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An optimization approach to strategic sourcing: A case study of the United States Air Force

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ABSTRACT

The DoD annually procures billions of dollars worth of systems, supplies, and services in support of the national military strategy. Faced with budget cuts and other resource constraints, the DoD must transform its procurement process to ensure cost-effective sourcing of critical supplies and services. One aspect of current transformation in the DoD is the use of a strategic sourcing approach for the procurement of services at military installations. Using the Air Force's strategic sourcing process as our context, we developed an optimization model for selecting a set of proposals from among multiple offerors for services to be performed at multiple installations. The selection achieves the most favorable objective by balancing the confidence level in an offeror's past performance with the cost of services to the Air Force. The research findings, which are based on a realistic scenario, demonstrate improvements over the current sourcing process in both overall performance and cost.

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1. Introduction

Government agencies today are operating in an environment characterized by countless economic and political disruptions to their sources of supplies and services (S&S). In order to survive in this turbulent marketplace, these agencies must continually monitor both their competitive position and their internally controllable processes—especially the contract management process. The Department of Defense (DoD) is no exception. It annually procures billions of dollars worth of systems, supplies, and services in support of the national military strategy. In Fiscal Year 2009, contract obligations for the DoD included \$370 billion for defense-related supplies and services (FPDS, 2010). Faced with fiscal battles of budget cuts and resource constraints, the DoD must transform its procurement process to ensure a cost-effective sourcing of S&S. The procurement process at the DoD will continue to increase in importance as the DoD acquires mission-critical and complex S&S.

In addition, the DoD has been undergoing a transformation from a transaction-oriented perspective to a strategic-oriented enterprise. No longer viewed as a tactical, clerical, or administrative function, the procurement function is gaining enhanced status and importance. This transformation can be attributed to the fact that leading organizations, including the DoD, have begun to understand and realize the importance of procurement in

helping an organization achieve its strategic objectives as well as the impact of procurement on competitive advantage. Furthermore, organizations are including procurement objectives in the development of corporate strategy and have placed increased emphasis on developing corporate procurement strategies. One aspect of this transformation in DoD is the acquisition of services at the location where the service is delivered, that is, at each military installation. The U.S. Air Force is geographically organized in regions that are comprised of installations. Our research studies the use of a strategic sourcing approach for the procurement of services for each of the installations. Examples of installation-level services include custodial, grounds maintenance, housing maintenance, and refuse collection. The Air Force has taken the lead in adopting a strategic sourcing approach for the procurement of its major S&S (Rendon, 2005; USAF, 2009).

Using the Air Force's strategic sourcing process as our context, we discuss the development and application of quantitative strategic sourcing. Our approach uses a mathematical model for evaluating and selecting an optimal set of offeror's proposals. Quantitative strategic sourcing using optimization has been used in the private sector (Akinc, 1993; Cochran and Uribe, 2005; Current and Weber, 1994; Gupta and Krishnan, 1999; Lang et al., 2008; Nepal et al., 2009). However, most of the existing research in this topic is for products with a focus on cost. We study services acquisition in the public sector with focus on cost as well as confidence in the performance level of the service provider given by their historical performance.

The objective of the research is to show how a pricing optimization (PO) model can be successfully used in optimal bidding approaches, in which multiple offerors submit bids for

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both individual and multiple installation locations. Specifically, this research employs a set covering problem to find a set of proposals that will achieve the most favorable objective. A manager may set the objective based on both the confidence level of an offeror's past performance and the cost of the service to the Air Force.

The remainder of this article begins with a literature review of the relevant topics to identify the gaps in the research articles published so far which establish the backdrop for our contribution. We then discuss how the Air Force is adopting strategic sourcing in its Installation Acquisition Transformation (IAT) initiative. Following this, we discuss our approach to strategic source selection. We then describe implementation of the model and results. We conclude by discussing our contribution, summarizing our study, and suggesting possible extensions to other DoD (Army and Navy) strategic source selections.

2. Literature review

In this exploratory research, we develop a quantitative model for the strategic sourcing initiative for services acquisition in the Air Force. Therefore, our literature review focuses on strategic purchasing, public procurement and quantitative strategic sourcing models.

2.1. Strategic purchasing and public procurement

The transformation of the purchasing function from a passive, administrative, and reactive process to a proactive, strategic, boundary-spanning function reflects a new integrated approach to purchasing that embraces the other supply chain management functions of materials management, logistics, and physical distribution. This integrated approach to purchasing and supply management plays a strategic role within the organization by contributing to the bottom line, serving as an information source, increasing efficiency and productivity, enhancing the continuous improvement process, and improving competitive position and customer satisfaction (Benton, 2010).

The strategic purchasing focus requires organizations to adopt a strategic orientation to their procurement function and to look more at the total supply chain management process and its effect on the organization's competitive strategy. More specifically, it involves linking the organization's procurement or sourcing strategy with its corporate competitive strategy. This requires supply managers to become active participants in developing their organization's strategic business plan, which now includes the integration of supply, marketing, finance, and conversion strategies. Other major developments in the transformation to strategic purchasing include the breaking down of functional walls with the use of cross-functional teams, the development and management of supply chains and supply alliances, the use of electronic procurement systems, and the adoption of strategic sourcing approaches (Burt et al., 2010). Strategic purchasing strategies have been successfully implemented by IBM (Carbone, 1999; Reed et al., 2005), Deere & Co. (Smock, 2001), Lucent Technologies (Carbone, 2002), Cessna Aircraft Co. (Avery, 2003), and Hewlett-Packard (Carbone, 2004). Each of these world-class purchasing organizations has successfully implemented strategic purchasing initiatives and has reaped the benefits of transforming its purchasing function to a strategically integrated supply management process.

Strategic purchasing has been explored in the context of cross-culture, organizational relationship, supplier development, and supplier relationship. Strategic purchasing has been studied in a cross-cultural context by Ogden et al. (2007) in which differences in

three factors associated with strategic sourcing—professionalism, status, and techniques between North American and European countries are analyzed. Their research determines that general differences exist between countries in terms of purchasing professionalism and status, but not in terms of the degree to which supply management techniques are practiced.

Cousins and Spekman (2003) identify some of the barriers, internal to the organizations as well as throughout its supply chain, to implementing strategic purchasing and supply management. Their research also identifies two relationship clusters throughout the supply chain—opportunistic relationships, which are focused on short-term price reductions, and collaborative relationships, which are focused on long-term cost reductions. Additionally, the effect of supplier development practices on the supplier's product and delivery performance, the firm's buyer-supplier relationship, and the customer firm's competitive advantage is analyzed by Wagner (2006). He identifies a positive relationship between customer firm's indirect supplier development activities and the supplier firm's product and delivery performance and supplier relationship improvement. Wagner (2006) also identifies a positive relationship between supplier relationship improvement and the customer firms' attainment of a cost leadership strategy and a differentiation strategy.

Just as the commercial sector has experienced success in transforming to strategic purchasing, the United States public sector, specifically the federal government and the DoD, has put into place strategic purchasing initiatives to improve its purchasing processes (Husted and Reinecke, 2009). Many of these transformation initiatives previously implemented by commercial companies are recommended by the United States Government Accountability Office (GAO) for the DoD. Reports by the GAO recommend that the transformation to strategic purchasing taken by the leading companies can serve as a general framework to guide the DoD's contracting initiatives (GAO, 2002, 2003a, b).

Although strategic purchasing in public procurement is still relatively new, current research in public procurement has focused on areas such as promoting competitive markets, innovative practices using private partnerships, demand-oriented policy, and the establishment of public sector purchasing as an academic discipline. Caldwell et al. (2005) research how public procurement agencies address establishing and maintaining competitive markets. Based on three case studies, they identify the following: in order to maintain competitive markets suppliers should be incentivized to meet broader public sector requirements; public agencies should look beyond choosing the best supplier and instead focus on managing suppliers within a portfolio of market relationships; and that the skills of public procurement officials need to evolve to reflect strategic post-award contracting issues. Lawther and Martin (2005) identify major trends promoting public procurement partnerships (government procurement workforce crisis, changing role of the public procurement officer, contracting for IT, competitive contract negotiations, risk management, use of long-term contracts). They use two case studies to demonstrate how the public, private, and non-profit sectors can work together in public procurement partnerships. Edler and Georghiou (2007) discuss public procurement as a key element of a demand-oriented innovation policy and a potential instrument for mobilizing innovation, public policy goals, and delivering better services. Rendon and Snider's (2010) comparison of supply management within the fields of business administration and public administration indicates that supply management is more developed in the business administration field than in the public administration field. They identify various reasons for this uneven academic development in the two fields, to include supply management identity issues in public administration, structural differences between private and public

entities, and differences between the “bottom-line” in business administration and the “public interest” in public administration (Rendon and Snider, 2010, p. 104).

2.2. Quantitative strategic sourcing models

“Outsourcing takes place when an organization transfers the ownership of traditional functions and value-added activities to a vendor” (Sucky, 2007, p. 3638). The DoD is one such organization which routinely outsources services. Therefore studying best practices in strategic sourcing is a necessary element in services acquisition.

Methodologies using quantitative modeling for strategic sourcing can be found in the supply chain management literature. In order to select a vendor, Sucky (2007) proposes a dynamic decision model. The author formulates a mixed-integer programming model to minimize all the costs. The dynamic process incorporates interdependencies in time due to investment costs of choosing and/or switching to a new vendor. Supplier switching decisions are discussed by Wagner and Friedl (2007). Here, the authors analyze asymmetry of information using principal-agent framework.

The evaluation process can include an objective framework such as principle-agent theory or dynamic decision models as opposed to qualitative approaches (Talluri and Narasimhan, 2004). These authors consider multiple strategic and operational factors by categorizing the suppliers in groups based on performance. Their emphasis is on strategic supplier development initiatives. They claim that their method is more robust than the existing Data Envelopment Analysis in vendor selection literature.

Degraeve et al. (2000) use total cost of ownership as a basis for comparing supplier selection models in strategic sourcing. One of the methodologies is mathematical programming models (Akinc, 1993; Chaudhry et al., 1993; Current and Weber, 1994; Pan, 1989; Rosenthal et al., 1995; Sadrin and Yoon, 1994; Turner, 1988; Weber and Current, 1993; Weber and Deasai, 1996). Most of these models use either single item or multiple item scenarios with or without inventory management over time. They consider product suppliers and determine vendors (i.e., suppliers or offerors) as well as order quantities for the product.

Given the current literature of strategic purchasing, there seems to be a lack of research in the area of strategic sourcing, specifically within the area of services contracting in the public procurement sector. In terms of research in quantitative strategic sourcing models, most of the research studies are product-oriented with focus on various costs such as switching costs, price to the buyer, or total ownership costs. We, on the other hand, focus on services as opposed to product. Suppliers of services face unique challenges because services are intangible in measurement of quality and are difficult to store. Due to this aspect we also use past performance of the service provider as one of the factors for our objective. This treatment is found in the work by Talluri and Narasimhan (2004). They also categorize the suppliers based on performance. Our research is developed, similar to Wagner and Friedl (2007), based on economies of scale. However, we use an integer programming model to find our answers as opposed to principal-agent theory or dynamic decision model.

3. Strategic purchasing in the US Air Force

The strategic purchasing process in the private sector is very similar to the process used in the public sector. However, within the public sector, specifically the DoD, other public policy goals

such as, competition, small-business participation, transparency and accountability are of increased importance.

One example of strategic purchasing in the DoD is the U.S. Air Force Installation Acquisition Transformation (IAT) program. The IAT was approved by the Secretary of the Air Force in August 2007 to transform contracting operations at all Air Force installations in the continental United States (USAF, 2009). The Air Force business case analysis identified the \$15 billion annual spend as a prime target for strategic sourcing. Benefits from the IAT strategic sourcing include reduction of total cost of ownership, management of consumption, improved operating efficiency, and improved focus on socio-economic goals (USAF, 2009).

3.1. Contract management process

The Air Force strategic sourcing model can be described using the basic DoD contract management process (Rendon and Snider, 2008). The contracting pre-award phases include planning the procurement (conducting stakeholder, requirement and market analysis, selecting the procurement method, and determining the contract type), developing the solicitation document (such as request for proposal), issuing the solicitation document (using an internet-based portal), and then receiving offeror bids. Once the bids are received, the source selection process involves evaluating the bids (cost and technical), conducting negotiations with the offerors, and awarding the contract to the selected offeror. This source selection process is the key phase in our research study. Our efforts are focused on making this step of the contract management process more efficient. After contract award, the contract administration phase involves monitoring the contractor's performance, processing contractor requests for payments, and managing changes to the contract. The final contract management phase is contract closeout, which involves completing and settling the contract (including resolving any open items), making final payment, and documenting contractor performance information. Using the contract management process described above, we will now discuss some specific elements of strategic sourcing, which forms the basis for our research.

3.2. Proposal evaluation strategy

During the source selection phase of the contract management process, the offerors' submitted bids are evaluated in accordance with the basis for evaluation stated in the solicitation. In defense procurement, multiple criteria are often used in proposal evaluation and supplier selection. The evaluation of offerors' proposals for determining contract award includes mandatory evaluation factors such as cost, quality, past performance, and sometimes, subcontracting to small or minority businesses. In addition to the mandatory evaluation factors discussed above, the procuring agency may also include evaluation factors unique to the specific procurement. For example, in aircraft development procurement, fuel efficiency or the use of alternate fuel sources could be an important evaluation factor. The procuring agency has flexibility in determining the relative importance of these evaluation factors. Some evaluation factors may be assigned higher importance and used in a tradeoff process in the source selection decision.

The complexity of the source selection process will depend on the bid evaluation strategy selected. In some contract source selections, in which the requirement (supply or service being procured) is clearly definable and the risk of unsuccessful contract performance is minimal, cost or price may play a dominant role in the award decision. In these procurements, the government uses the lowest-priced, technically acceptable bid evaluation strategy. In other source selections, in which the requirement is less definitive and more development work is required (resulting in

greater performance risk), technical, quality, or past performance considerations may play a dominant role. In these procurements, the government uses a trade-off process (permitting trade-offs among cost and non-cost factors) to award to an offeror anywhere on the best value continuum between the *lowest-priced* technically acceptable offeror and the *highest technically* rated offeror.

Strategic purchasing source selections typically use the trade-off proposal evaluation strategy. An often used bid evaluation strategy for installation-level services is the Performance Price Trade-off (PPT) strategy. The PPT process is a source selection strategy that permits a trade-off between price and an offeror's past performance in reaching the award decision. Past performance information reveals how well the offeror performed work relevant to the type of effort and type of requirement described in the solicitation and confirms the recency of the performance. In a PPT source selection, the contract can be awarded to an offeror with a higher past performance rating over a lower performance-rated offeror if the price differential is warranted and considered to be best value. A common PPT approach is to first evaluate the offeror's technical bid on an acceptable/unacceptable basis. Next, the technically acceptable offerors are evaluated for price reasonableness and ranked by total evaluated price. Finally, the offeror's recent and relevant past performance is evaluated resulting in a performance confidence assessment rating. This evaluation process will result in an overall performance confidence assessment of Substantial Confidence, Satisfactory Confidence, Limited Confidence, No Confidence, or Unknown Confidence.

If the past performance of the lowest-priced, technically acceptable offeror is rated as *Substantial Confidence* (the highest performance rating), then that bid would be considered the best value to the government and would be awarded the contract. If the past performance of the lowest-priced, technically acceptable offeror is not rated as *Substantial Confidence*, then the next lowest-priced, technically acceptable offeror is assessed until an offeror is identified that is rated *Substantial Confidence* or until all offerors are evaluated. In the award to a higher priced offeror with a better performance confidence assessment rating, the government must decide whether the past performance advantage of that offeror is worth the difference in price. This decision involves a best value integrated assessment documenting the merits of the tradeoffs between price and performance.

The DoD procurement regulations allow for a tradeoff process when it may be in the best interest to consider award to other than the lowest priced offeror or other than the highest technically rated offeror. This process permits tradeoffs among cost or price and non-cost factors and allows the DoD to accept other than the lowest priced proposal. For example, in some source selections, small business participation may be more important than cost, or quality. In the aircraft procurement example, the procuring agency may tradeoff price in favor of fuel efficiency or the use of alternate fuels in its evaluation of the offerors'

proposals. Thus, the agency may award the contract to a higher-priced offeror, if the offeror proposes an aircraft that is more fuel efficient or uses alternate fuel sources.

The Air Force's strategic sourcing procurements typically involve a specific commodity of supplies or services—such as custodial, grounds maintenance, housing maintenance, and refuse collection—needed at multiple installations across the continental United States. Because of the level of uncertainty in regard to the delivery and quantity of the needed services at each installation, an Indefinite Delivery/Indefinite Quantity (ID/IQ) contract is typically used. An ID/IQ contract provides for an indefinite quantity, within stated limits, of supplies or services during a fixed period. The government places task or delivery orders for individual requirements. Quantity limits may be stated as a number of units or as dollar values. In addition, according to federal procurement regulations, the contracting officer must give a preference to making multiple awards of ID/IQ contracts under a single solicitation for the same or similar supplies or services to two or more sources. Multiple-award contracts allow the government to leverage the advantage of price competition to obtain optimum prices for DoD.

The proposal evaluation process discussed above is quite straightforward and noncomplex. However, in source selections for major strategic sourcing projects, the bid evaluation process can significantly increase in complexity. This would especially be the case in the acquisition of services that are to be performed at multiple installations, evaluating bids for individual as well as multiple installations, awarding multiple Indefinite Delivery/Indefinite Quantity contracts, and using a trade-off source selection strategy such as PPT. These strategic sourcing procurements present some unique challenges. Fig. 1 describes the approximate process of evaluating bids to award contracts.

One challenge is identifying the optimum procurement arrangement given the multiple installations, multiple offerors with varying performance ratings, and different proposal prices for each installation, as well as proposals for a combination of installations. In this complex source selection, the use of mathematical modeling will help in identifying the optimum procurement arrangement. The next part of this paper will introduce the price optimization model and discuss how it can be used in complex strategic source selections.

4. A pricing optimization approach to strategic source selection

4.1. Set covering problem

Set covering problem (SCP) is a classic problem in operations research (e.g., Nemhauser and Wolsey, 1999, pp. 6–7). In SCP, given a finite set U and a family S of subsets of U , the goal is to find

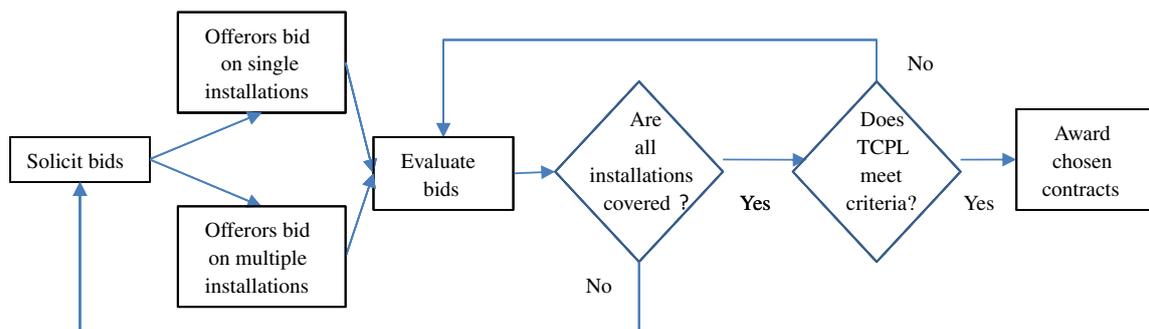


Fig. 1. Evaluation process at the Air Force.

a minimum-cost subfamily of S , referred to as a “cover,” $C \subset S$, such that the union of all the sets in C is U . Assuming that each $s \in S$ incurs a fixed cost $c(s)$, the SCP can be formulated as follows:

$$\text{minimize } \sum_{s \in S} c(s)X_s \tag{1}$$

$$\text{subject to } \sum_{s \in S | u \in s} X_s \geq 1, \quad u \in U \tag{2}$$

$$X_s \in \{0,1\}, \forall s \in S \tag{3}$$

In this formulation, Eq. (1) minimizes the total cost of the cover, (2) ensures every element in the original set U is covered by at least one subset in the cover, and (3) describes that every subset either is in the cover or not.

Applications of SCPs are abound. In emergency management, for example, a local government may use SCP to establish the locations of fire stations so that all communities are covered with the smallest number of fire stations that result in the lowest fixed cost. This problem, with an objective function that typically minimizes the number or cost of facilities required, is also known as the least-cost, maximal covering problem (Toregas et al., 1971). A survey of these problems can be found in Brandeau and Chiu (1989), Church and ReVelle (1974), and Klose and Drexel (2005).

There have been various modifications of this model, as reviewed extensively by Marianov and ReVelle (1995), for emergency services.

In our study we use SCP for strategic sourcing in order to assign each installation with a service provider. But, in order to set the stage for illustrating our model development, we first describe how SCP has been used in strategic sourcing, in the existing literature. Nepal et al. (2009) illustrate how SCP can be used for optimizing sourcing of microcontrollers in an automotive supplier company. The authors’ case study demonstrates the economies of scales principle to meet the requirements while minimizing the cost.

Approaches to product development also use integer-programming models where performance of the product itself and costs are taken into account (Gupta and Krishnan, 1999). This study provides an insight into strategic sourcing for product families, especially for integrated components.

Lang et al. (2008, p. 1) focus on services, specifically software systems using “service-oriented architecture” paradigm. Their decision incorporates selection of the suppliers and integration of certain services under various cost scenarios that maximizes profit. This is an example of a revenue-based model satisfying functionalities and the demands of a service.

Somewhat similar to our study, Akinc (1993) proposes a bi-objective approach, seeking to find both the least-cost suppliers and the fewest suppliers that can deliver all the items. A trade-off analysis between these two objectives is performed.

Current and Weber (1994) use a facility location model to formulate the vendor selection problem, minimizing the number of suppliers. They propose a model based on p -median analysis,

but in the end they also introduce SCP to minimize the number of suppliers. However, they assume that the cost is not important.

Cochran and Uribe (2005) illustrate the use of SCP in capacity planning within the supply chain. The objective is to generate alternative equipment configuration when production dictates use of expensive multifunctional equipment for changing demand. They use modified SCP for equipment selection and allocation while minimizing the cost.

Our research study uses a similar approach to the aforementioned work by Nepal et al. (2009). However, our case study is in services acquisition as opposed to product procurement (as is also the case in most of the studies reviewed here). In addition to focusing on cost, we also consider the past performance rating like Gupta and Krishnan (1999). Again, we do that for suppliers as opposed to the products themselves. Our focus is on modeling cost to the Air Force, versus revenue (Lang et al., 2008), and confidence in the performance level of the service provider based on the past performance, as opposed to number of suppliers (Akinc, 1993). We use weights so that the managers can calibrate cost or confidence in performance level as they find fit. Cost is important in our development of the model unlike the approach by Current and Weber (1994). Similar to equipment selection and allocation (Cochran and Uribe, 2005), our SCP model selects suppliers and allocates them to different customers while minimizing the cost. In order to understand our process we must explain the methodology.

4.2. The bids

We model the strategic sourcing of bids submitted by technically acceptable offerors on multiple installations as an SCP, see Eqs. (1)–(3). In this case, the universal set consists of all the bids—single as well as multiple contract types, as explained in the previous sections.

For example, consider two offerors, A and B, bidding for a certain service to be performed at three installations, 1, 2, and 3. Table 1 lists all the possible bids by these offerors on all three installations. For example, Bid #1 is a bid offered by A on installation 1 alone (single bid), whereas Bid #6 is a bid offered by A on installation 1 and installation 2 (combined bid), and Bid #7 offers the same service for all the three installations, 1, 2, and 3, combined together. There are 14 such possible bids. However, in reality, all offerors may not bid on all possible bids due to their own preference or conditions imposed by the Air Force. The underlying principle is that the more installations combined in a bid by the offeror, the more the discount (due to economies of scale or geographic proximity) in price. In other words, the sum of the individual prices in Bid #1 and #2 (single bids for installations 1 and 2 individually considered, respectively) is higher than the pricing in Bid #4 (for installations 1 and 2 combined in a single bid). More generally, let b denote a bid for installations I_b , and let p_b be its price. We assume the following

Table 1
List of possible bids.

Offeror	Bid #	Installation 1	Installation 2	Installation 3	Offeror	Bid #	Installation 1	Installation 2	Installation 3
A	1	x			B	8	x		
	2		x			9		x	
	3			x		10			x
	4	x	x			11	x	x	
	5		x	x		12		x	x
	6	x		x		13	x		x
	7	x	x	x		14	x	x	x

“triangular” relationship occurs:

If $I_b \cup I_{b'} = I_{b'}$, then for any contractor bidding for $I_b, I_{b'}$, and $I_{b'}, p_b + p_{b'} > p_{b'}$.

(Note that if the above is not true, then we may trivially eliminate bid b' from the pool.)

The decision to be made is which bids should be selected in order to achieve the strategy preset by the authority. The strategy might be to choose those bids that enjoy the most confidence in performance level (CPL) without any consideration to the cost, or the bids that are least expensive with no consideration to CPL. Common sense dictates that in most cases the strategy will be a compromise between these two objectives. We account for this by incorporating a weight as an input to our optimization model. The objective of the model is to achieve this preset strategy subject to fundamental constraints that all installations receive the service.

4.3. Notation

- I set of installations, for $i \in I$
- C set of offerors (contractors), for $c \in C$
- B set of bids, for $b \in B$
- $B_i \subset B$ subset of bids that contain installation i
- $B_b \subset B$ subset of installations in bid b
- $c_b \in C$ offeror for bid b
- p_b price of bid b [\$]
- ν_c performance rating of offeror c [rating] (the lower the rating, the better the performance)
- w penalty weight of performance with respect to cost [\$/performance rating]
- h_i penalty factor to reflect importance of having a good performance offeror for installation i [multiplicative factor]
- x_b binary decision variable: 1 if bid b is selected, and 0 otherwise

4.4. The pricing optimization (PO) model

$$\text{minimize}_x \sum_b (p_b + w\nu_{c_b} \sum_{i \in I_b} h_i) x_b \tag{4}$$

$$\text{subject to } \sum_{b \in B_i} x_b \geq 1 \quad \forall i \tag{5}$$

$$x_b \in \{0, 1\} \quad \forall b \tag{6}$$

In the PO model, Eq. (4) minimizes the cost of the bids and the measure of CPL, subject to providing service to all installations (Eq. (5)). In the next section we discuss the implementation of this model.

The use of a relative weight w in our objective function (4) implicitly acknowledges a linear tradeoff between price and performance. A weighed sum of the individual objectives is a well-known mechanism to deal with the problem of establishing a compromise between two (possibly conflicting) objectives. In our case, we fix the weight for price to 1, and let the planner choose the weight w for performance. Despite these weights must be empirically established (see next section), the technique has the advantage that for any set of those weights, the resulting solution will be “efficient” (also known as Pareto-optimal) (Ehrgott, 2005, pp. 24, 65–80); that is, from the given solution it is not possible for one objective to improve without worsening the other objective.

5. Implementation

We now describe our implementation of the PO model. The names of the installations and offerors provided by the Air Force have been altered to maintain confidentiality. This specific instance of implementation has 18 offerors and 13 installations. Based on the importance given to cost and confidence in performance level (CPL) of the service provider, we assign the weight, w , in the objective function of the PO model. Each instance with different weight is a numbered model-scenario.

5.1. Data

The Air Force provided us with raw data on various contracts, consisting of offerors and their bids on individual installations for the service of ‘Refuse collection and recycling.’ We processed these data to arrive at the total cost that was validated by the Air Force. Table 2 shows all of the single bids. For example, offeror OC1 bids \$298,565 on installation IG1. OC1 also bids individually on installations IL1, IR1, and IT1. On the other hand, installation IA1 receives a single bid from each of the offerors OP1, OD1, OA1, OS3, OK1, and OC3.

In order to demonstrate the strategic sourcing concept using economies of scale for this study, we have used the single bids to

Table 2
Single bids in dollars.

	IA1	IC1	IG1	IK1	IL1	IL2	IL3	IL4	IM1	IR1	IS1	IT1	IV1
OC1			298,565		1,309,276					582,403		495,784	
OP1	723,485	237,556	286,125	917,634	1,425,608	156,354				592,445			
OD1	650,125	215,445	245,369	925,618	1,350,874	175,894	408,996	278,996		585,226	579,445		
OS1				921,658		225,789	424,608	292,115	817,779	601,298			
OA1	627,569			952,325			375,000	262,395		587,497			
OA2			398,565					268,975		592,668		492,961	
OM1				932,548			364,860		882,285	592,235			
OS2													
OQ1			456,000										
OM2		199,064		928,546					837,601			508,556	
OC2									825,883				
OW1			241,635					250,976					
OS3	925,684												832,564
OI1		208,565	237,169	930,584	1,625,897	250,325			850,316	658,988	602,555		
OG1			421,882	948,687	2,148,562					985,236			
OK1	823,186			942,685	1,526,512	113,274	384,509	265,128	905,112		602,595		548,126
OC3	715,889												19,761
OC4												585,365	

create combined bids using following two rules:

1. Each offeror combines individual bids (to create multi-installation bids) up to a maximum number of installations per bid, n . In our examples, we set $n=5$. That is, if an offeror initially has $m \geq 5$ individual bids, we will add new bids combining 2, 3, 4, and 5 of those bids, respectively, that is, a total of $(m/2)+(m/3)+(m/4)+(m/5)$ bids. Of course, if the offeror has $m < 5$ individual bids, then we only generate $(m/2)+\dots+(m/m)$ new combined bids.
2. All offerors offer the same percentage of quantity discounts, which are based on the number of installations combined in the bid. Specifically, we set the discount rate r_k offered by any offeror who is awarded k installations simultaneously to 2, 5, 8, and 10% for $k=2,3,4$, and 5 installations, respectively. We also assign numerical values to CPL for utilizing the mathematical model solely for ease in developing the scenarios. These are given in Table 3.

Based on the given category of confidence in performance levels (such as Substantially Confident or Not Confident, for instance) and on the numerical scale described in Table 3, each offeror is assigned a numerical value for the CPL. These are listed in Table 4. The smaller the value of CPL, the better the confidence in the performance level.

In order to understand the effects of changes in the strategies, we first evaluate total CPL (TCPL) and the corresponding cost based on the current process of selection of the bids. Current processes of selection (before applying the model) are based on two distinct principles. The first process of selection (“Selection 1: Lowest Cost”) chooses the least expensive single bid for an installation with no regard to CPL. This process parallels the procurement process with emphasis on lowest cost. The second process of selection (“Selection 2: Best CPL and Lowest Cost”) first chooses the offeror with the best CPL for that installation. If there is a tie, then it is broken based on cost. Whoever offers the least cost is selected. This selection process parallels the PPT approach. It is clear that these selection processes may not be good strategies. For example, if the lowest cost criterion were to be used and one bid were just \$1 higher than another, then it would not be selected (even if the offeror were highly superior in CPL). In our example (with 18 offerors and 13 installations given in Table 2), the current selection process has 74 single bids for the 13 installations.

In order to implement the PO model, we generate additional multiple-installation bids using the above-mentioned rules. For 18 offerors and 13 installations (with a maximum of five

Table 3
Numerical values for CPL.

Substantial Confidence	Satisfactory Confidence	Unknown Confidence	Limited Confidence	No Confidence
1	2	3	4	5

Table 4
Numerical values of CPL for offerors.

Offeror	CPL	Offeror	CPL	Offeror	CPL
OA1	2	OK1	2	OD1	1
OM2	3	OM1	3	OA2	3
OI1	3	OW1	1	OC3	3
OP1	1	OS1	3		
OC1	1	OC1	1		

installations in a combined bid), in addition to the given 74 single bids, there are 1535 combined bids. It is important to note that this number increases rapidly due to combined opportunities, making the selection process computationally complex and justifying the use of our PO model.

As was described in the formulation of the model, the objective function is to minimize cost in addition to incorporating the importance of CPL. Strategies depend on the importance given to TCPL and, of course, on the cost. Therefore, in order to vary the importance of CPL, we use a weight, w , ranging from 10^2 to 10^8 (which is the coefficient of CPL in the objective function). This allows us to favor selection based predominantly on cost, CPL, or combination of these objectives (see Table 5), where lower the weight means lower the preference for CPL. Among model-scenarios, Model-Scenario-1 has objective function that favors CPL the least whereas Model-Scenario-4 has objective function that favors CPL the most.

5.2. Results and analysis

The results of the current selection processes are shown in Table 6. The first selection process (similar to procurement process with emphasis on lowest cost) yields TCPL of 27 for a cost of \$6,512,174, and the second selection process (similar to PPT process) yields a TCPL of 15 for a cost of \$7,261,312. These results show that the least expensive strategic sourcing has a total CPL of 27, which translates to about an average TCPL of 2 per

Table 5
Scenarios and w .

Scenario	w
Model-Scenario-1	100
Model-Scenario-2	10,000
Model-Scenario-3	1,000,000
Model-Scenario-4	100,000,000

Table 6
Results from current selection process 1 and 2.

Installation	Selection Process 1			Selection Process 2		
	Offeror	CPL	Cost (\$)	Offeror	CPL	Cost(\$)
IA1	OA1	2	627,569	OD1	1	650,125
IC1	OM2	3	199,064	OD1	1	215,445
IG1	OI1	3	237,169	OW1	1	241,635
IK1	OP1	1	917,634	OP1	1	917,634
IL1	OC1	1	1,309,276	OC1	1	1,309,276
IL2	OK1	2	113,274	OP1	1	156,354
IL3	OM1	3	364,860	OD1	1	408,996
IL4	OW1	1	250,976	OW1	1	250,976
IM1	OS1	3	817,779	OK1	2	905,112
IR1	OC1	1	582,403	OC1	1	582,403
IS1	OD1	1	579,445	OD1	1	579,445
IT1	OA2	3	492,961	OC1	1	495,784
IV1	OC3	3	19,761	OK1	2	548,126
Total		27	6,512,174		15	7,261,312

Table 7
Results of the model scenarios.

Scenario	Total CPL	Cost
Model-Scenario-1	26	6,090,328
Model-Scenario-2	24	6,108,860
Model-Scenario-3	14	6,298,563
Model-Scenario-4	14	6,458,338

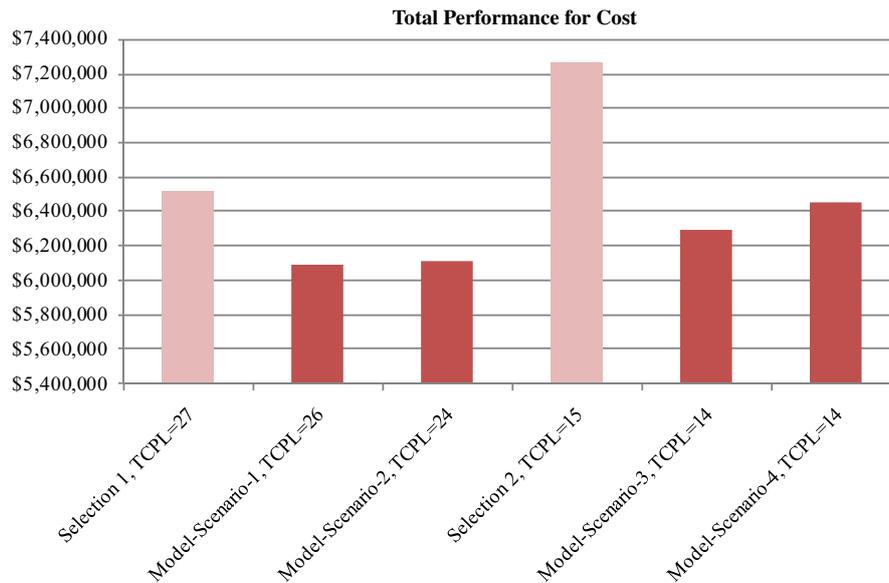


Fig. 2. Comparison of strategic sourcing and current processes of selection.

installation (*Satisfactory Confidence* in the performance level of the offerors). The second selection process which prioritizes the offeror's CPL and then the least expensive yields an average TCPL of about 1.15 per installation (translating to *slightly less than Substantial Confidence* in performance), but this occurs at an extra cost of \$749,138.

The results of the implementation of the PO model in Scenarios 1 through 4 (scenarios named for different values of w) are described in Table 7. The TCPL ranges from 26 to 14, with the corresponding cost varying from \$6,090,329 to \$6,458,338.

For about the same average confidence in the performance level (*Satisfactory Confidence*), the solution from the PO model (Model-Scenario-1) is cheaper than the current process (Selection 1) solution by more than \$500,000. On the other hand, for the best average TCPL (*Substantial Confidence*) the solution from the PO model (Model-Scenario-4) is less expensive than that from the current process (Selection 2) by almost one million US\$ in one case, whereas more than one million US\$ (Model-Scenario-3) in the other. It should be noted that the highest cost solution from the PO model is cheaper with better TCPL than the cheapest solution from the current process. In addition, the most expensive pricing strategy obtained from the PO model is cheaper than the least expensive pricing strategy obtained from the current process. Fig. 2 shows the comparison of these strategies.

6. Discussion and summary

Results of our implementation of the PO model suggest that such an approach is a useful methodology for strategic sourcing. We illustrate this approach in the context of the U.S. Air Force's services acquisition. The existing literature in strategic sourcing with quantitative methods has been predominantly product-oriented and focused on different types of costs. In our research study we develop an integer programming model, SCP, for choosing optimal mix of service providers for the Air Force. This strategic sourcing approach is particularly different since it is intended for service providers instead of product suppliers. In addition, instead of focusing only on the cost (Degraeve et al., 2000), we also leverage the confidence in performance level similar to past performance (Talluri and Narasimhan, 2004). Due to this flexibility, a manager can choose any combination of these objectives based on the preference,

designated by a parameter for weight. Thus, unlike either solely basing the objective on cost or solely using past preferences we created a management lever for strategically sourcing the services in the Air Force.

The PO model was developed for scenarios that were based on choice of amount of preference given to CPL. The model chose the bids based on importance given to TCPL and cost. This example shows that the Air Force could realize important savings (with no change in TCPL) by using the PO model. Similarly, this example shows that by placing more importance on TCPL, the Air Force will realize even higher savings.

We have discussed and verified that this approach was superior to current practices in the Air Force in many respects. It is an analytical approach that can be replicated and repeated for various services acquisitions. In addition, the PO model uses realistic data that are readily available to planners, and can be modified to accommodate different preferences such as the importance of cost relative to performance.

This methodology can also be applied to various regions in the Air Force in addition to other DoD agencies, such as the Navy (Dieges et al., 2009) and the Army. Moreover, the scope of the model in this research is limited to a single type of service, but it could easily be increased to multiple types of services. Another natural extension of this research is to develop a similar model for the strategic sourcing of supplies or specific commodities.

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