Program[41]	-0.047026	0.166912	-0.28	0.7788
Program[42]	-0.128177	0.120352	-1.07	0.2899
Program[43]	-0.054195	0.088304	-0.61	0.5410
Program[44]	-0.063818	0.165587	-0.39	0.7009
Program[45]	-0.100617	0.075239	-1.34	0.1847
Program[46]	0.322224	0.14567	2.21	0.0297*
Program[47]	-0.029197	0.147597	-0.20	0.8437
Program[48]	-0.118967	0.074726	-1.59	0.1151
Program[49]	-0.140142	0.155521	-0.90	0.3701
Program[50]	-0.099366	0.087861	-1.13	0.2613
Program[51]	-0.087459	0.181662	-0.48	0.6315
Program[52]	0.3761279	0.113593	3.31	0.0014*
Program[53]	-0.110517	0.074776	-1.48	0.1432
Program[54]	0.1538726	0.107613	1.43	0.1565
Program[55]	0.1374875	0.147423	0.93	0.3537
Program[56]	0.0891739	0.12421	0.72	0.4748
Program[57]	-0.100833	0.122819	-0.82	0.4140
Program[58]	-0.085451	0.102653	-0.83	0.4075
Program[59]	0.0894484	0.160688	0.56	0.5792
Program[60]	-0.034025	0.077666	-0.44	0.6624
Program[61]	-0.02168	0.200332	-0.11	0.9141
Program[62]	-0.01059	0.146066	-0.07	0.9424
Program[63]	-0.07478	0.149372	-0.50	0.6179
Program[64]	-0.064218	0.090402	-0.71	0.4794
Program[65]	0.1824371	0.201992	0.90	0.3690
Program[66]	-0.000332	0.112267	-0.00	0.9976
Program[67]	7.9584e-5	0.090374	0.00	0.9993
Program[68]	0.2253737	0.08871	2.54	0.0129*
Program[69]	0.0536538	0.10745	0.50	0.6188

Figure 39. Model 6 (Production)

Response |PAUC %Δ|

Whole Model

Summary of Fit

RSquare	0.535203
RSquare Adj	0.146961
Root Mean Square Error	0.14671
Mean of Response	0.13098
Observations (or Sum Wgts)	157

Analysis of Variance

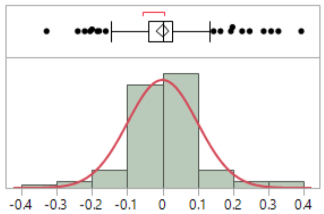
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	71	2.1066613	0.029671	1.3785
Error	85	1.8295283	0.021524	Prob > F
C. Total	156	3.9361896		0.0781

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%	Std Beta	VIF
Intercept	0.1327002	0.036953	3.59	0.0006*	0.0592279	0.2061725	0	.
Quantity	-3.934e-5	0.000116	-0.34	0.7349	-0.00027	0.0001909	-0.09248	13.551724
Work Complete %	0.0979056	0.11544	0.85	0.3988	-0.13162	0.327431	0.173839	7.6832719
Program[1]	-0.014313	0.106553	-0.13	0.8935	-0.226168	0.1975428	-0.01443	2.1099381
Program[2]	0.07476	0.149226	0.50	0.6177	-0.221941	0.3714614	0.065197	3.0971866
Program[3]	-0.017066	0.10636	-0.16	0.8729	-0.228538	0.1944056	-0.0172	2.1022992
Program[4]	-0.001489	0.148138	-0.01	0.9920	-0.296027	0.2930497	-0.0013	3.0521952
Program[5]	-0.114241	0.148124	-0.77	0.4427	-0.408751	0.1802687	-0.09963	3.0516004
Program[6]	0.0087389	0.148138	0.06	0.9531	-0.2858	0.3032773	0.007621	3.0521952
Program[7]	-0.131713	0.108008	-1.22	0.2260	-0.346461	0.0830346	-0.13278	2.1679453
Program[8]	-0.07894	0.078969	-1.00	0.3203	-0.235951	0.0780704	-0.09726	1.7309806
Program[9]	-0.082974	0.108267	-0.77	0.4456	-0.298238	0.1322898	-0.08364	2.1783701
Program[10]	-0.09582	0.080324	-1.19	0.2362	-0.255526	0.0638853	-0.11805	1.7909064
Program[11]	0.046195	0.148783	0.31	0.7570	-0.249626	0.3420163	0.040286	3.0788384
Program[12]	0.0240778	0.075967	0.32	0.7521	-0.126964	0.17512	0.029664	1.6018798
Program[13]	-0.018925	0.147998	-0.13	0.8986	-0.313184	0.2753346	-0.0165	3.0464149
Program[14]	0.0347166	0.185753	0.19	0.8522	-0.334609	0.4040425	0.046107	11.129516
Program[15]	0.1741347	0.146858	1.19	0.2390	-0.117858	0.4661277	0.151861	2.9996678
Program[16]	-0.157631	0.148034	-1.06	0.2900	-0.451962	0.1367005	-0.13747	3.0479023
Program[17]	-0.111251	0.080564	-1.38	0.1709	-0.271433	0.0489318	-0.14775	2.0935686
Program[18]	0.0539345	0.146989	0.37	0.7146	-0.238318	0.3461872	0.047036	3.0050048
Program[19]	0.0435058	0.087528	0.50	0.6204	-0.130523	0.2175341	0.049002	1.7774042
Program[20]	0.0505908	0.089918	0.56	0.5752	-0.128191	0.2293726	0.062328	2.2442946
Program[21]	0.1155322	0.086733	1.33	0.1864	-0.056917	0.2879816	0.130129	1.7452983
Program[22]	-0.07719	0.088502	-0.87	0.3856	-0.253156	0.0987766	-0.08694	1.8172092
Program[23]	-0.189201	0.164636	-1.15	0.2537	-0.516541	0.1381389	-0.165	3.7698681
Program[24]	-0.009948	0.076943	-0.13	0.8974	-0.162931	0.143035	-0.01226	1.6433122
Program[25]	0.1265392	0.076154	1.66	0.1003	-0.024875	0.2779533	0.155897	1.6097787
Program[26]	0.1124428	0.10605	1.06	0.2920	-0.098413	0.323299	0.113351	2.0900801
Program[27]	0.1382503	0.146751	0.94	0.3488	-0.15353	0.4300307	0.120567	2.9953004
Program[28]	-0.01893	0.07844	-0.24	0.8099	-0.17489	0.1370307	-0.02332	1.7078999
Program[29]	0.4360555	0.148381	2.94	0.0042*	0.1410337	0.7310772	0.380279	3.0622193
Program[30]	-0.109187	0.107486	-1.02	0.3126	-0.322897	0.1045235	-0.11007	2.1470451
Program[31]	0.3843227	0.107237	3.58	0.0006*	0.1711076	0.5975377	0.387425	2.1371038
Program[32]	-0.041666	0.091311	-0.46	0.6493	-0.223217	0.1398859	-0.05133	2.3143739
Program[33]	-0.153759	0.174403	-0.88	0.3805	-0.50052	0.1930014	-0.13409	4.2304584
Program[34]	-0.004605	0.089912	-0.05	0.9593	-0.183374	0.174164	-0.00519	1.8755643
Program[35]	-0.020167	0.089713	-0.22	0.8227	-0.198541	0.1582078	-0.02271	1.8672886
Program[36]	-0.049782	0.147675	-0.34	0.7369	-0.3434	0.2438348	-0.04341	3.0331317
Program[37]	-0.112764	0.155743	-0.72	0.4710	-0.422422	0.1968952	-0.09834	3.3736116
Program[38]	-0.093378	0.084696	-1.10	0.2734	-0.261776	0.0750204	-0.10518	1.6642571
Program[39]	-0.045286	0.147971	-0.31	0.7603	-0.339492	0.2489206	-0.03949	3.0453171
Program[40]	0.0795003	0.156728	0.51	0.6133	-0.232116	0.391117	0.069331	3.4164076
Program[41]	-0.035086	0.168803	-0.21	0.8358	-0.370712	0.3005402	-0.0306	3.9631403
Program[42]	-0.148776	0.121236	-1.23	0.2232	-0.389826	0.0922745	-0.14998	2.731528
Program[43]	-0.061688	0.089274	-0.69	0.4915	-0.23919	0.1158134	-0.076	2.2122681
Program[44]	-0.067333	0.16759	-0.40	0.6889	-0.400547	0.2658809	-0.05872	3.9063813
Program[45]	-0.130177	0.074223	-1.75	0.0831	-0.277753	0.017399	-0.16038	1.5292005
Program[46]	0.3344616	0.147274	2.27	0.0257*	0.041641	0.6272822	0.29168	3.016696
Program[47]	-0.016906	0.149226	-0.11	0.9101	-0.313608	0.2797952	-0.01474	3.0971866
Program[48]	-0.126943	0.075496	-1.68	0.0963	-0.27705	0.0231634	-0.1564	1.5820979
Program[49]	-0.101685	0.155845	-0.65	0.5159	-0.411547	0.2081772	-0.08868	3.3780462
Program[50]	-0.087113	0.08865	-0.98	0.3286	-0.263373	0.0891457	-0.09812	1.8232655
Program[51]	-0.177513	0.176391	-1.01	0.3171	-0.528226	0.1731997	-0.15481	4.3274403
Program[52]	0.3881906	0.114765	3.38	0.0011*	0.1600068	0.6163744	0.391324	2.4477076
Program[53]	-0.096022	0.075223	-1.28	0.2053	-0.245586	0.0535415	-0.1183	1.5706721
Program[54]	0.1661632	0.108692	1.53	0.1300	-0.049946	0.3822722	0.167505	2.1955114
Program[55]	0.1497748	0.149049	1.00	0.3178	-0.146575	0.4461247	0.130617	3.089853
Program[56]	0.05579	0.12424	0.45	0.6545	-0.191231	0.3028115	0.05624	2.8685306
Program[57]	-0.14877	0.121202	-1.23	0.2230	-0.389753	0.0922124	-0.14997	2.7299972
Program[58]	-0.105265	0.103273	-1.02	0.3110	-0.310599	0.1000694	-0.10611	1.9820422
Program[59]	0.0168523	0.157166	0.11	0.9149	-0.295637	0.3293412	0.014697	3.4355574
Program[60]	-0.107287	0.0663	-1.62	0.1093	-0.239109	0.0245342	-0.16079	1.8054787
Program[61]	-0.009921	0.202657	-0.05	0.9611	-0.412858	0.3930152	-0.00865	5.7121699
Program[62]	0.0016637	0.147675	0.01	0.9910	-0.291954	0.2952809	0.001451	3.0331317
Program[63]	-0.126444	0.148227	-0.85	0.3960	-0.421159	0.1682703	-0.11027	3.0558423
Program[64]	-0.076428	0.091232	-0.84	0.4045	-0.257821	0.1049645	-0.08608	1.9310165
Program[65]	0.1941876	0.204339	0.95	0.3446	-0.212093	0.6004677	0.169349	5.8073677
Program[66]	-0.042249	0.111035	-0.38	0.7045	-0.263015	0.1785175	-0.04759	2.8603039
Program[67]	0.0123694	0.091199	0.14	0.8924	-0.168959	0.1936974	0.013932	1.9296386
Program[68]	0.2409231	0.089342	2.70	0.0084*	0.0632882	0.4185581	0.271362	1.8518388
Program[69]	0.0182831	0.10683	0.17	0.8645	-0.194123	0.2306889	0.018431	2.1209125

Figure 40. Normality Test (Model 5 – Development)

Residual |PAUC %Δ|



Quantiles

100.0%	maximum	0.3933869267
99.5%		0.3933869267
97.5%		0.2947679933
90.0%		0.1091848339
75.0%	quartile	0.0283916909
50.0%	median	8.673617e-17
25.0%	quartile	-0.041507727
10.0%		-0.095162238
2.5%		-0.210880528
0.5%		-0.328532553
0.0%	minimum	-0.328532553

Summary Statistics

Mean	1.312e-16
Std Dev	0.0989928
Std Err Mean	0.0082494
Upper 95% Mean	0.0163065
Lower 95% Mean	-0.016307
N	144

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	1.312e-16	-0.016307	0.0163065
Dispersion	σ	0.0989928	0.0887287	0.1119634

-2log(Likelihood) = -258.405677737621

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.893725	<.0001*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Appendix C - MDAP used in the Models

Development:

1. Advanced Pilot Trainer (APT)
2. B-1 - Vertical Situation Display Upgrade (VSDU)
3. B-1B - Central Integrated Test System (CITS)
4. B-1B - Inertial Navigation System (INS)
5. B-1B - Radar Reliability and Maintainability Program (RMIP)
6. B-2 - Common VLF Receiver (CVR)
7. B-2 - Extremely High Frequency (EHF) Inc 1
8. B-2 - Flexible Strike Phase 1 (FSP1)
9. B-52 - Combat Network Communications Technology (CONECT)
10. B-52 - Radar Modernization Program (RMP)
11. Battlefield Airmen
12. C-130H - Avionics Modernization Program (AMP) Inc 1
13. C-130J
14. C-130J - Automatic Dependent Surveillance Broadcast (ADS-B Out)
15. C-17 - Communications Navigation & Capability Mandates (CNCM)
16. C-17 - Filter Fire
17. C-17 - Globemaster III
18. C-17 - Replacement Head-Up Display (RHUD)
19. C-17A - Common Configuration
20. C-27J
21. C-5 - Avionics Modernization Program (C-5 AMP)
22. C-5 - CMC Weather
23. C-5 - Reliability Enhancement and Re-engining Program (RERP)
24. C-5M - Communication Navigation Surveillance (CNS) Air Traffic Management (ATM)
25. Contracting Information Technology (CON-IT)
26. Defense Enterprise Accounting & Management System (DEAMS)
27. F-15 - Advanced Display Core Processor II (ADCP II)
28. F-15 - Electronic Passive Active Warning and Survivability System (EPAWSS)
29. F-15 - Infrared Search and Track (IRST)
30. F-15E - Radar Modernization Program (RMP)
31. F-16 - Active Electronically Scanned Array (AESA)
32. F-16 - Auto Ground Collision Avoidance System (AGCAS)
33. F-16 - COMM Suite Upgrade (CSU)
34. F-16 - Mission Trainer Center (MTC)
35. F-16 - Modular Mission Computer (MMC) Programmable Display Generator (PDG)
36. F-16 - Multifunctional Information Distribution System-Joint Tactical Radio System (MIDS-JTRS)
37. F-22 - Increment 3.2B
38. F-22 - Tactical Mandates (TacMan)
39. F-22 - Update 6
40. HC-MC-130J - Recapitalization

41. HH-60W - CRH
42. Joint Terminal Control Training & Rehearsal System (JTC TRS)
43. JPATS
44. JPATS - T-6A/B - Automatic Dependent Surveillance Broadcast (ADS-B Out)
45. KC-46
46. Maintenance, Repair, and Overhaul Capability Initiative (MROi)
47. MC-130H - Talon Plus 10
48. MQ-1 - Airborne Cueing and Exploitation System - Hyperspectral (ACES HY)
49. MQ-1 - Predator
50. MQ-1 - Predator CCIP
51. MQ-9 - Reaper
52. Non-Invasive Warming and Cooling Device (NIWCD)
53. Predator Mission Aircrew Training System (PMATS)
54. Presidential Aircraft Recapitalization (PAR)
55. Program and Budget Enterprise Service (PBES)
56. RQ-4
57. RQ-4 - Ground Segment Modernization Program (GSMP)
58. RQ-4 - MS-177
59. UH-1N - Replacement
60. VC-25 - Avionics Modernization Program (AMP)

Production:

1. Advanced Pilot Trainer (APT)
2. Air Force Integrated Personnel and Pay System (AFIPPS)
3. B-1 - Vertical Situation Display Upgrade (VSDU)
4. B-1B - Central Integrated Test System (CITS)
5. B-1B - Fully Integrated Data Link (FIDL)
6. B-1B - Inertial Navigation System (INS)
7. B-1B - Radar Reliability and Maintainability Program (RMIP)
8. B-2 - Common VLF Receiver (CVR)
9. B-2 - Extremely High Frequency (EHF) Inc 1
10. B-2 - Flexible Strike Phase 1 (FSP1)
11. B-2 - Military GPS User Equipment (MGUE)
12. B-52 - Combat Network Communications Technology (CONECT)
13. B-52 - Radar Modernization Program (RMP)
14. Battlefield Airmen
15. C-130 - Avionics Modernization Program (AMP)
16. C-130H - Avionics Modernization Program (AMP) Inc 1
17. C-130J
18. C-130J - Automatic Dependent Surveillance Broadcast (ADS-B Out)
19. C-17 - Communications Navigation & Capability Mandates (CNCM)
20. C-17 - Extended Range (ER)-OB2
21. C-17 - Extended Range OB2
22. C-17 - Filter Fire

23. C-17 - Globemaster III
24. C-17 - Replacement Head-Up Display (RHUD)
25. C-17A - Common Configuration
26. C-27J
27. C-5 - Avionics Modernization Program (C-5 AMP)
28. C-5 - CMC Weather
29. C-5 - Reliability Enhancement and Re-engining Program (RERP)
30. C-5M - Communication Navigation Surveillance (CNS) Air Traffic Management (ATM)
31. Contracting Information Technology (CON-IT)
32. Defense Enterprise Accounting & Management System (DEAMS)
33. Electronic Board Operation Support System (eBOSS)
34. F-15 - Advanced Display Core Processor II (ADCP II)
35. F-15 - Electronic Passive Active Warning and Survivability System (EPAWSS)
36. F-15 - Infrared Search and Track (IRST)
37. F-15C - APG-63v3 Radar Upgrade
38. F-15E - Radar Modernization Program (RMP)
39. F-16 - Active Electronically Scanned Array (AESA)
40. F-16 - Auto Ground Collision Avoidance System (AGCAS)
41. F-16 - COMM Suite Upgrade (CSU)
42. F-16 - Mission Trainer Center (MTC)
43. F-16 - Modular Mission Computer (MMC) Programmable Display Generator (PDG)
44. F-16 - Multifunctional Information Distribution System-Joint Tactical Radio System (MIDS-JTRS)
45. F-22 - Increment 3.2B
46. F-22 - Tactical Mandates (TacMan)
47. F-22 - Update 6
48. HC-MC-130J - Recapitalization
49. HH-60 - Operational Loss Replacement (OLR)
50. HH-60W - CRH
51. JPATS
52. JPATS - T-6A/B - Automatic Dependent Surveillance Broadcast (ADS-B Out)
53. KC-46
54. Maintenance, Repair, and Overhaul Capability Initiative (MROi)
55. MC-130H - Talon Plus 10
56. Mobility Air Force Distributed Mission Operations (MAF DMO)
57. MQ-1 - Airborne Cueing and Exploitation System - Hyperspectral (ACES HY)
58. MQ-1 - Predator
59. MQ-1 - Predator CCIP
60. MQ-9 - Reaper
61. Night Vision Cueing Device (NVCD)
62. Non-Invasive Warming and Cooling Device (NIWCD)
63. Predator Mission Aircrew Training System (PMATS)
64. Presidential Aircraft Recapitalization (PAR)
65. Program and Budget Enterprise Service (PBES)

66. RQ-4
67. RQ-4 - Ground Segment Modernization Program (GSMP)
68. RQ-4 - MS-177
69. UH-1N - Replacement
70. VC-25 - Avionics Modernization Program (AMP)

Bibliography

Air Force Cost Analysis Agency. (2007). *Air Force Cost Risk and Uncertainty Analysis Handbook (CRUH)*. Washington, DC.

Air Force Cost Analysis Agency. (2008). *Air Force Cost Analysis Handbook (AFCAH).* Washington, DC.

Arena, Mark V., Obaid Younossi, Lionel A. Galway, Bernard Fox, John C. Graser, Jerry M. Sollinger, Felicia Wu, and Carolyn Wong, *Impossible Certainty: Cost Risk Analysis for Air Force Systems*, Santa Monica, Calif.: RAND Corporation, MG-415-AF, 2006.

Brown, G. E. (2019). Eliciting Expert Opinion in Acquisition Cost and Schedule Estimating.

Capen, E. C. (1975). The difficulty of assessing uncertainty. *Society of Petroleum Engineers and the American Institute of Mining, Metallurgy, and Petroleum Engineers 50th Annual Fall Conference and Exhibit*, Dallas, Texas

Capen, E. C. (1976). The Difficulty of Assessing Uncertainty. J Pet Technol 28 (8): 843-850. Doi: 10.2118/5579-PA

Coleman, R. L., Braxton, P. J., & Druker, E. R. (2010). *The Correct Use of Subject Matter Experts in Cost Risk Analysis*.

Dalkey, N. C. (1969). *Delphi Method: An Experimental Study of Group Opinion. Santa Monica, CA: RAND Corp.* https://www.rand.org/pubs/research_memoranda/RM5888.html.

Defense Acquisition University (2015), "Glossary of defense acquisition acronyms and terms", available at https://dap.dau.mil/glossary/Pages/1688.aspx (accessed 8 October, 2019).

Department of Defense (2018). Work Breakdown Structures for Defense Materiel Items. MIL-STD-881D. Washington: DoD.

Flyvbjerg, B. (2011). Over Budget, Over Time, Over and Over Again. *Oxford Handbooks Online.*

Galway, L. A. (2007). *Subjective Probability Distribution Elicitation in Cost Risk Analysis: A Review*. RAND Corporation: Santa Monica, CA.

Hilmer, C. E., & Hilmer, M. J. (2014). *Practical Econometrics*. McGraw-Hill Education.

Janis, I. (1991). Groupthink. In E. Griffin (Ed.) *A First Look at Communication Theory* (pp. 235 - 246). New York: McGrawHill

Kahneman, D. (2011). Thinking, fast and slow. New York: Farrar, Straus and Giroux.

McKenzie, C.R.M., Liersch, M.J. & Yaniv, I. (2008) Overconfidence in interval estimates: what does expertise buy you? *Organizational Behavior and Human Decision Process*, 107, 179-191. https://doi-org.afit.idm.oclc.org/10.1016/j.obhdp.2008.02.007

Meyer, M. A., & Booker, J. M. (2001). *Eliciting and analyzing expert judgment: a practical guide*. Society for Industrial and Applied Mathematics.

Mislick, G. K., & Nussbaum, D. A. (2015). *Cost estimation: methods and tools*. John Wiley & Sons.

Naval Center for Cost Analysis. (2014). *Joint Agency Cost and Schedule Risk and Uncertainty Handbook*, Washington, DC.

O'Hagan, A (2019) *Expert Knowledge Elicitation: Subjective but Scientific*, The American Statistician, 73:sup1, 69-81, DOI: 10.1080/00031305.2018.1518265

O'Hagan, A., Buck, C. E., Daneshkhah, A., Eiser, R. J., Garthwaite, P. H., Jenkinson, D. J., … Rakow, T. (2006). *Uncertain Judgements: Eliciting Expert Probabilities*. John Wiley & Sons.

Porter, G., Gladstone, B., Gordon, V., Karvonides, N., Kneece, R.R.,Jr, Mandelbaum, J. and O'Neil, W. (2009), The Major Causes of Cost Growth in Defense Acquisition Volume I: Executive Summary, (IDA P-4531), Institute for Defense Analysis, Alexandria, VA.

Smith, Alfred. (2008). "How Many Iterations Are Enough?" Paper presented at SCEA/ISPA Joint Conference & Training Workshop, Industry Hills, CA, June 24-27.

Sullivan, M. J. (2011). *DoD cost overruns: Trends in Nunn-McCurdy breaches and tools to manage weapon systems acquisition costs* (No. GAO-11-499T). GOVERNMENT ACCOUNTABILITY OFFICE WASHINGTON DC.

Tredger, E., Lo, J., Haria, S., Lau, H., Bonello, N., Hlavka, B., & Scullion, C. (2016). Bias, guess and expert judgement in actuarial work. *British Actuarial Journal*, *21*(3), 545-578. doi:10.1017/S1357321716000155

Tversky, A. & Kahneman, D. (1974). Judgement under Uncertainty: Heuristics and Biases. *Science*, 185(4157), 1124-1131.

Valentine, S. (2019, August 1). Personal interview

Weick, M., Hopthrow, T., Abrams, D., & Taylor-Gooby, P. F. (2012). Cognition: Minding Risks. *Lloyd's Emerging Risk Reports*.

Williams, B. S. . M. (2010). Heuristics and biases in military decision making. *Military Review*, (5), 40.

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14. ABSTRACT

This research compares the efficacy of subject matter expert (SME) elicitation methods to other cost estimation methods using a development and production dataset provided by AFLCMC/FZC. First, by using descriptive statistics to evaluate low versus high amount of the respective cost estimation methods by analyzing the means of percent cost growth for both groups. Next, this research involved using a statistics-based approach to investigate whether SME based cost estimating methods have an associated relationship to percent change of Program Acquisition Unit Costs (PAUC), which will be our proxy variable to cost growth. Using a pooled cross-sectional OLS regression analysis model with adjusted R^2 of 0.298, 144 POEs sample for development have statistical evidence to support SME based cost estimates have a positive association with Program Acquisition Unit Cost (PAUC). Lastly, this research critically examines SME elicitation methods used within DoD and provides best practices used by industry and academia when eliciting SMEs that the cost estimating community should consider implementing.

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