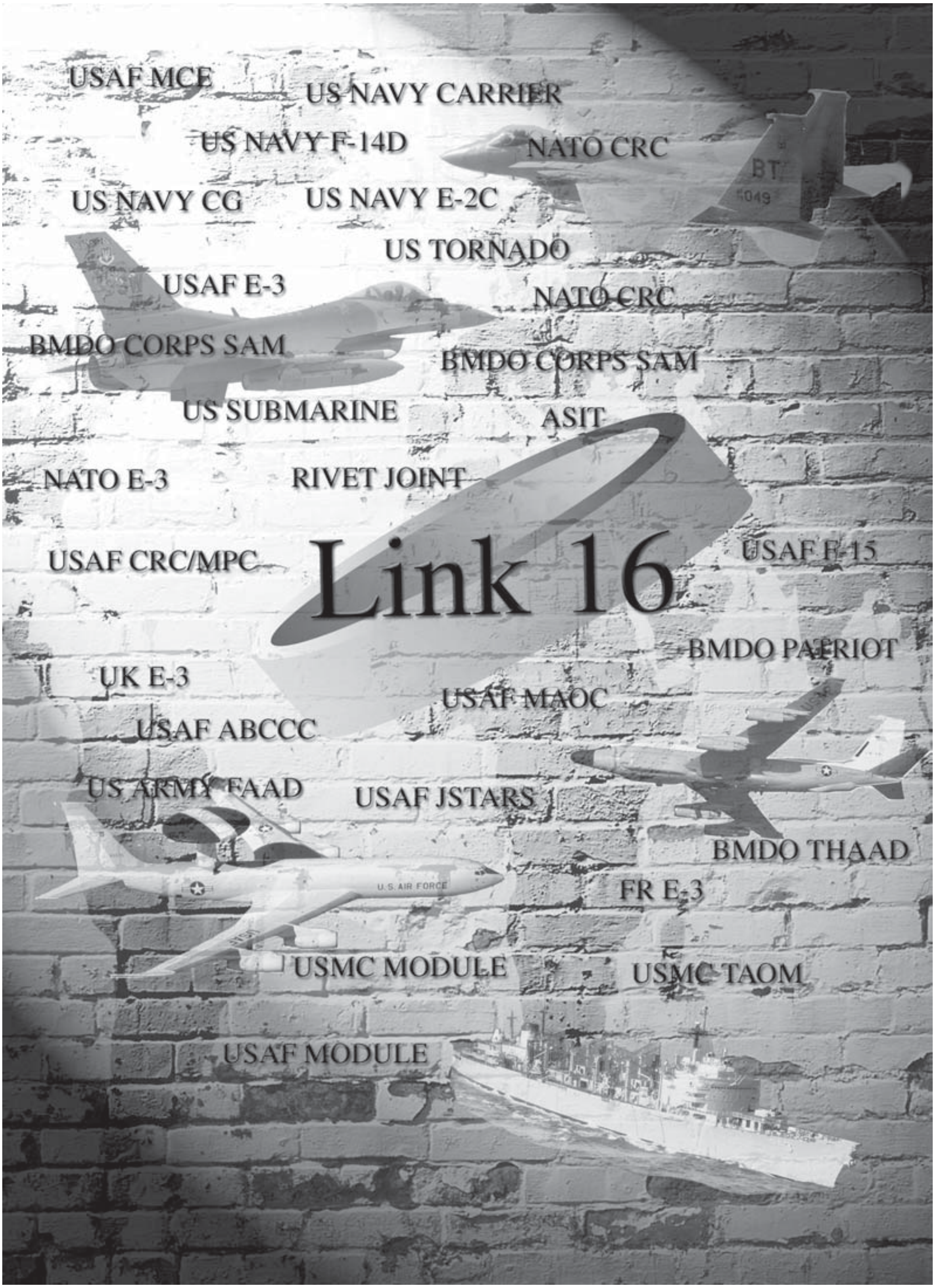

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Price Enumeration and Probabilistic Evaluation in System Acquisition**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **ESC/JS,Hanscom AFB,MA,01731**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Acquisition Review Quarterly, Fall 2002

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**14**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

PRICE ENUMERATION AND PROBABILISTIC EVALUATION IN SYSTEM ACQUISITION

Maj Kevin Gaudette, USAF and Kevin Sweeney

A number of environmental uncertainties in system acquisition can lead to situations where exact requirements are difficult to estimate. The uncertainties are often disregarded in favor of a simple point estimate. This point estimate, or Best Estimated Quantity (BEQ), is then used in the Request for Proposals (RFP) and subsequent source selection, with the evaluation conducted at the BEQ price using deterministic techniques. An alternative approach is presented for BEQ and deterministic price evaluation. The approach involves the solicitation of a range of bid prices for all potential quantities in lieu of a BEQ, with a complementary probabilistic analysis technique in lieu of a deterministic price evaluation. The probabilistic approach is then used to evaluate the range of bid prices and make an award decision. The methodology is presented in the context of an actual case study in which it was implemented in 1996.

Many acquisition programs face a challenging and ever-changing environment. Uncertain, dynamic requirements make program decisions and cost estimates extremely difficult. This difficulty is magnified at the time of a source selection, when the requirements must be frozen for communication to potential bidders. In a typical source selection, proposals are evaluated at the quantity that is certain at the time of the Request for Proposal (RFP), regardless of *how certain* that quantity is.

This quantity, often called the Best Estimated Quantity (BEQ), is therefore simply a crude point estimate made at a distinct point in time. When quantities are certain and static, as is sometimes the case, the BEQ is a perfectly acceptable methodology. When program characteristics make requirements uncertain and dynamic, however, the use of a BEQ and deterministic evaluation techniques drives cost risk to unnecessary levels. In fact, the only thing certain about a forecast made in an uncertain environment is that it will be wrong. This is an important concern, because inaccurate quantity estimates result in one of only two possible outcomes, illustrated by the "bath tub" curve in Figure 1.

In the first outcome, the quantity required is lower than the estimate used and evaluated in the source selection. Three things can happen in this case. If the lesser quantity was not priced in the contract, then the buyer is forced to renegotiate and will likely pay a significantly higher price. If the lesser quantity was priced in the contract, it is still likely that the unit price will be significantly higher. This stands to reason, given that the bidders will seek to reduce their own risk and that price is normally evaluated only at the BEQ. Finally, the buyer may be forced to buy excess items to satisfy the terms of the contract and avoid default penalties.

The second possible outcome is that the quantity needed increases. As was the case with the overestimated quantity described above, if the higher quantity is priced in the contract, it is likely to be a higher unit price. If not priced, the buyer must either conduct a new source selection for the additional units or must renegotiate the existing contract. Either option will result in a higher price than if the higher quantity had been considered in the original procurement.

The increased cost risk described above is often reduced, albeit to a limited extent, by the use of such techniques as Variable

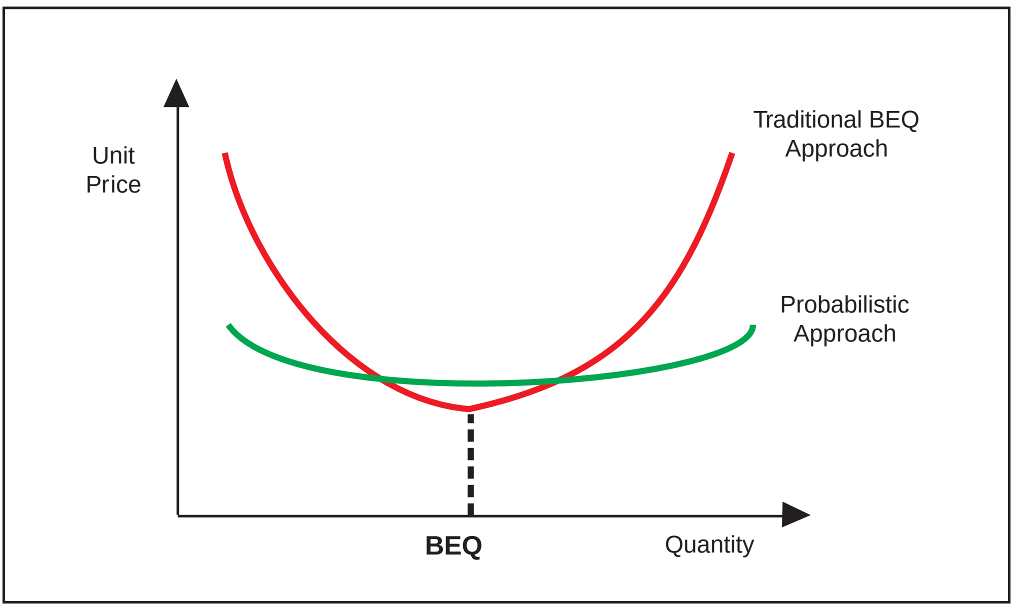

Figure 1. Notional Example of the Relationship Between Unit Price and Actual Quantity Purchased for BEQ and Probabilistic Approaches

Indefinite Quantity (VIQ) contract options and limited liability termination clauses. Unfortunately, these techniques are partial solutions. The latter is a "safety net" designed to limit the government's liability, while the bid prices in the former are usually not incorporated effectively into the proposal evaluation. These problems can be more rigorously addressed using a simple probabilistic approach. This paper describes the use of one such approach in system acquisition and presents a case study in which it was developed and applied. The method, which abandons the point estimate methodology altogether, was successfully used in a $200 million source selection for the Joint Tactical Information Distribution System (JTIDS) in 1996.

For simplicity, the approach is hereafter referred to as PE². The acronym, although admittedly contrived for convenience, nevertheless captures both primary components of the methodology described in this paper. The first "PE" is the request for an all-inclusive set of proposal prices covering the entire range of possibilities, called *price enumeration*. The second is the use of probabilistic techniques to evaluate that set of proposal prices, called *probabilistic evaluation*. When used together (PE²), the efficacy of these two techniques is maximized for reasons that will become clear.

The remainder of the paper is organized into four major sections: *Case Study, Methodology, Discussion, and Results*. The *Case Study* section provides an overview of the program in which the methodology was implemented and describes some of the unique program characteristics that made it necessary. The *Methodology* section describes the method in detail using supporting calculations, examples from the case study, and a brief discussion of its advantages. The *Discussion* section offers a discussion of the general program conditions that make probabilistic methods attractive. Strengths and potential pitfalls are included to aid acquisition professionals in implementation efforts. Finally, the *Results* section reports the outcome of the case study source selection.

Case Study

Program Background

PE² was implemented during a 1996 source selection for JTIDS, an Acquisition Category ID joint program. The primary function of JTIDS is to distribute tactical information in digital form. Specifically, JTIDS terminals provide jam-resistant digital communication of data and voice for command and control, navigation, relative positioning, and identification. JTIDS technology also locates and identifies subscribers with respect to other users and is capable of transmission rates far above those of most existing communication systems. In effect, the system gives airmen, sailors, and soldiers a real-time "God's-eye view" of the battlefield (Scott, 1996). JTIDS platforms range from Marine ground-based trucks, to Navy ships, to Air Force fighters, Airborne Warning and Control Systems (AWACS), and Joint Surveillance Target Attack Radar

"The acronym [PE²], although admittedly contrived for convenience, nevertheless captures both primary components of the methodology described in this paper."

Systems (JSTARS). The 1996 source selection was held to award the final production contract of JTIDS Class 2/2H terminals. Two contractors had been involved in the research and development, low-rate initial production, and first full-rate production contracts, and they were the only companies realistically capable of performance.

PROGRAM CHARACTERISTICS

The JTIDS program has many characteristics that illuminate the advantages of using a probabilistic methodology. All four U.S. military services had expressed requirements for 10 different variants of the terminals and had personnel working in the Joint Program Office (JPO) at Hanscom Air Force Base. In addition, there were several NATO customers, one of which was physically represented on the JPO staff. The diverse customer base, each with its own independent line of funding, made requirements forecasting extremely difficult. Projections would often change on a daily basis, depending on the funding posture of each service and NATO customer.

"The JTIDS program has many characteristics that illuminate the advantages of using a probabilistic methodology."

Since JTIDS is a subsystem installed on various land, sea, and airborne platforms, the requirements were also subject to fluctuations in projected platform end-strengths. In addition, the final full-rate production (FRP) contract spanned five years, making forecasts even more difficult. Firm requirements were a relatively simple matter for the first year, but for the four subsequent years the services were reluctant to commit due to budget uncertainties in the federal Planning, Programming, and Budgeting System (PPBS).

In combination, the diversity of the customer base, budget uncertainties, and the time span of the contract made the quantities nearly impossible to forecast. This highly uncertain and dynamic environment rendered the traditional BEQ approach to estimating quantities for a long-term contract inadequate. A probabilistic approach was therefore used to reduce program cost risk, while ensuring a reasonable price for all JTIDS users.

METHODOLOGY

THE DISCRETE PROBABILITY DISTRIBUTION

As discussed previously, PE^2 actually consists of two techniques used in tandem — price enumeration and probabilistic evaluation of the complete set of prices. The two are technically independent, but their symbiotic relationship dictates that they be used together for maximum effectiveness. A complete range of prices can certainly be solicited without using probabilistic techniques to evaluate them, although it makes little sense to do so in practice. Likewise, any probabilistic technique could be employed in an evaluation even if a limited number of bid prices are solicited in the RFP, but this limits the efficacy of the technique since the full range of potential prices will not be explicitly included in the contract.

It should be noted that the evaluation technique described in this section, although chosen for several reasons that will be discussed, is only one of many techniques that are available. Alternative techniques like Monte Carlo simulation, stochastic math programming, and simple sensitivity analysis, used individually or in combination, can all perform equally well. They can also be used to enhance PE^2.

The probabilistic evaluation used in the JTIDS program involves a technique employing a discrete probability distribution and expectation values. The primary reason that this technique was chosen over competing probabilistic techniques for the JTIDS source selection is simplicity. Traditional methods like those mentioned above are excellent tools for analysis of a set of possible outcomes, but they can be unnecessarily complex for the problem at hand. Additionally, the results can be difficult to interpret and explain to decision makers. Since the solicitation of prices for all possible quantities is a straightforward concept, it is omitted from the methodological discussion for brevity. Implementation issues associated with bid price enumeration are discussed in the *Discussion* section, but for now the focus is directed toward the probabilistic evaluation technique.

In the context of a source selection for uncertain quantities, a discrete probability distribution is composed of a finite set N of quantities q, for each of M line items — each with an associated probability of occurrence $p(q)$. The expected contract cost $E(C)$ is simply the sum of the products of all possible outcomes and their associated probabilities of occurrence, summed over all line items in the contract (Ross, 2000). The equation illustrates this mathematically.

$$E(C) = \sum_{i=1}^{M} \sum_{j=1}^{N_i} (q_{ij} c_{ij} p(q_{ij}))$$

Where

- q_{ij} = j^{th} possible value of q for line item i
- c_{ij} = bid unit price (cost) when buying j units of line item i
- $p(q_{ij})$ = probability of buying j units of line item i
- M = number of different line items on contract
- N_i = number of possible quantities for line item i
- $E(C)$ = expected cost of the contract

For each item, it is improtant to note that the sum of all probabilities must equal one.

$$\sum_{j=1}^{N_i} p(q_{ij}) = 1 \quad \forall i$$

Although the equation represents one of the most basic concepts in probability theory, its use is predominantly absent from military acquisition. This simple equation, however, can significantly reduce the cost risk in a program if used properly. By explicitly incorporating prices for all potential quantities in the price evaluation, direct incentive is provided to bidders to offer reasonable prices across the entire range of quantities. In the JTIDS source selection, the equation was incorporated into a spreadsheet that was distributed on a floppy disk with the Request for Proposal (RFP) (See Figure 2). The formulas and probabilities, therefore, were fully visible to the bidders. Although hundreds of bid prices were required, the bidders could easily fill in the blanks and conduct internal "what if" analyses to arrive at their desired bottom lines.

Qty	Weight %	Total Price	Avg Unit Price (AUP)	Weighted AUP
0	45.00%	$200,000	$0	$0
1	25.00%	$200,000	$200,000	$50,000
2	20.00%	$350,000	$175,000	$35,000
3	10.00%	$450,000	$150,000	$15,000

Figure 2. Sample Spreadsheet Entry for JTIDS Class 2 Terminals, Configuration 1 (F-15/MAOC), Fiscal Year 1997

In Figure 2, for example, the hypothetical bids show a nonincreasing unit price for increasing quantities. This example illustrates the quantity discount one would expect. Since the BEQ (in bold border) is zero units, the F-15 terminal would likely not have been included in a traditional BEQ-based solicitation. Its inclusion here avoids costly changes later should the user decide to exercise an option to buy terminals. This example is purposely chosen here, since an option was in fact later exercised for F-15 aircraft at Mountain Home Air Force Base participating in a Theater Missile Defense (TMD) Advanced Technology Concept Demonstration (ATCD) (Scott, 1996).

Advantages

A probabilistic approach offers four primary advantages over the traditional BEQ method. First, the evaluation price that ultimately drives the cost evaluation is a probabilistically-weighted average of all possible quantities. This leads to a more defendable forecast of the expected cost of the contract than does a simple point estimate (Anderson & Cherwonik, 1997). It also offers incentive to bid fairly for all quantities, since each will ultimately impact the price evaluation.

Second, the bidders *explicitly* submit bids for each possible quantity. This has the obvious benefit of eliminating nearly all cost risk associated with quantity uncertainty, since the unit prices for all possible quantities are contained in the contract. Lloyd (2000) was a proponent of this approach whenever possible contract changes threaten future prices.

Third, it allows program offices the ability to proceed with a source selection, if it makes sense to do so, even if the final funded quantities are still uncertain (Lloyd, 2000). In the case of JTIDS, if the JPO had waited until quantities were certain to conduct the source selection, it would have been delayed indefinitely.

Finally, any attempt to take advantage of the system using complex bidding strategies is immediately evident to the source selection evaluation team. Should some of the bid prices be unreasonable, it is a simple matter to translate that unreasonableness into technical risk. This advantage is consistent with the recent push toward Best Value source selections, in which awards to a bidder other than the one with the lowest cost are often deemed advantageous to the government. Any proposed prices that are considered unreasonable can be directly and quantitatively penalized in the technical evaluation (O'Connor, Faris, & Lovelace, 1997). This alleviates the problem of subjective technical evaluations that fail to stand up to protests by the losing bidders — a perennial problem in source selections (Lloyd, 2000; Raymond, 1999).

DISCUSSION

Certain conditions tend to favor the use of PE^2 in source selections. As alluded to throughout this paper, the method has many advantages over traditional point estimate evaluation techniques. Unfortunately, there are also several pitfalls inherent in the methodology that must be carefully avoided. Program managers and cost analysts need to recognize the conditions under which the use of PE^2 is both appropriate and preferred, and also must have a firm grasp of the strengths and potential pitfalls. The conditions favoring application of PE^2 are discussed first.

CONDITIONS FAVORING PE^2

Although the list of four conditions discussed here is certainly not intended to be all-inclusive, it contains four of the most important conditions in terms of any probabilistic methodology. It is not necessary that all conditions be met for PE^2 to be used, but obviously the number met and the degrees to which they are met are factors that must be considered. The four conditions are quantity uncertainty, current and accurate cost data, large quantities, and high unit cost. The first two can be distinguished from the latter two as prerequisites, for reasons that will become apparent.

Quantity Uncertainty – Quantity uncertainty is an obvious prerequisite condition for the use of probabilistic techniques, since there is no need for these techniques if the quantity is known. The degree of uncertainty, however, must be evaluated to determine whether it is high enough to warrant application of PE^2. In the JTIDS source selection, the degree of uncertainty was clear. The firm requirements totaled just 40 terminals, representing the minimum buy in the first contract year. Over the course of three years of terminal buy options, however, the maximum quantity was 230 terminals. The high degree of uncertainty and range of potential quantities warranted the use of probabilistic techniques. Uncertain procurement quantities in the JTIDS case resulted from a diverse customer base, budget uncertainties, multiple platforms, and multi-year contracts; but other programs may experience other causal factors leading to quantity uncertainty.

"Certain conditions tend to favor the use of PE^2 in source selections."

Current and Accurate Cost Data – The second prerequisite condition presented here is that of current and accurate cost data. Because the proposals will contain a large number of bid prices, each must be assessed for reasonableness. Any bid prices that are deemed unreasonable can then be translated to the technical evaluation in the form of risk. Without current and accurate cost data, it is very difficult in practice to quantify that risk and thereby discourage bidders from taking advantage of the system. In the case of

JTIDS, the maturity of the program meant that the JPO had a great deal of historical cost data to use in the evaluation.

Large Quantities – A large procurement in terms of quantity can also warrant the use of PE^2 or similar techniques. For such contracts, even a small percent deviation from the estimate can represent a significant increase or decrease. Again, in the case of JTIDS the range of quantities for terminals was 190, with a firm (minimum) requirement of 40 and a maximum of 230. If only 10 percent of the uncertain quantities were subsequently purchased, the total buy would increase by 19 terminals. This represents nearly a 50 percent increase in units from the firm BEQ originally contemplated for the source selection.

High Unit Cost – A related but distinct condition is the unit cost of the items in the contract. Just as large quantities can be significant even at low unit costs, large unit costs can be significant even at low quantities. JTIDS terminals cost between $50 thousand and $180 thousand each, depending on the type, so even a deviation of one terminal can translate to a substantial increase in cost. When combined with large quantities, the sensitivity to small deviations becomes even more significant.

"PE^2 has many advantages... risk reduction, visibility, ease of implementation, and flexibility."

STRENGTHS OF PE^2

PE^2 has many advantages. The four discussed here are, by nature of the underlying conditions, the most important. These are risk reduction, visibility, ease of implementation, and flexibility.

Risk Reduction – Risk reduction is the most obvious advantage, and in fact the one that drove the use of probabilistic techniques in the JTIDS program. In any program where quantity uncertainty is present, program managers run the risk of paying higher prices when quantities change (Lloyd, 2000). PE^2 can reduce or even eliminate that risk by requiring prices for all possible quantities at the time of proposal, rather than adjusting those quantities later. The possibilities are explicitly enumerated and probabilistically evaluated from the beginning.

Visibility – Because the complete set of prices is required in the proposal, any attempt to take advantage of the system is immediately visible to source selection evaluation team members. Where underlying bidding strategies are masked to the team using the BEQ method, they are uncovered using enumerative pricing. This makes the quantitative assessment of risk straightforward and defendable, avoiding the traps that a subjective technical evaluation can bring (Lloyd, 2000).

Ease of Implementation – PE^2 is relatively straightforward to implement. Although its application to source selection is unique, the equation is a mathematically simple concept. The evaluation price can easily be described to decision authorities as a probabilistically-weighted average, and therefore should be readily accepted by program managers, cost analysts, and contracting officers alike. As demonstrated in Figure 2, the equation can be incorporated into a spreadsheet and distributed to potential bidders electronically with the RFP.

Flexibility – Finally, PE^2 is flexible. In some programs, quantity uncertainty may exist only for a subset of contract line items. There may also be more uncertainty with some items than with others. In JTIDS, the degree of quantity uncertainty varied both by terminal type and by customer. The F-14 variant, for example, had no firm or expected requirements and a maximum of nine terminals over three years. This was due to the fact that the Navy was in the process of developing the next generation Multifunctional Information Distribution System (MIDS), but wanted to retain an option of purchasing a few JTIDS terminals should the MIDS schedule be delayed. In contrast, the Navy had a firm requirement for nine shipboard terminals, with an expectation to buy an additional 10 in the second year and a maximum possible requirement of 48. PE^2 may not have been justified for the F-14 terminals alone, but it is flexible enough to be used for many uncertainty levels under the umbrella of the same contract.

Pitfalls

The final consideration for implementing PE^2 is its potential challenges or pitfalls. There were many challenges encountered in the development and refinement of the implementation, but three were by far the most problematic. Coordination and approval of the methodology, price execution, and probability estimation are discussed below.

Coordination and Approval – Given the preceding discussion on the ease of implementation, it may seem somewhat contradictory that the coordination and approval of the use of PE^2 is listed as a potential pitfall. This is not a reflection of the complexity of the methodology, but is instead a reflection of the entrenched paradigms of point estimates and BEQ. Since the technique has not historically been used in system acquisition, there is a natural organizational resistance that must be overcome. Although this was initially a secondary concern in the JTIDS source selection, the proper vetting of the concept required a great deal of time and effort in practice. Only when the source selection and subsequent protest were complete were the cost analysis and program management directorates convinced of its efficacy.

Price Execution – A second pitfall to avoid can be termed "price execution," since it involves the actual execution of the contract and its associated prices. For each line item, the contract will stipulate unit prices that are a function of the total number bought in a given fiscal year. The total number to be bought should therefore be known at the time of the first purchase in order to take advantage of quantity discounts. In other words, the buyer must hypothetically order all quantities at once.

"Coordination and approval of the methodology, price execution, and probability estimation... were the most problematic."

For JTIDS, since multiple customers were involved and quantities often changed continuously throughout the year, ordering a definite number once each year was not technically feasible. To address this problem, a provision was inserted to require the government to commit by a certain cutoff date in each year of the contract. The date needed to be early enough to determine the price level for that year's buy, but late enough to ensure that the budget had been resolved before any orders were placed. With that in mind, an ordering deadline in January was deemed reasonable for JTIDS, given that the federal government's fiscal year begins on 1 October.

This solution is relatively straightforward in practice. All customers commit to a quantity by the deadline and obligate funds to cover that quantity. Beyond the ordering deadline, the buyer pays the unit price associated with the original quantity. For example, if the buyer can commit to buying 10 units by the deadline, the price at 10 units is used even if additional units are subsequently purchased in that fiscal year. Interestingly, the winning JTIDS bidder offered a flat price for each terminal, regardless of the quantity purchased, so the contractual deadline was not necessary in the end. In fact, the methodology actually encourages this type of bidding strategy, as illustrated in Figure 1.

Probability Estimation – The final pitfall discussed here is that of probability estimation. Although the use of discrete probabilities in a stochastic process certainly has an advantage over a single point estimate, the realistic *a priori* estimate of the probabilities can be a challenge. Unfortunately, this process is highly subjective. In general, however, the buyer will have several subsets of requirements that can help with the estimation process. Market research can help to define these subsets.

One set consists of firm requirements, either accompanied by obligated funds or confirmed in writing by high-level decision makers in all customer organizations. At the opposite end of the spectrum are the "wish list" requirements, in the out years of the contract, that have not been included in future budget estimates but that the customer organizations are working to include. Between these two extremes

Qty	Weight %	Total Price	Avg Unit Price (AUP)	Weighted AUP
8	6.25%		$0	$0
9	6.25%		$0	$0
10	7.50%		$0	$0
11	7.50%		$0	$0
12	45.00%		$0	$0
13	7.50%		$0	$0
14	7.50%		$0	$0
15	6.25%		$0	$0
16	6.25%		$0	$0

Figure 3. Probability Distribution for E-3 AWACS Terminals, Fiscal Year 1997

there may be several sets of requirements that have varying degrees of certainty.

By stratifying the quantities in this way, realistic probabilities can be applied relatively easily. In addition, the use of quantity zero (0), when market research supports that possibility, should be considered with an appropriate probability applied. Although somewhat counter-intuitive, this option maintains a total probability of one, and therefore the mathematical integrity of the method.

In the JTIDS case, the highest probabilities were assigned to the quantities in the first year of the contract for which funds had been obligated. Other quantities in the first year were assigned lower probabilities as appropriate. For the subsequent two years of terminal buys, the probabilities were more evenly distributed across the range of quantities due to the increased uncertainty in those years. Figures 3 and 4 offer examples of the two cases cited above, respectively, while Figure 4 also illustrates the inclusion of a quantity of zero.

A final word of caution is warranted with regard to the determination of probabilities. Because the process is somewhat subjective, the probabilities are susceptible to scrutiny by both decision-makers and bidders. Decision-makers will likely question their validity during the source selection process, and losing bidders will likewise focus any protest efforts on such subjective decisions. A sensitivity analysis should therefore be considered as a means of defending the probabilities. This analysis can be as simple as a recalculation of the evaluation price using several sets of probabilities that are slightly different from the primary set, or as complex as a Monte Carlo simulation. In any event, the probabilities can be more readily defended if these techniques are used throughout the source selection process, rather than waiting until the questions are asked.

RESULTS

Despite the challenges faced by the JTIDS JPO in refining and implementing PE^2 in its source selection, it worked as designed. The details of the evaluation methodology were clearly communicated in the RFP, so that each bidder had a complete and common understanding of the process prior to submitting their bids.

Qty	Weight %	Total Price	Avg Unit Price (AUP)	Weighted AUP
0	30.00%		$0	$0
1	23.33%		$0	$0
2	23.33%		$0	$0
3	23.33%		$0	$0

Figure 4. Probability Distribution for F-14 Terminals, Fiscal Year 1999

Examples were articulated clearly in the RFP and questions were answered for clarification purposes wherever necessary. To ease the process for both the evaluation team and the bidders, a spreadsheet accompanied the RFP that contained all quantities, their probabilities, and the formulas for calculating the total cost.

When the proposals were received, one bidder submitted a proposal that attempted to take advantage of the system. The overall evaluation price *E(C)* had been artificially lowered by the insertion of unrealistically low prices for all quantities with a low probability of occurrence. As a result, increased risk associated with the low prices was assessed in the technical evaluation. The contract was therefore awarded to the competing bidder, even though its evaluation price was higher. The resulting contract contained a flat set of prices for each terminal type, covering all potential quantities, spares, and warranty repair throughout its five-year duration. The risks of additional source selections or renegotiation of the existing contract, and by extension the risk of higher costs, was effectively eliminated. In fact, the PE^2 methodology subsequently withstood the scrutiny of the General Accounting Office (GAO) when the losing bidder submitted an unsuccessful protest against the government's award decision.

CONCLUSION

Probabilistic techniques have been used in a wide range of operational settings for decades. The success of the 1996 JTIDS source selection in a challenging and uncertain environment provides evidence of the efficacy of these techniques in government acquisition programs. This paper presented a methodology using price enumeration and a probabilistic evaluation of price to address quantity and cost risk. The methodology is ideal for procurements that have one or more of the following characteristics:

1. Quantity Uncertainty – Due to a diverse customer base, budget uncertainties, multiple platforms, multi-year contracts, or other factors.

2. Current and Accurate Cost Data.

3. Large Quantities.

4. High Unit Cost.

Primary strengths of the approach include risk reduction, visibility of bidders' pricing strategies, ease of implementation, and flexibility. However, acquisition professionals are cautioned to take time to explain the methodology to decision-makers well in advance, make appropriate arrangements for executing the resulting contract prices, and conduct careful market research to estimate the probabilities associated with different quantities.

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