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Coordinated selection of procurement bids in finite capacity environments

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ABSTRACT

Pressure to increase agility and reduce costs is pushing enterprises to dynamically select among offers from a broader range of suppliers. This process is facilitated by the adoption of web services standards. An important requirement in this context is the ability to move away from unidimensional price-based e-procurement models and develop richer solutions that are capable of capturing other important attributes in the selection of supplier bids. Research on the evaluation and selection of supplier bids ("winner determination") has traditionally ignored the temporal and finite capacity constraints under which manufacturers and service providers often operate. We consider the problem faced by a firm that procures multiple key components or services from a number of possible suppliers. Bids submitted by suppliers include both a price and a delivery date. The firm has to select a combination of supplier bids that will maximize its overall profit. Profit is determined by the revenue generated by the products (or services) sold by the firm, the costs of the components (or services) it acquires as well as late delivery penalties it incurs if it fails to deliver its products/services in time to its own customers. We provide a formal model of this important class of problems, discuss its complexity and introduce rules that can be used to efficiently prune the resulting search space. We proceed to show that our model can be characterized as a pseudo-early/tardy scheduling problem and use this observation to build an efficient heuristic search procedure. Computational results show that our heuristic procedure typically yields solutions that are within a few percent from the optimum. They further indicate that taking into account the manufacturer/service provider's capacity can significantly improve its bottom line.

1. Introduction

Today's global economy is characterized by fast changing market demands, short product lifecycles and increasing pressure to offer high degrees of customization, while keeping costs and lead times to a minimum. In this context, the competitiveness of both manufacturing and service companies will increasingly be tied to their ability to dynamically select among multiple possible supply chain partners in response to changing market conditions. In this paper, we consider an environment where a firm needs to meet customer delivery commitments while procuring a combination of key components or services from multiple possible suppliers. At any point in time, components or services offered by different suppliers may vary both in terms of prices and delivery dates. Such a situation arises in a number of different contexts. This includes manufacturers with long-term relationships with more than one supplier (possibly independently managed plants owned by the same firm) as well as manufacturers or service providers dynamically selecting prospective suppliers in response to changing market demands. These latter scenarios arise in the context of capacity subcontracting in manufacturing and logistics [1], as well as in a wide range of other sectors (e.g., call center capacity, dynamic procurement of programming services (Programmingbids.com [19]), translation services (Language123.com [12]), and a growing number of other services [13]). These dynamic practices are increasingly facilitated by the emergence of web services standards, such as ebXML [6], W3C SOAP [26], OASIS UDDI [15]and W3C WSDL [27].

Prior research on bid selection ("winner determination") has generally ignored temporal and capacity constraints under which companies operate (e.g., due dates by which different orders need to be delivered to customers as well as the limited capacity available to assemble components/services obtained from suppliers). The work presented herein shows that taking such constraints into account can help companies make more judicious decisions when it comes to selecting among multiple supply alternatives.

Specifically, we present techniques aimed at exploiting temporal and capacity constraints to help a firm select among supply alternatives that differ in price and delivery date. We refer to this problem as the *Finite Capacity Multi-Component Procurement* (FCMCP) problem. This article provides a formal definition of the FCMCP problem, discusses its complexity and introduces several rules that can be used to prune its search space. It presents

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an efficient pseudo-early/tardy heuristic search procedure that takes advantage of these pruning rules. Computational results show that accounting for the firm's finite capacity can significantly improve its bottom line, confirming the important role played by finite capacity considerations in procurement problems. Results are also presented that compare the performance of our heuristic search procedures both in terms of solution quality and computational requirements under different supply profiles (or "bid profiles"). These results suggest that our pseudo-early/tardy procedure is generally capable of generating solutions that are within just a few percent from the optimum and that it scales nicely as problem size increases.

The balance of this paper is organized as follows. Section 2 provides a brief review of the literature. In Section 3, we introduce a formal model of the FCMCP problem. Section 4 identifies three rules that can help a firm (manufacturer or service provider) eliminate non-competitive procurement bids or bid combinations. Section 5 introduces a heuristic search procedure that exploits a property of pruned FCMCP problems introduced in Section 4 to solve the resulting problem as a pseudo-early/tardy scheduling problem. Section 6 presents a post-processing procedure that can further improve the quality of a solution. An extensive set of computational results are presented and discussed in Section 7. Section 8 provides some concluding remarks and discusses future extensions of this research.

2. Literature overview

A number of different studies have examined tradeoffs associated with different sourcing and procurement strategies, going back to work comparing Japanese and US sourcing and procurement models in the automotive industry in the late 80s [28]. More recent work includes that of Pyke and Johnson [20] who argue that different types of sourcing strategies are better suited for different situations: critical, high-value added components or components with complex interfaces are often better handled through strategic partnerships, whereas commoditized components available from multiple sources are often more effectively handled through dynamic e-procurement. Peleg et al. [17] compare three procurement strategies: the above two plus a mixed strategy combining both short-term and long-term elements. They show that the superiority of one strategy over the others depends on contract terms. Bensaou [4] reports on a study that debunks the myth that Japanese car manufacturers rely solely on long-term strategic partnerships with suppliers and advocates the management of portfolios of buyer–supplier relationships covering a wide spectrum of possible arrangements. A review of models for constructing short-term and long-term contracts in business-to-business markets has been conducted by Kleindorfer and Wu [11]. Elmaghraby [7] also provides an excellent review of research done in the fields of economics and operations research on tradeoffs between different sourcing strategies. Collectively, this body of research indicates that many environments warrant considering dynamic sourcing and procurement strategies, where one can dynamically select between offers from multiple possible suppliers. As already indicated in Section 1, these scenarios are not limited to the manufacturing sector. They also extend to the service industry.

Reverse auctions are commonly used for procurement in large enterprises. First-price sealed bid auctions and English auctions have become popular in maintenance, repair, and operations ("MRO") procurement. The literature on winning bid selection goes back to research by Stanley et al. [23], who employed linear programming techniques for a static, single-attribute, single-item procurement auction. The past few years have also seen a growing realization that for reverse auctions to be practical in settings that go beyond simple MRO procurement environments, they have to be able to accommodate non-price attributes such as quality or leadtimes [3], to incorporate supplier capacity constraints [8], and to consider multiple items [10,22]. In contrast to many earlier studies, the work we present is not restricted to single-attribute, price-based procurement auctions but rather extends to richer, more expressive situations where a manufacturer/service provider has to select among multiple procurement options (or bids) that can differ in both price and delivery date. In this richer context, the manufacturer/service provider can explicitly compute the profits associated with different (non-dominated) bid combinations and can identify combinations that maximize its overall profit. This is done taking into account the synchronization requirements associated with the procurement of multiple components (or services) required by a given end product (or service) as well as the costs of different procurement bids, the limited capacity of the manufacturer (e.g., to assemble finished products) and potential late delivery penalties.

Another related area of research has studied the coordination of procurement and production planning. Most work in this area has assumed stochastic models in which capacity is either ignored or modeled at a relatively coarse level. For example, Bassok and Akella [2] consider a single type of raw material and one or more finished products with stochastic demand, and Gurnani et al. [9] consider a single finished product with stochastic demand that requires two critical components. In contrast, the FCMCP model introduced in this paper explicitly captures the finite capacity of the manufacturer/assembler (or service provider) and allows for environments with multiple finished products, each requiring a possibly different set of components. It does so in a deterministic setting. Demand is modeled with each order having its own delivery date and its own marginal penalty for not meeting that date. By differentiating between different orders, their individual due dates, tardiness costs and component requirements, it becomes possible to develop solutions that capture the finer tradeoffs entailed by these requirements and the finite capacity of the manufacturer/service provider.

3. The finite capacity multi-component procurement problem

The finite capacity multi-component procurement (FCMCP) problem involves a manufacturer or service provider (later referred to as the "manufacturer") that has to satisfy a set of customer commitments or orders O_i, $i \in \{1,\ldots,m\}$, where m is the total number of orders (see Fig. 1). Table 1 provides a summary of the notations used in this article. Each order i needs to be completed by a due date dd_i, and requires one or more components or services (later referred to as "components" or "supplies"), which the manufacturer can obtain from a number of possible suppliers. The manufacturer has to wait for all the components before it can start processing the order (e.g., waiting for all the components required to assemble a given product or waiting for different tasks to be completed before being able to deliver a service). For the sake of simplicity, we assume that the processing required by the manufacturer to complete work on customer order O_i has a fixed duration du_i, and that the manufacturer can only process one order at a time ("capacity constraint").

Formally, for each order O_i and each component $Comp_{ij}$, $j \in \{1,\ldots,n_i\}$, where n_i is the number of different components required for order O_i, the manufacturer can select from a set of multi-attribute bids $\{B_{ij}^1, \ldots, B_{ij}^{n_{ij}}\}$ from prospective suppliers, where n_{ij} is the total number of procurement bids for component $Comp_{ij}$. Each bid B_{ij}^k, from supplier $k \in \{1,\ldots,n_{ij}\}$, includes a bid price bp_{ij}^k and a proposed delivery date dl_{ij}^k. Below we use the notation $B_{ij}^k = (dl_{ij}^k, bp_{ij}^k)$.