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# Dynamic green supplier selection and order allocation with quantity discounts and varying supplier availability

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A B S T R A C T

This paper aims to solve a multi-period green supplier selection and order allocation problem with all-unit quantity discounts, in which the availability of suppliers differs from one period to another. The proposed approach involves three stages. In the first stage, decision makers use fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) to assign two preference weights to every potential supplier based on the supplier's performance in two sets of criteria considered separately: traditional and green. In the second stage, top management uses the analytic hierarchy process to assign an importance weight to each of the two sets of criteria based on the organization's strategy. The outputs of the first and second stages serve as inputs for a single-product bi-objective integer linear programming model with deterministic demand that takes into account all-unit quantity discounts and a varying number of suppliers in each period of the planning horizon. We implement the proposed mathematical model in MATLAB R2014a software using the weighted comprehensive criterion method and the branch-and-cut algorithm. Statistical analysis helps determine the most suitable ranking approach for suppliers when their availability changes in each period. This paper presents a numerical comparison between two settings: the first considers all-unit quantity discounts, and the second does not. Moreover, a time study shows that the proposed bi-objective integer linear programming model has an exponential computation time.



## 1. Introduction

In the current competitive and global environment in which most businesses evolve, one of the most important processes in managing the supply chain of any organization is the selection of its suppliers. This process plays an important role in determining the cost, the quality, and other aspects of the finished product. Therefore, selecting the right suppliers to contract with for procuring physical products or services has become a multi-criteria decision-making process. More specifically, to select the best suppliers, organizations must take into account multiple aspects related to these potential suppliers (e.g., price, lead time), to the product (e.g., quality, materials), and more recently to aspects related to the environment and society (e.g., amount of carbon dioxide emitted in production and transportation operations). In addition, national and international regulations as well as international competition are putting more pressure on companies to consider the environmental aspects in the production and delivery of their products and services (Akman, 2015; Hafezalkotob, 2015; Zhang, Wang, & Ren, 2014). Therefore, taking the environmental aspects into consideration while selecting the right suppliers not only protects the environment but also improves companies' environmental performance and image and helps them achieve environmental goals (Büyüközkan & Çifçi, 2012; Kannan, Khodaverdi, Olfat, Jafarian, & Diabat, 2013).

In addition to the decision of selecting suppliers, the procurement process, through which the company allocates orders to the selected suppliers, allows for some economies of scale through the right choice of the quantities to allocate to each supplier. Indeed, the unit price for large orders is usually smaller than the unit price of small orders, even if the orders are made from the same supplier (Taleizadeh, Stojkovska, & Pentico, 2015). The decrease in the unit price due to the increase in the ordered quantity is known as the quantity discount. Quantity discounts can be part of a pricing strategy and can be a powerful incentive to motivate buyers to increase the amount of their ordered quantities (Mansini, Savelsbergh, & Tocchella, 2012). The three major types of quantity discounts are incremental quantity discounts, business

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volume quantity discounts, and all-unit quantity discounts (Ayhan & Kilic, 2015).

This combined supplier selection and order allocation problem with quantity discounts makes considering a multiple period framework more relevant. On the one hand, a supplier with excellent performance may not be available during the entire planning horizon, due to capacity limitation for example, which creates the need to consider less performing suppliers during some periods of the planning horizon and then to return to the excellent supplier in the following periods. On the other hand, because of the quantity discounts, ordering large quantities from few suppliers may be profitable and therefore requires the consideration of the capacity limitations and the estimation of the inventory holding costs over the entire planning horizon, especially for short life-cycle products.

This paper introduces a single-product, multiple-periods model with deterministic demand in which suppliers are selected and orders are allocated according to cost, traditional criteria, and green criteria. The model allows the available suppliers to vary between the periods of the planning horizon and considers all-unit quantity discounts. The model comprises three stages. In the first stage, decision makers use fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) to calculate two preference weights for each available supplier in each period of the planning horizon based on two sets of criteria taken separately: traditional and green. The set of traditional criteria includes aspects such as cost, quality, and lead time. The set of green criteria includes aspects such as the existence of a supplier's environmental certification and the modes of transportation it uses to deliver the products. The two performance weights of each supplier are calculated on the basis of the historical performance of the supplier or a feasibility study. Fuzzy TOPSIS models the uncertainty or fuzziness of the decision makers' evaluation through the use of Triangular Fuzzy Numbers (TFNs). In the second stage, the highest levels of the organization's hierarchy use the analytic hierarchy process (AHP) to give an importance weight to the traditional criteria as a set and to the green criteria as a set based on the strategic importance of each set in the organization's strategy. The performance weights of each supplier are then combined with the importance weights of the two sets of criteria to produce two final performance weights for each supplier: one traditional and one green. This approach provides the decision maker with flexibility in evaluating the available suppliers, in the sense that a supplier with excellent performance in the traditional criteria and poor performance in the green criteria will not rank among the best suppliers if the set of green criteria has a high importance weight. The use of fuzzy TOPSIS is justified because it does not have any inconsistency issues (Lima Junior, Osiro, & Carpinetti, 2014). Moreover, it allows the model to account for any uncertainty that may arise from the experts while ranking the different alternatives on the basis of the traditional or green criteria, especially when the number of alternatives or criteria is large (Lima Junior et al., 2014). Furthermore, an advantage of using TFNs to model the uncertainty in fuzzy TOPSIS is their facilitating role in the ranking process for the decision makers through the use of linguistic variables. TFNs allow for partial membership, whereas crisp sets allow for either full membership or non-membership. Moreover, using only AHP for both levels (category and criteria) would add more complexity in terms of number of matrices and may result in inconsistent rankings because of the large number of criteria. The use of AHP to calculate the two sets of importance weights is justified because this method is completely consistent when the number of alternatives is equal to two, where the random consistency index becomes equal to zero (Deng, Hu, Deng, & Mahadevan, 2014). The combined performance weights of the suppliers are then used as inputs for a bi-objective optimization model, which minimizes the fixed and variable costs and maximizes the preference weights of the selected suppliers. The model is solved using the weighted comprehensive criterion method (Dehghani, Esmaeilian, & Tavakkoli-Moghaddam, 2013).

The rest of this paper proceeds as follows: in Section 2, we provide a detailed literature review on the studied subject. In Section 3, we describe the problem and then provide the model formulation and the solution approach. In Section 4, we compare two ranking approaches, as the available suppliers vary during the periods, and recommend the best approach. We also compare the quantity discount framework with another framework in which no quantity discounts are allowed. Last, we present a study of the computation time to solve the developed bi-objective optimization model. Section 5 concludes the study.

## 2. Literature review

The rich literature on supplier selection without capacity constraints includes the use of approaches such as fuzzy simple multi-attribute rating technique (SMART) (Chou & Chang, 2008), fuzzy hierarchical TOPSIS (Wang, Cheng, & Huang, 2009), SMART with fuzzy set theory (Kwong, Ip, & Chan, 2002), AHP combined with fuzzy set theory (Bruno, Esposito, Genovese, & Simpson, 2016), and grey system theory with uncertainty theory (Memon, Lee, & Mari, 2015). In addition, research has examined the case when the capacity of one supplier may not satisfy the entire demand by developing models using different techniques, such as mixed integer programming (Amorim, Curcio, Almada-Lobo, Barbosa-Póvoa, & Grossmann, 2016; Zhang & Zhang, 2011), goal programming (Karpak, Kumcu, & Kasuganti, 1999), Monte Carlo simulation with fuzzy goal programming (Moghaddam, 2015), and fuzzy TOPSIS with mixed integer linear programming (Kilic, 2013).

Recently, some researchers have begun integrating green aspects into the supplier selection and order allocation problem (Freeman & Chen, 2015; Ghorbani, Bahrami, & Arabzad, 2012; Hamdan & Cheaitou, 2015, 2017b; Mafakheri, Breton, & Ghoniem, 2011). Doing so means evaluating suppliers on the basis of product-related criteria, such as the amount of toxic substance, the use of resources, and the use of green technology and environmental labeling (Igarashi, de Boer, & Fet, 2013). Suppliers can also be evaluated on the basis of organizational-related criteria, such as the environmental management certification, compliance with environmental policies and regulations, staff training on environmental awareness, and the organization's green market share (Igarashi et al., 2013). In particular, research has been conducted in the area of supplier selection and order allocation with quantity discount. For example, Dahel (2003) proposed a multi-objective mixed integer programming model to deal with total business volume discounts in supplier selection and the order allocation problem in multi-item environments. The model is solved using either a preference-oriented approach or the generating approach. Xia and Wu (2007) proposed a two-stage supplier selection and order allocation model with total business volume discounts. In the first stage, AHP improved by rough set theory is used to assign weights, while in the second stage, a multi-objective, multi-product mixed integer linear programming model is developed to maximize the total weighted quantity of purchasing, to minimize the total purchasing cost, to minimize the number of defective items, and to maximize the number of on-time delivered items. Burke, Carrillo, and Vakharia (2008) developed a heuristic to measure the effect of quantity discounts in supplier selection and the order allocation problem for a single item and a single period. They developed three models: the first model considers the linear quantity discount, the second the incremental unit price, and the third the all-unit quan-