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Soft time-windows for a bi-objective vendor selection problem under a multi-sourcing strategy: Binary-continuous differential evolution

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ABSTRACT

This paper introduces a novel and practical integration of the inventory control and vendor selection problems for a manufacturing system that provides multiple products for several stores located in different places. The replenishment policy of each store is the economic order quantity under a multi-sourcing strategy in which the demand rate decreases as the selling price increases. In this strategy, the ordered quantity of each store for each product can be replenished by a set of selected vendors among all. In addition, the selected vendors can deliver the required products within a certain time window based on a soft time-window mechanism. The aim is to minimize the total system cost and delivery schedule violations, simultaneously. A trade-off between the two objectives is generated using the min–max approach to obtain near fair non-dominated solutions. As the problem is known to be NP-hard, a novel meta-heuristic algorithm called binary-continuous differential evolution (BCDE) is developed to make the original differential evolution capable of solving both binary and continuous optimization problems. Moreover, an improved genetic algorithm with a multi-parent crossover operator is designed to solve the problem. While the applicability of the proposed approach and the solution methodologies are demonstrated, the solution algorithms are tuned and their performances are analyzed and compared statistically. Finally, sensitivity analyses on the size of the soft time-window and the bandwidth factor of the BCDE algorithm are conducted.

1. Introduction

Outsourcing refers to the way companies entrust some of their business processes to some external vendors. It can energize a business to focus on building the brand, providing higher value added services, and investing in research and development. This mainly includes functions such as transaction processing, payroll and order, and inventory management. Research relevant to outsourcing has substantially grown in the past two decades, where researchers have studied the importance of outsourcing business processes, activities, and functions in order to lower the costs and risk and to improve efficiency, flexibility, and quality. In these works, outsourcing has been shown crucial due to (i) its capability to provide operational and specialized technology in many organizations; (ii) its ability to help reduce staffing levels; and (iii) its ability to enhance the advancement and innovation in technologies [42]. Nevertheless, there are several risks such as data/security protection, loss of business knowledge, bad vendor selection, and so on involved in outsourcing. In today's increasing competitive business world in which proper strategic purchasing decisions can reduce resources significantly (40–80% of the total product cost), the vendor selection and evaluation is one of the most critical activities for companies, especially in outsourcing processes. That is why the selection of suitable vendors is one of the most important decisions of a company during the outsourcing process [14,48]. The vendor selection problem (VSP), in essence, is an unstructured and complicated multi-criteria decision making problem with various objectives that are usually in conflict with each other [25]. One of the reasons that has been stated by Kumar et al. [25] is: "*the selected suppliers may impose several constraints on the supplying process to meet their own minimum or maximum order quantities that are based on their production capacity*."

The VSP is often studied in two important outsourcing strategies; single and multi-sourcing. In contrast to single sourcing

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where the client faces problems with only one supplier, multi-sourcing is a rapid trend in real applications. Although single sourcing, which is a powerful approach in stable environments, can create many risks for a firm, multi-sourcing may lead to higher costs due to the management of more sources. Nonetheless, Costantino and Pellegrino [7] showed the advantages of adopting the multi-sourcing strategy especially in risky environments.

According to Aissaoui et al. [1], there are three major questions raised in VSP: (1) *What product to order*? (2) *In what quantities and from which supplier(s) to order a product*? *In which periods to order a product*? Here, the question arises what the relationship between VSP under the multi-sourcing strategy and the ordered quantity decisions is. To answer this question, the relationship between the VSP and the ordered quantity decisions should be analyzed. Obviously, ordered quantity decisions are related to inventory-related decisions (i.e. when and how much to order). In the following, some works related to the outsourcing strategy, VSP, and integrated VSP and inventory decisions are presented.

While most of the works on the VSP are investigated based on the single-sourcing strategy, the multi-sourcing strategy has not been investigated in depth. Besides, most of the literatures on the VSP only aim to select the best vendor, not focusing on its integration with important inventory-related decisions. In other words, the integration between the VSP and important inventory-related decisions, transportation consideration, and budget restriction are often overlooked. However, this integration would create additional opportunities for system-wide operational efficiency and cost effectiveness for many manufacturing systems. Furthermore, many works on the VSP focus on either minimizing the total cost or maximizing the quality level of the purchased quantity, ignoring on-time delivery. Additionally, the market demand has usually been assumed deterministic, fuzzy, or probabilistic, where less attention has been paid to effects of the factors such as market scales, demand elasticity, and retail prices, represented as the market-related parameters. These parameters have significant influence on the demand and manufacturers' profits.

To summarize, the important issues on VSP such as multi-sourcing strategy, integration between VSP and important inventory-related decisions, soft time windows, and the market-related parameters have been overlooked. The review of the works on the VSP models presented by Deshmukh and Chaudhari [11] confirms the above gaps. Therefore, different from the models already proposed in the literature, the aim of this study is to fill the gaps mentioned above by presenting a more realistic bi-objective optimization model. In other words, this study presents a more realistic bi-objective mixed integer nonlinear programming (MINLP) model for a firm that provides multiple products for different stores located in several places. The well-known Cobb–Douglas function is considered to describe the demand faced by each store for each product, as a function of their selling prices represented by a price-sensitive demand. It is assumed that the replenishment policy of each store is based on the assumptions involved in the multi-product economic order quantity (EOQ) model with backorder by considering the multi-sourcing strategy, which is chosen for its popularity and simplicity [31,40]. The EOQ model is formulated under throughput, dispatch, and budget constraints. Moreover, the selected vendors can deliver the required products within a time based on a soft time-window mechanism. In this mechanism, each vendor can deliver the products within a reasonable period without affecting the vendor selection process. Therefore, under a soft time-window, the decision makers are able to incorporate on-time delivery metrics for vendor evaluations. Providing a model for this closer to real-world problem is beneficial for manufacturing systems and organizations whose vendors deliver items within a certain time window.

The two objectives are minimization of the total cost of the firm and delivery schedule violations incorporating the soft time-window. The total cost of the firm includes costs associated with the vendor selection process such as vendor-specific fixed management costs, purchasing costs, distance-based transportation costs, and also costs associated with inventory decisions such as ordering, holding, and backorder. This research tries to obtain fair non-dominated solutions by establishing a trade-off between the proposed objectives using the min–max approach. In short, it seeks to address the following questions, (i) which vendors are selected; (ii) which store is allocated to the selected vendors; (iii) and what the optimal value for the inventory-related decisions is.

As the proposed problem is known as NP-hard, exact methods are not suitable to solve large problems in a reasonable computational time. Therefore, an improved genetic algorithm (GA) with multi-parent crossover is utilized. Furthermore, we develop a novel meta-heuristic algorithm namely binary-continuous differential evolution (BCDE) to solve the problem. The advantage of BCDE is that it utilizes a probability estimation operator as a new operator to make the original DE capable of solving the problems associated with both binary and continuous variables. The Taguchi method is applied to tune the parameters of both GA and BCDE. The performances of these algorithms are analyzed and then compared using several problems. While this study has been motivated by the need of integrating supplier selection and inventory-related decisions, the highlights of its differences with the above-mentioned studies are as follows:

- Integrating the vendor selection problem and inventory-related decisions under the multi-sourcing strategy.
- Generating a trade-off between the two objectives to obtain near fair non-dominated solutions; and.
- Developing a novel binary-continuous differential evolution algorithm to solve the problem.

The remainder of the paper is organized as follows. Section 2 is devoted to literature review. The problem description and the mathematical formulation of the problem come in Section 3. Section 4 discusses the solution methodologies, where a brief review of the min–max approach is given. In order to demonstrate the application of the proposed model and the solution approaches, several problems are investigated in Section 5. Finally, conclusion is provided in Section 6.

2. Literature review

As mentioned above, VSP is the most important strategic decision to make in an outsourcing process. The VSP has been the area of focus since 1960 s when Dickson [13] published his work on the analysis of vendor selection systems and decisions. Weber et al. [46] reviewed 74 articles related to the vendor selection problem since 1966. Recently, Deshmukh and Chaudhari [11] have provided a review on supplier selection criteria and methods. Considering these studies, it can be seen that there are three different approaches on VSP; (i) linear weighting methods, (ii) mathematical programming models, and (iii) statistical procedures [25].

The VSP literature of this paper can be classified into the second category that is related to cost-based criteria rather than vendor evaluation. Turner [41] introduced a single-objective linear programming model for British Coal in order to minimize the total discounted price under the vendor capability, maximum, and minimum order quantities. Based on the concept of ownership's total cost, Degraeve et al. [10] developed a mathematical programming model as a basis to compare VSP models. Kumar et al.