The Capacitated Supplier Selection problem with Total Quantity Discount policy and Activation Costs under uncertainty

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ABSTRACT

We study the Capacitated Supplier Selection problem with Total Quantity Discount policy and Activation Costs, a procurement problem where a company needs a certain quantity of different products from a set of potential suppliers, and introduce its variant under uncertainty. In its deterministic form, the problem aims at selecting a subset of the suppliers and the relative purchasing plan satisfying the demands at minimum cost, taking into account that the suppliers offer discounts based on the total quantity of products purchased and that the activation of a business activity with a supplier has a fixed cost. However, due to the long-term nature of the problem, several parameters may be affected by uncertainty. Thus, we propose a two-stage stochastic programming formulation with recourse, highlighting the strategic and the operational decisions involved, as well as the effect of the different sources of uncertainty. In particular, we focus on the cases in which only the products price or only the products demand are stochastic. The general model and the recourse actions are adapted for these special cases, and the resulting modeling approaches are validated on a large set of instances. The experiments show the convenience of having in place models considering uncertainty explicitly with respect to using expected values for approximating it, and give rise to interesting managerial insights. Due to the computational burden of solving the resulting stochastic models (for a sufficiently large number of scenarios), we also propose a branch-and-cut solution framework based on valid inequalities and other accelerating mechanisms.

1. Introduction

Procurement logistics problems mainly concern the operational decisions of a company that needs to buy products/raw materials from several potential suppliers. Since a large portion of a firm total cost is represented by procurement expenditure, regardless of the type of purchased goods, it is of crucial importance to optimize this aspect through the use of sophisticated mathematical models and efficient solution algorithms. That is why, despite of its long history in the specialized literature, procurement problems still foster new research contributions (see, e.g., Manerba, 2015).

In general, decisions underlying the procurement processes aim to elaborate a purchasing plan that adequately satisfies an internal demand while minimizing the procurement costs depending on product prices. Let $M$ be a set of suppliers, indexed by $i$, and let $K$ be a set of products, indexed by $k$. Each product $k \in K$, for which a positive integer demand $d_k$ is required, can be purchased in a subset $M_k \subseteq M$ of suppliers at a positive basic price $f_{ik}$, potentially different for each supplier $i \in M_k$. The so-called Supplier Selection (SS) problem consists in deciding which suppliers have to be visited and which amount of each product has to be purchased in each visited supplier (Aissaoui et al., 2007). However, real procurement settings may be complicated by several factors making the basic SS problems inadequate to provide a solution to the actual decision process:

- **restricted product availabilities**: when a supplier cannot guarantee a priori to satisfy completely a product demand, then the purchase of each product has to be split over different suppliers thus complicating the creation of a purchasing plan. In this work we assume that, for each product $k \in K$, a quantity $q_{ik}$ is available at each supplier $i \in M_k$ (capacitated SS);
- **discount policies**: to be more competitive, suppliers often try to push-up their sales by offering discounts). In this paper we assume that all the suppliers propose the so-called total quantity discount (TQD), a policy in which the cumulative quantity purchased (i.e., the

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number of units bought regardless of the type of products involved) determines the discount rate applied by the supplier to the total purchase cost. More precisely, each supplier $i \in M$ defines a set $R_i = \{1, \ldots, r_i\}$, indexed by $r$, of $r_i$ consecutive and non-overlapping intervals represented by $[u_r, w_r]$ and associated with a discount rate $\delta_r \in [0, 1]$ such that $\delta_{r+1} \geq \delta_r$ for $r = 1, \ldots, r_i - 1$ (i.e., the higher the interval, the greater the discount). Then, for each supplier $i \in M$, the discount rate $\delta_r$ is applied to the total purchase cost if the total quantity purchased lies in the interval $r \in R_i$, i.e., is greater than or equal to $u_r$ and less than or equal to $w_r$. An example of the cost function for a specific supplier $i$ offering a TQD policy is plotted in Fig. 1, where only the lower bound of each interval is indicated;  

- **contract activation costs**: in general, clients can benefit from the discounts only by previously activating a contract with the selected suppliers. In this paper we consider a cost $a_i$ for each supplier $i \in M$, corresponding to the fee that the company has to pay in order to undertake a business activity with that supplier. Trade-offs between these activation costs and the possible saving due to the discounted purchase further complicate the supplier selection;  

- **data uncertainty**: high market competition and globalization, with the consequent larger possibility of products availability but also with a longer time for obtaining them (due to the delocalization of the factories), push the companies to sign long-term purchasing contracts in order to sustain their offer. This increases the volatility of some parameters particularly affected by uncertainty. For example, a precise forecast of the future product demand is hard to obtain since it depends on several unknown a-priori internal and external factors. Again, product prices and availabilities at the suppliers are also subject to fluctuations due to market and environmental conditions. Since using approximated/estimated data may result in non-convenient or even infeasible purchasing plans, when the actual information reveals, in this work we propose an explicit modeling of the possible sources of uncertainty for the problem.  

![Fig. 1](image.png)

Fig. 1. Piece-wise linear function representing the cost of buying $Q$ units from a supplier $i$ offering a TQD policy.

Under this setting, some research questions arise. First, how the data uncertainty can affect the supplier selection when involving total quantity discounts? Second, can we incorporate this uncertainty in a model able to ensure a competitive advantage to the company?

To face the aforementioned questions, we consider the Capacitated Supplier Selection problem with Total Quantity Discount policy and Activation Costs (CTQD-AC) and introduce its variant under uncertainty (CTQD-ACu). The problem aims at selecting a subset of the suppliers and the relative purchasing plan that satisfies the demands at minimum cost, taking into account that the suppliers offer discounts based on the total quantity of products purchased and that the activation of a business activity with a supplier has a fixed cost. In order to tackle different sources of uncertainty we propose two-stage Stochastic Programming (SP) formulations with recourse, highlighting the strategic and the operational decisions involved. To the best of our knowledge, this represents the first study concerning the CTQD-AC problem under uncertainty.

The rest of the paper is organized as follows. In Section 2, we review the literature concerning SS problems with quantity discount policies and stochastic data. In Section 3, we propose a mixed-integer linear programming (MILP) formulation for the deterministic CTQD-AC. In Section 4, we study the possible sources of uncertainty of the problem and propose a two-stage SP model to explicitly cope with them. In particular, we focus on the cases in which only the product prices (Sections 4.2) or only the product demands (Section 4.3) are stochastic variables. A solution framework is presented in Section 5, whereas the generation of the deterministic benchmark instances and that of the scenario trees are presented in Section 6. Section 7 is devoted to the experimental validation of our modeling and solution approaches and to the discussion of some economic/managerial insights. Finally, conclusions and possible future extensions are drawn in Section 8.

## 2. Literature review

Given their critical impact on the supply chain cost, Supplier Selection (SS) problems have a long history in the specialized literature and a great number of qualitative and quantitative aspects (reliability, economy of scale, transportation costs) have been studied concerning this decision process. Since the seminal paper of Dickson (1966), an enormous quantity of works has been published on SS. We just refer the reader to Wetzstein et al. (2016) for a very comprehensive survey on the topic. Worth noticing, a great part of the most recent contributions study this process within the context of a green and sustainable but resilient supply chain (see, e.g., Dobos and Vörösáry, 2014, Hosseini, 2016, Hosseini and Barker, 2016, Hosseini and Khaled, 2016). In the following, we propose instead a detailed literature review on SS in the presence of quantity discounts and data uncertainty.

**Quantity discounts**, i.e. price discounts provided by suppliers with respect to large orders of products (Munson and Rosenblatt, 1998), have existed as ubiquitous tools of commerce incentive for hundreds of years within any type of application context. Evidently, they have a great impact on purchasing, transportation, and inventory costs as well as on marketing and supply-chain coordination goals. The monograph by Munson and Jackson (2015) reviews the most relevant quantity discount scenarios from both the buyer’s and seller’s perspective. Concerning the buyer’s side, it emerges that the most common issues to face are about a) how many units should be ordered when suppliers offer quantity discounts, and b) in which conditions should a buyer attempt to negotiate a discount schedule from its suppliers. The order sizing issue, complicated by the selection of suppliers among a predefined set, actually represents the SS problem already discussed. Since the last two decades, SS variants involving quantity discounts have been studied under a quantitative perspective and the assumption of deterministic data. For these problems, mathematical programs (mostly MILPs) have been developed and both exact and heuristic solution algorithms have been proposed. For example, Mirmohammadi et al. (2009) consider a single-item multi-period material requirement planning problem and propose a branch-and-bound algorithm exploiting some properties as fathoming rules. Munson and Hu (2010) analyze the inventory impact of incorporating quantity discounts into centralized purchasing scenarios for a multi-site organization, whereas Krüchen et al. (2011) study the convenience of a retailers coalition in the presence of a single-supplier and permissible delay in payments through cooperative game theory. Recently, Jalai et al. (2013) propose a multi-objective mixed integer nonlinear programming model for solving a multi-item multi-period and multi-supplier problem taking into account linear discount pricing scheme, the limits on the suppliers availability, the delivery rate and the quality of the items, the minimum order quantities, and the budgetary limitations. In the present paper we study a multi-supplier and
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