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Optimal sourcing from alternative capacitated suppliers with general cost structures[☆]

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ABSTRACT

Most manufacturers or retailers must procure items or services necessary for their businesses, in an environment that typically includes a number of competing suppliers with varying cost structures, price schemes, and capacities. In this paper, we consider the sourcing problem in which the buyer determines the sources that should be utilized and to what extent, in turn, dictating the total quantity available for the buyer to sell/utilize, subject to stochastic demand/requirement. Our approach advocates not to determine the quantity to be sourced a priori. We allow for capacitated sources and any cost structure in which fixed costs and quantity discounts are special cases. Some simpler versions of this problem are shown to be NP-hard in the literature. By proving that the order of the sources is irrelevant for the optimal solution, we devise a dynamic programming model with pseudo-polynomial complexity to solve the multiple supplier sourcing problem to optimality. We propose two extensions: one limits the number of suppliers, and the other allows multi-period sourcing.

1. Introduction and related literature

Consider a manufacturer or retailer who procures (or, ‘sources’) a certain product or service, to use directly or indirectly in meeting the stochastic demand that she faces. Considering the manufacturing environment as an example, the product that is to be procured (or, the ‘item’) can be supplied by a finite number of capacitated external suppliers, and the manufacturer must decide which of the sources to utilize and to what extent. One could prefix the procurement quantity based on inventory- and production-related costs, and then find the least costly solution from the available pool of suppliers with corresponding price structures and capacities. However, the optimal sourcing (procurement) decision under stochastic demand requires an integrated approach, using all of the cost parameters and capacity and price information of alternative suppliers simultaneously.

Supplier price and capacity information could be collected by making use of e-business infrastructure or organized industrial associations, or by contacting qualified suppliers, using a request-for-quotations (RFQ). These sources may have different capacities and price structures, but we consider them to be identical in terms of their function, i.e. the item's characteristics do not depend on the supplier. We do not restrict our analysis to a particular cost function for procurement, and we allow, for example, for a separate fixed cost for initiating the use of each source, for logistics costs that might depend on the geographical location of the suppliers, and for non-linear unit variable costs. Progressive or all-units quantity discounts are special cases. Moreover, the “cost-of-doing business” with each supplier might incur non-linear cost factors [22]. The suppliers' capacity utilization might result in re-evaluating the remaining available capacities, inducing quantity-dependent price quotations.

Purchasing is a common operation for all types of businesses. Kaplan and Sawhney [20] analyze business-to-business e-commerce marketplaces and classify the purchasing market as manufacturing inputs and operating inputs, in terms of what businesses buy and as systematic sourcing and spot sourcing, in terms of how they buy. Our approach applies to any type of manufacturing or operating inputs that face stochastic demand and that are purchased from the spot market: the ‘exchanges’ and ‘yield managers’, respectively [20]. There are numerous web-based platforms on the market that can materialize the sourcing methodologies prescribed in this study. There are general purpose B2B e-commerce platforms such as Ariba [5], Fiatech [13], and 1 Point Commerce [1] and specific platforms operated by companies for their operations such as the ones by Ford [14], Foster Wheeler [15], and Hilton [18].

We note that our problem environment is extremely general and is not necessarily confined to procurement of goods and a supply chain context. To name some other environments, consider transportation logistics, manufacturing options, carbon offsetting, and the make-or-buy problem. As for transportation logistics, suppose that the materials ordered by a manufacturer or a retailer are shipped by vehicles with certain capacities. For each vehicle utilized, there may

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exist a fixed cost as well as a unit variable cost and possibly quantity discounts. The total order may be satisfied with a number of vehicles with varying characteristics. As for the manufacturing options, consider a heating process using industrial ovens. Each oven may have a different capacity and a particular cost of operation, including fixed costs. Similarly, consider a production environment with flexible and dedicated machines, in which each machine incurs different set-up and production costs. As for carbon offsetting, consider a socially responsible company that wants to offset its carbon emissions by investing in carbon abatement projects. The company must choose the 'best' (cost minimizing or utility maximizing) way of offsetting, from a number of certified offsetting options with different cost parameters (or utilities) and carbon abatement capacities. Finally, our methodology can be used to find the optimal in-house production versus outsourcing decision (considering the cost aspect of the problem in isolation), as in-house production can be considered one of the available sourcing options. In such situations, it is likely that the total cost of allocating some or all in-house capacity for producing the item would have a non-linear nature, stemming from cost components such as fixed costs, incremental capacity usage costs, and concave or convex capacity allocation (opportunity) costs. The complexity of in-house capacity costs is also illustrated by a Darden School of Business case on Emerson Electric Company [11]. The flexibility of our proposed methodology in its ability to handle all kinds of cost functions is one of our major contributions to the literature.

Procurement decisions should consider the cost of materials procured, delivery punctuality, the quality of items procured, creation of effective strategic partnerships, possibly the carbon footprint, and the like. Therefore, one of the key processes of effective supply chain management is the supplier selection process, which consists of determining a supplier base (a set of potential suppliers to operate with), the supplier(s) to procure from, and the procurement quantities. We refer the reader to Elmaghraby [12] for an overview of research on single- and multiple-sourcing strategies. Aissaouia et al. [2] present a comprehensive review of the literature related to several aspects of the procurement function, including the supplier selection process and in-house versus outsourcing decisions. Firms sometimes employ multiple criteria in selecting their suppliers [28]. A recent survey of multi-criteria approaches for supplier evaluation and selection processes is presented by Ho et al. [19]. More recently, Kumar et al. [23] introduce a supplier selection approach taking carbon footprint of the suppliers into account. In our work, we do not include the multi-criteria supplier evaluation phase. We assume that the supplier base has already been determined and that the immediate supplier selection decisions are based on the cost criterion.

In our analysis, we consider a single-item, make-to-stock setting. We address a single period problem and extend it to a multi-period case in Section 4.2. The procurement problem has received much attention, mostly under the deterministic demand assumption (which results in a preset total procurement quantity). When the demand is deterministic, the problem becomes either (i) to determine the set of suppliers to purchase a given quantity, or (ii) to determine the suppliers and the purchasing frequency for a given demand rate. Chauhan and Proth [10] consider a version of the problem, in which there is a lower and an upper bound for the capacity of each supplier, and the supply costs are concave. They propose heuristic algorithms. Chauhan et al. [9] show that the problem considered by Chauhan and Proth [10] is NP-hard. Burke et al. [7] consider this problem under different quantity discount schemes and capacitated suppliers. They propose heuristic algorithms to solve the problem. Burke et al. [8] discuss that this particular problem is a version of the 'continuous knapsack problem', in which the objective is to minimize the sum of separable concave functions, and show that this problem is NP-hard. Romeijn et al. [26] analyze the continuous knapsack problem with nonseparable concave functions and propose a polynomial time algorithm. We note that the supplier selection problem with stochastic demand results in a nonseparable cost function; it is actually not a knapsack problem, because the size of the knapsack (the amount allocated to the suppliers) is itself a decision variable. We provide an exact pseudo-polynomial algorithm to solve the stochastic version of this problem, while not imposing restrictions on the supply cost. We refer the interested reader to Burke et al. [8] for a further review of the related literature and to Qi [25], Kawtummachai and Hop [21], and Mansini et al. [24] for different aspects of the problem under deterministic demand. In this study, we contribute to the literature by considering stochastic demand and by including general cost structures.

The stochastic demand version of the procurement problem under capacitated suppliers has also received attention to a certain extent in the literature. Alp and Tan [4] and Tan and Alp [27] analyze the problem with two supply options, in a multi-period setting under fixed costs of procurement. Alp et al. [3] consider an infinite horizon version of this problem with identical suppliers and a linear cost function with a fixed component, which is a special case of ours. Awasthi et al. [6] consider multiple suppliers that have minimum order quantity requirements and/or a maximum supply capacity, but no fixed cost is associated with procurement. They show that this problem is NP-hard, even when the suppliers quote the same unit price to the manufacturer and propose a heuristic algorithm for the general version. Hazra and Mahadevan [17] analyze an environment in which the buyer reserves capacity from a set of suppliers through a contracting mechanism. The capacity is reserved before the random demand is observed and allocated uniformly to the selected suppliers. If the capacity is short upon demand realization, the shortage is fulfilled from a spot market at a higher unit price. Our work differs from these articles, because we consider multiple suppliers and general cost functions, and we do not impose a particular structure on the allocation of purchased quantity to the suppliers.

Zhang and Zhang [30] consider a similar environment to ours. A single item that faces stochastic demand is procured from potential suppliers that have minimum and maximum order sizes, and a fixed procurement cost is considered. They propose a nonlinear mixed integer programming formulation and a branch-and-bound algorithm. Our problem is more general than this, as we do not impose restrictions on the supply cost structures, a situation that cannot be handled by the methodology proposed by the aforementioned authors. Finally, we note that Zhang and Ma [29] also consider a similar problem for multiple items. They assume that suppliers are capacitated and offer quantity discounts. A mixed integer nonlinear programming formulation that determines the optimal production quantities of each product, purchasing quantities of the raw materials, and the corresponding suppliers to make the purchases is proposed.

In this paper, we build a dynamic programming model to find the optimal solution to the NP-hard procurement problem, under a fairly general setting consisting of stochastic demand, general cost structures, and capacitated suppliers. The computational complexity of the solution that we propose is pseudo-polynomial. We also evaluate the performance of decoupling procurement and production decisions and build managerial insights.

2. Modeling approach

In this section, we analyze the procurement problem in a single-period setting, under a given set of alternative capacitated suppliers, with corresponding general procurement cost functions. The procured quantity also dictates the stock quantity, subject to stochastic demand. There are two decisions in such an environment: which sources