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Estimating the Estimate: Toward a Quick and Inexpensive Method for Weapons System Cost Estimation

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Abstract

This paper describes a process to provide low-cost and timely cost estimation for weapons system and services procurements based on data analytics. This will enable quick estimation that can serve as a sanity check for more formal estimation methods. Specifically, this cost estimation technique is built on the price-to-win methodology used by defense companies to respond to DoD solicitations. The process is based on market clearing prices as reflected by actual winning bids, expert knowledge to validate the scope of work, and an algorithm developed to incorporate these aspects into an estimate. The process is an “estimate of the estimate” and meant as an adjunct to formal cost estimating processes. The value lies in the ability to create quick, inexpensive estimates responsive to management needs while the formal cost estimating process proceeds.

Introduction

Cost estimation is as much science as it is art. And, like most science and art, it is resource intensive and time-consuming. The science is driven by the desire to accurately capture the elements of cost—including the amount of labor required, labor rates, overhead rates, and so forth—to provide an accurate starting point for budgeting and program management activities. The art of cost estimation is the fine line between accepting provided data and critically examining that data before accepting it. The most basic inputs to a cost model are the cost elements defined and captured by accountants: direct labor, materials, and overhead. However, identifying these cost elements is just the science. The art demands experience with both the data and the requirements of systems development. Good cost estimates at every stage of the development process must have this mixture of art and science. The goal of this paper is to present a tool that uses the art and science to provide inexpensive and timely initial cost estimates for weapons systems and services procurements based on data analytics.

Realistic cost estimation is a necessity for successful weapon systems development and services contracts. However, cost estimates are frequently wrong, or unrealistic, and in many cases, time-consuming and unresponsive. Further, as the GAO states, “bias and over optimism creep into estimates that advocates of weapon systems prepare, and the estimates tend to be too low” (GAO, 2009). The science of cost estimation depends on accurate data consisting of unambiguous definitions of the tasks, standardized work breakdown structures, recognition of the uncertainties of system development, and the recognition that significant program changes will cause changes in the estimate (GAO, 2009). The art is found in the familiarity and know-how of both the cost estimators as well as the cost engineers and others involved in applying knowledge of developments to develop estimates.

Current challenges with the cost estimation process include

- known costs being excluded without adequate justification
- invalid historical cost data
- inconsistent consideration of inflation
- cost and time necessary to accomplish

It is this last issue of cost and time necessary to accomplish that is the focus of this effort. Whether cost estimator, cost engineer, or project manager, the need for quick, ROM (rough order of magnitude) cost estimates is an ever-present requirement of the DoD acquisition workforce. Users and contractors routinely ask for more capability from existing systems, as well as proposing new systems. Young (Young & Markley, 2008) describes the scenario:

> "How soon can you get me a rough order of magnitude [ROM] on the cost?" The project engineer does a mental retrieval and concludes that a full bottoms up engineering estimate is needed, but that will take too long—about three to four months. The project engineer knows it has to be faster, so he throws a number out. "I need a month to develop a ROM." "Give me a ROM in two weeks if you really want any chance of funding this initiative," is the reply.

Unfortunately, the time and money to act on these requests is in short supply. We need a tool that can react to the demands of present-day acquisition, yet be accurate enough to satisfy the standards of cost estimating.

The proposed tool was developed for the defense industry while the authors were employed by one of the major defense contractors. The development of this tool initially focused on one business-focused cost estimating activity, determining the price-to-win (PTW) in defense markets. We believe this process, however, offers the means to address the scenario described above, and those similar situations that occur every day across the DoD acquisition space. It is important to note this process is not a formal cost estimation process, nor is it meant to supplant the recognized cost estimating processes. This "estimating the estimate" is an adjunct to formal cost estimating to enable cost estimators, cost engineers, and the PMO a quick way to develop an estimate—of the formal cost estimate. The process is based on basic economic theory—the law of supply and demand and market clearing theory, the point where producers' products and consumers' demand are equal. This quick estimation process can serve as a sanity check for the more validated and formal estimation methods. It can also help address the challenge of responding to requests for ROM pricing in case of extra funding availability, end of year funding, etc.

Cost estimation is serious business with very real fiscal and operational consequences. This tool builds on the *science* of cost estimation by incorporating both the actual winning bids for DoD competitions and the associated costs throughout the development. In other words, it models the market using prices that were successfully bid. This becomes the market clearing price. This approach offers the possibility of providing macro-level estimates based on microeconomic theory and historical trends and weapon systems development using a data analytics approach. The *science* still defines the determinants or drivers of cost such as productivity or labor rates. The *art* is in modeling the market.

The following is the research question to be examined:

Can market pricing provide a reasonably accurate cost estimating methodology that is quick and less expensive to execute that provides actionable information to government program managers?

Specifically, we seek to examine whether a data analytics approach based on market pricing will yield actionable cost estimates.

Cost Estimation

The field of cost estimation is rich in research. However, of late the preponderance of the effort appears to be focused on software cost estimation. This is understandable given the importance of software in the modern world, and the opaque nature of estimating software development. And, of course, the fact that an ever-larger percentage of capability in weapons systems comes from the software-hardware integration, rather than hardware itself. Regardless of the focus, the basic quantitative and qualitative methods are used in all cost estimating.

Cost estimation for both software, hardware, and service projects is a formal, documented process. Review of the field identifies the broadly defined methods to estimate costs. These include the following (Boehm, 1984; Evans, Lanham, & Marsh, 2006; Jorgensen, 2005; Leung & Fan, 2002):

- analogy;
- top-down;
- bottom-up;
- Parkinson;
- algorithmic models;
- expert judgment; and
- Price-to-Win (PTW).

The most commonly used techniques in the DoD are analogy, parametric (top-down), and engineering (bottom-up) estimating (Mislick & Nussbaum, 2015). Analogy simply compares similar developments using historically captured cost information. A parametric or top-down estimate builds a cost estimate for the development project from historical data comparing variables through a statistical relationship. Finally, an engineering or bottom up estimate is a comprehensive cost estimate starting at the work package level and aggregating costs to build a more complete estimate.

The Parkinson estimation is based on the Parkinson principle that "work expands to fill the available volume." It is only mentioned to acknowledge that while not a rigorous estimating tool, there are times when the cost is determined by available resources, rather than a defined end-state.

Algorithmic cost estimation models use one or more algorithms to analyze variables considered to be the major cost drivers for the weapons system. The algorithmic methods are based on mathematical models that produce cost estimates as a function of a number of variables that are considered to be the major cost factors (Leung & Fan, 2002).

Expert judgment simply acknowledges that engineering experts should be able to estimate the effort necessary to accomplish development tasks and translate those estimates to costs in technological activities—where they have experience. Thus, expert judgment is defined as the consultation of one or more experts (Hughes, 1996).

Some disagree on whether the final category, price-to-win (PTW), is actually a cost estimation methodology, categorizing it as a cost management process rather than a cost estimating process (Boehm, 1984). In the PTW, the cost estimate is equated to the price believed necessary to beat competitors. In other words, PTW is a market-focused estimate focused on identifying the price necessary to win a government competition. Defense companies regularly use PTW as a target price to drive internal cost-savings measures as well as to drive the design-to-cost (DTC) target. Notwithstanding this characterization, we propose that certain aspects of the PTW process can be used to approximate initial system costs. The proposed tool combines two of these cost estimation methodologies, expert judgment to define an algorithm as a PTW to provide an initial cost estimate.

Price-to-Win

Regardless of stated evaluation criteria, price is a significant factor in most government contract decisions. PTW is used in industries that have limited customers—monopsonies including the U.S. defense industry. While often mentioned in the broad category of pricing methodologies, it is often dismissed as "the price believed necessary to win the contract," thus not acceptable for formal cost estimating. This definition has evolved into developing a strategy that fits the customer budget rather than the effort required to complete the work (Leung & Fan, 2002). It is true the defense industry uses PTW for competitive reasons. Industry competitors want to present the government customer with their lowest price, while ensuring adherence to RFP requirements, at least in comparison to other competitors. The PTW is part of a decision-making process that includes an assessment of the firms' ability to develop a cost-competitive offer within their risk tolerance. PTW is focused on ensuring the industry solution meets the government needs, while emphasizing the competitive advantage of individual companies. It is worth noting that PTW is widely practiced in the U.S. defense industry. In fact, as a matter of process, many firms require a PTW determination before deciding to spend the money necessary to prepare a proposal, and throughout the proposal development.

The PTW approach consists of estimating the price for each competitor, a potentially expensive process in that the current practice of PTW requires accurate assessments and analysis of competitive intelligence on the competition. Defense companies seek to understand in detail both competitor companies' strengths and weaknesses, as well as their pricing structure. PTW also analyzes the nuances of the government customer, specifically what the award history is, as well as any trends in reasons for selections. The competitive intelligence is based on open source materials to try to determine both any competitive advantages individual companies may have, as well as any unique approaches to solving the government's problem. A type process of PTW includes the steps shown in Table 1.

Table 1. The Price-to-Win Process

Task	Description
Strategic Assessment of the Market/Opportunity	An ongoing process that tracks winning bids, usually done by the business development organization of a company
Competitive Analysis	Competitor company capabilities/services/competitive advantage Specifications of products Estimation of rates Estimation of solution
Customer Assessment	Customer contract award history Bottom up cost modeling
Risk Assessment	Assessment of cost and technical risk

A consideration in competitive intelligence assessments is that the U.S. defense industry is more or less balanced in capability across like companies. For instance, Raytheon and Lockheed Martin have legacy radar and missile businesses and compete in those areas. Boeing and Lockheed Martin compete in the high-performance fighter aircraft market and so on. The drawdowns and consolidations of the defense industry in the 1990s, as well as more recent consolidation, make competition in those areas fierce. Losing a government contract could mean exiting that line of business, thus determining what the competitor is going to do, and deciding an offer price is a high-stakes effort.

By industry capability we also mean intellectual property, manufacturing efficiency, and human resources. Intellectual property is driven by the investment firms make in Independent Research and Development (IRAD) efforts. Manufacturing efficiency tends to mirror the overall industry and remains a source of potential profit if managed cost-effectively. Human resources refer to engineering talent—the product of quality education and individual potential. The defense industry capability is driven by the labor market, and manufacturing efficiency is determined by the overall state-of-the-art. The defense industry draws from the same talent pool. Differences in competitive pricing originate from specific qualifications or competitive advantage of intellectual property from self-developed research and development programs, not necessarily widely varying labor rates. The PTW reflects the market clearing price.

For the defense firm, the PTW analysis should yield a value that addresses customer need that also will be successful against competition. A finalized PTW analysis reflects a schedule-performance tradeoff that becomes a pacing item for development of the proposed system.

The PTW approach is a macro-economic examination of an existing DoD program. While not specific enough to address the actual development of a cost estimate, it could serve as both ROM and as an indicator in the continued pursuit of a detailed cost estimate. These estimates would not replace the detailed parametric cost estimates, or IGCE, nor be a substitute for market research. Instead, the solution would provide the PM/contracting officer a means to validate/confirm the results of more in-depth cost analysis, while providing program office personnel a starting point for budgeting, and cost realism.

The PTW Process Translated

As noted, this tool leverages the science and art of cost estimation through the application of expert judgment and algorithmic data modeling. Expert judgment is an estimate based on the expertise of one or more people familiar with the costs and scope of similar system developments (Keeney & Winterfeldt, 1989; Morris, 1974). In the case of

PTW, the expert judgment comes from people familiar with the market for that particular product. In defense firms this includes cost engineers, specific engineering domain engineering experts, and the business development staff. In use as a cost estimation tool for the DoD, expert judgment would include government cost engineers and domain experts, as well as results of the market research activities (RFI—Requests for Information).

The data used for the tool consists of the actual winning bids and the associated scope of past programs, plus a mechanism to track the inevitable changes to the cost estimate as changes occur throughout the development. This approach could be more accurately described as an "algorithmic" method. It offers the possibility of providing macro-level estimates based on microeconomic theory and historical trends and weapon systems development using a data analytics approach.

Three data elements—scope, budget, and contract award price—were used to develop an algorithm to explain the winning price ranges for the competitive solicitations chosen. Although focused on the price necessary to win a contract, we believe these price ranges should correspond to the initial cost estimates provided by the government. Cost is estimated as a mathematical function of product, project, and process attributes whose values are estimated by project managers.

An essential factor of this analysis is the ability to identify both initial costs against specific SOW tasks, as well as track cost-growth/scope increase as the product developed. As we continue to develop the tool, we expect this analysis to show relationships between similar contracts of similar value scope.

In developing the tool, we started with three basic macro-economic assumptions:

1. In non-commodity markets the equilibrium price is the mean of a range of prices which are normally distributed about the equilibrium price. The government contracting market is a non-commodity market.
2. The equilibrium price represents the balancing of costs, risks, and margin for the government and the contractor. If one of these three elements is negatively skewed for a specific supplier, they would exit the market. If one of these three elements is positively skewed for a specific supplier, competition would respond and the price would adjust accordingly.
3. In the government contracting market, a monopsony, supply exceeds demand and the price for the goods or services will be below the equilibrium price.

The first step in this cost estimation process is to identify an equilibrium price (EP). The EP is approximated by developing two extreme estimates for a given government provided statement of work (SOW). This first task depends on expert judgment to establish an initial range of possible prices, a low-price estimate (LPE) and a high-price estimate (HPE). These expert estimates are considered from both the government and contractor perspective, acknowledging the different ways government and contractor cost estimators consider a system cost. The low end of the estimate reflects the expert's opinion on the cost associated with meeting the minimums of schedule and performance. The low-price estimate is the absolute minimum the government estimator believes is necessary for schedule and performance execution, and therefore reflects a price that represents the extreme risk for a contractor to execute. Figure 1 shows the normal distribution of the LPE-HPE estimates.

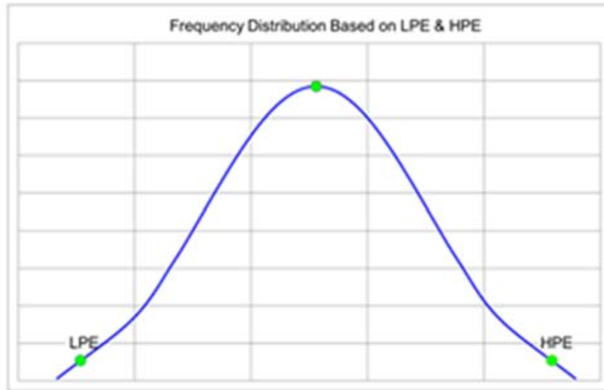

Figure 1. Equilibrium Price

On the other end of the spectrum, the HPE represents a price the government believes addresses the risk for both government and contractor. These two extremes should define the possible market for the system to be developed, with the mean representing the equilibrium price in balanced market where the price reflects an optimal balance between costs, risks, and contractor margin.

As noted, the normal market clearing distribution will tend to be skewed because of monopsony in defense markets. In this case, supply will always exceed demand; therefore, the mean will tend to be lower than the equilibrium price. Figure 2 represents that distribution.

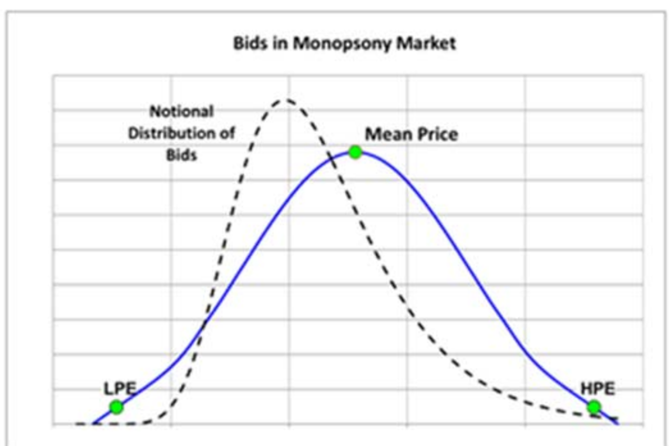

Figure 2. Bids in a Monopsony Market

Obviously, the government expert estimator needs access to the contractor perspectives on price, but that is normal. We believe government marketing research RFI could assist in this data collection. There are two steps to solicit these estimates. First, as is often done today, the PMO would request a ROM price as part of the market research effort. The challenge with ROM pricing estimates provided by potential contractors is the contractor concern their ROM will become the government target price. Thus, contractors will always add a "pad" to the ROM to reflect unknown and unforeseen risk. The government expert should be the arbiter of these estimates. In planning the RFI, the PMO should also request an LPE and HPE using the definitions provided above. Assuming multiple responses to the market research, the government expert would be able to develop a reasonable estimate of the LPE and HPE. The government expert could use those estimates in developing a government LPE/HPE or maintain separate analysis and weigh the results prior to the next step.

The next step determines the cost estimate range and uses the second aspect of cost estimation, the algorithmic cost model. This step consists of two sequential activities built on historical contracting data (at this point proprietary in nature). The first part, which is ongoing, is to collect data on the defense industrial market in the United States. This data collection captures the open source information available on defense contracts. The data include the DoD request for proposal (RFP) details, including project scope and the government's budget. This information is matched to contract award price. Initially the emphasis has been on major programs (ACAT I); however, we intend to continue to gather as much data as possible. The initial dataset is small and reflects only the past three years. As more data becomes available over time, we believe the accuracy of the model will be improved.

The second part of this step uses a statistically relevant number of prior procurements (aligned to scope) to estimate the range of costs for a specific SOW type. The intent is to create a frequency distribution of the actual bids received. This information forms the basis for the algorithm used to identify the competitive price ranges for the sampled procurements. From the contractor perspective (PTW) the winning price should be below the equilibrium price by bidders altering the balance of cost, risk, and margin to win the contract—and reflecting the market clearing price. Thus, from a market clearing perspective, using historical data for like-system procurements, an initial estimate of the cost could be derived. Figure 3 represents that range. The final price is then determined by using statistical tools and applying the algorithm.

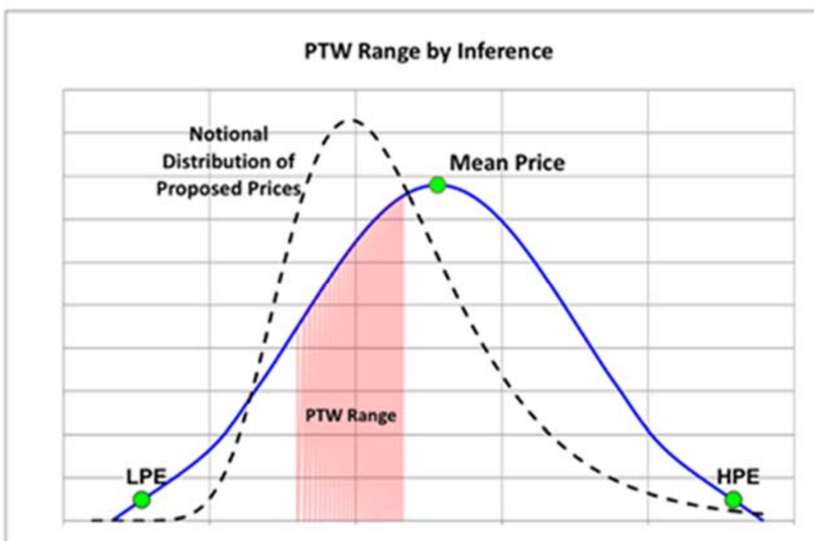

Figure 3. Algorithm Applied

Estimating the Estimate in Practice

To demonstrate the process, the following example is presented. The example project is a communications/electronics retrofit solution for surface ships for the U.S. Navy. The desired vehicle is a firm, fixed price contract, and the evaluation criteria is LPTA (Lowest Price Technically Acceptable). This effort is for a build-to-print production contract for 89 systems for three different ship types. The expert judgment estimate determined by RFI for the LPE and HPE is shown in Table 2.

Table 2. Cost Estimates Example

Ship	LPE ($M)	HPE ($M)
Ship Type A	$7.0	$9.5
Ship Type B	$7.5	$12.0
Ship Type C	$2.5	$5.0

The first step is to estimate the market price for each ship type. (For purposes of this example, we will estimate Ship A only.) The LPE and HPE represent the extremes of the market pricing for the solution fitted on the respective ship. LPE is defined as the estimate theoretically technically compliant (in this case LPTA), which minimizes labor costs and technical and programmatic risk. HPE is the estimate capturing all reasonable labor costs and factors in all programmatic and technical risk. Other factors not apparent in this example are the quantities of ships and the corresponding communications/electronics system solution.

Using proprietary historical information, the following calculations in Table 3 represent a range of LPTA estimates for the Ship Type A work.

Table 3. LPTA Example

	LPTA Range Probabilities	
10%	$7,330,402	$7
16%	$7,373,314	$7
20%	$7,396,158	$7
40%	$7,484,087	$7
50%	$7,521,955	$8
60%	$7,559,822	$8
80%	$7,647,751	$8
90%	$7,713,507	$8

Using the same process, but approaching the problem from a best value approach, the results of the analysis are shown in Table 4. Figure 4 is a graphical representation of the plotted ranges for the Ship A estimate. In this example, the 90% probability value was within 3% of the actual winning bid.

Table 4. Best Value Example

	Best Value FFP Range Probabilities	
10%	$7,844,924	$8
16%	$7,894,477	$8
20%	$7,920,857	$8
40%	$8,022,393	$8
50%	$8,066,121	$8
60%	$8,109,849	$8
80%	$8,211,386	$8
90%	$8,287,318	$8

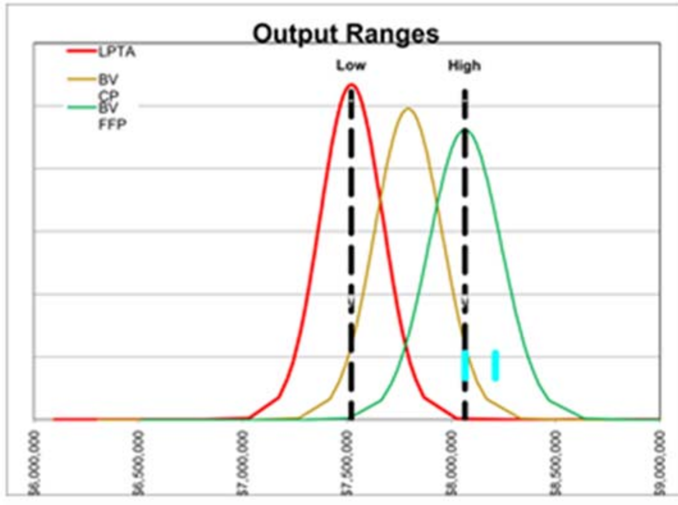

Figure 4. Plotted Ranges

Figure 5 shows the S-curves and the range of estimates for the different contract types, LPTA< CP and FFP (Best Value). The end state of this "estimate of the estimate" is a statistical range of pricing that provides the key layers, project engineers, cost estimators, program office, and contracting officials a starting point. To return to the scenario, instead of an expert judgment-only guided "guestimate" or worse, the project engineer can provide an empirically based estimate. To be sure, it will not be the final estimate, but it will provide a starting point. More importantly it will provide an answer to a very tough question.

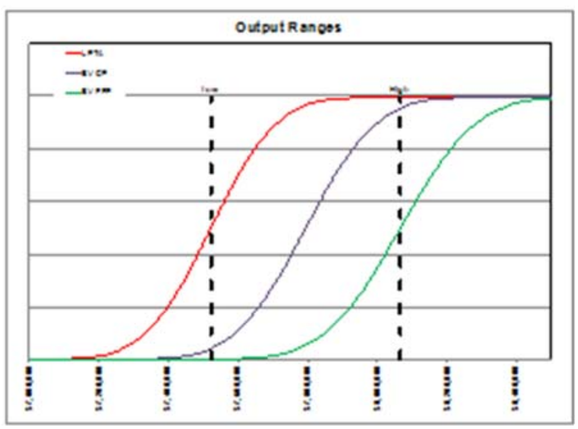

Figure 5. S-Curves for Example

Conclusion

This paper proposes using a defense industry tool, the price-to-win, to assist the cost estimating process for the DoD. Using market pricing and accepting the idea that while costs differ between competitors, their costs are generally similar, we suggest that applying economic market clearing ideas can provide a quick, inexpensive, and reasonably accurate cost estimate for most efforts.

This approach provides a macro-economic estimate of DoD programs. While not specific enough to address the actual development of a cost estimate, it could serve as both ROM, as well as an indicator in the continued pursuit of detailed cost proposals. The estimates would not replace the detailed parametric cost estimates, or IGCE, nor be a substitute for market research. Instead, the solution would provide a means to validate/confirm the results of more in-depth cost analysis, while providing program office personnel a starting point for budgeting and cost realism.

There are both pragmatic and theoretical limitations to this approach. Pragmatically, the technique must be tested using real data available only to the government. A second potential limitation is confidence in the ability of the government cost engineers (expert judgment) to define the LPE and HPE estimates. A major assumption of this approach is that government cost engineers and project managers are, in fact, experts and have a reasonable understanding of the range of costs for similar development projects. Our experience reinforces this belief, but it is clear that the better the estimates for the LPE and HPE, the better the overall estimate.

Theoretically, there must be a spread of at least one standard deviation but not too close to the end of the distribution in order to address the entire market. Theoretical limitations also include the available market data both in system and software procurements, and the amount of variance assumed to be in the distribution.

Finally, this tool can be improved and constantly updated by linking the DoD information on winning bids and the associated scope with the existing algorithm. A next step in this research is to request the use of said data and formally establish a validation effort to determine the quality of the results of the tools' computations.

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