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Optimizing a hybrid vendor-managed inventory and transportation problem with fuzzy demand: An improved particle swarm optimization algorithm

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ABSTRACT

Vendor-managed inventory (VMI) is a popular policy in supply chain management (SCM) to decrease bullwhip effect. Since the transportation cost plays an important role in VMI and because the demands are often fuzzy, this paper develops a VMI model in a multi-retailer single-vendor SCM under the consignment stock policy. The aim is to find optimal retailers' order quantities so that the total inventory and transportation cost are minimized while several constraints are satisfied. Because of the NP-hardness of the problem, an algorithm based on particle swarm optimization (PSO) is proposed to find a near optimum solution, where the centroid defuzzification method is employed for defuzzification. Since there is no benchmark available in the literature, another meta-heuristic, namely genetic algorithm (GA), is presented in order to verify the solution obtained by PSO. Besides, to make PSO faster in finding a solution, it is improved by a local search. The parameters of both algorithms are calibrated using the Taguchi method to have better quality solutions. At the end, conclusions are made and future research is recommended.

1. Introduction

Companies with integrated supply chains are shown to be more competitive than the others in today's market environments in the sense of reducing total cost. Supply chain management (SCM) involves integrated decisions on transportation, location, inventory, and production to give the best mix of efficiency and responsiveness to the market being served [21]. Inventory management plays an important role in SCM, where academic and industrial communities made many strategies in order to reduce total inventory cost. These strategies are used in making inventory-related decisions that coordinate suppliers and retailers. The vendor managed inventory (VMI), which is the most popular strategy in the inventory management area, was successfully implemented by retailers such as JC-Penney and Wal-Mart [11,45]. In the VMI approach, the vendor (or supplier) makes a decision for a chain consisting of some retailers and a vendor. The retailers share the inventory and sales information in order to cooperate with the vendor who determines the replenishment frequency and the order quantity. In general, the VMI approach can reduce the demand variability in order to reduce the total inventory cost.

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The consignment stock (CS), which defines the stock ownership in a supply chain, is a relatively new approach in VMI modeling, in which retailers pay for the goods that are sold only. In other words, the unsold stock belongs to the vendor who is the legal owner of the goods although a retailer holds the stock.

Customer demand is difficult to predict and is uncertain in most situations. While some researchers modeled this uncertainty using stochastic approaches, many others employed non-deterministic methods such as fuzzy set theory. The main reason to use fuzzy demand is unexpected changes in customer demand [45].

In an attempt to reduce transportation cost by determining the shortest route to deliver goods, this paper extends the VMI model of Zavanella and Zanoni [55] for a supply chain. The transportation cost corresponds to deliveries of the goods to the retailers located in different places, where optimizing the delivery routes of the vendor's vehicle is similar to the one in the well-known traveling salesman problem (TSP). Besides, a trapezoidal fuzzy number is used to model fuzzy demand. Moreover, there are three constraints; (1) the retailers' warehouse is limited; (2) the vendor has a limit on his average inventory; (3) there is an upper bound on the total number of replenishments. The aim is to find the order size, the replenishment frequency of the retailers, and the shortest route, such that the total inventory and transportation cost are minimized. We will show that the developed VMI model of the problem at hand belongs to the class of NP-hard problems. Accordingly, a hybrid particle swarm optimization (PSO) algorithm with a local searcher is utilized to find a near optimum solution, where the centroid defuzzification method is employed for defuzzification. Since there is no benchmark available in the literature, another meta-heuristic, namely genetic algorithm (GA) is presented in order to verify the solution obtained by PSO. Moreover, to find better quality solutions, the parameters of both algorithms are calibrated using the Taguchi method.

The structure of the remainder of the paper is as follows. The motivation and contribution of the paper is provided in the next section. Section 3 illustrates a brief review on the VMI problem. Section 4 presents the proposed VMI model along with the notations used and the assumptions made. Meta-heuristics and parameter tuning come in Sections 5 and 6, respectively. Section 7 presents the analysis of the solutions. Finally, conclusions and recommendations for future research are given in Section 8.

2. Motivation and contribution

VMI is one of the most popular strategies in retailer–supplier partnerships to decrease bullwhip effect as well as to reduce total inventory cost. Several successful retailers such as Wal-Mart and JC-Penny took advantages of the VMI policy [44]. The bullwhip effect, which is an observed phenomenon in forecast-driven distribution channels of SCM, concludes to greater safety stocks with increased total cost. Thus, it is important to employ supply chain policies that reduce demand variability. To reduce demand variability and hence to cope with the bullwhip effect in a supply chain, in this research the demand is considered fuzzy. Moreover, transportation cost has a key role in total cost of the chain. For example, the freight transportation costs of General Motors with a large production and distribution networks were about $4.1 billion in 1984 [44].

Reducing demand variability using fuzzy numbers and considering transportation cost of a supply chain that operates under CS and VMI policies are the two motivations of this research. This research is probably one of the first under fuzzy demands that considers a closer to reality VMI problem in which the consignment stock approach is employed, the transportation cost is taken into account, and that there are several constraints. Another novelty of this paper comes from proposing an algorithm based on PSO named hybrid PSO that not only utilizes the centroid defuzzification method to defuzzify membership functions, but also a local searcher to find better solution. This algorithm tries to find a near optimum solution of an integer nonlinear programming that belongs to the class of NP-hard problems. Furthermore, in order to improve the quality of the solution obtained, the parameters of the meta-heuristic are calibrated using the Taguchi method.

3. Literature survey

Since a VMI model based on the economic production quantity (EPQ) policy is developed in this paper, among many research works proposed in the literature of VMI, those that use either EPQ or the economic order quantity (EOQ) are first reviewed in the following two subsections. Then, relevant literature on fuzzy VMI modeling is surveyed in Section 3.3. The meta-heuristic algorithms proposed in VMI environments are next reviewed in Section 3.4.

3.1. VMI literature based on the EOQ policy

Regarding the EOQ policy, Yao et al. [52] proposed a VMI model in a supply chain involving a single vendor and a single retailer. Afterwards, Darwish and Odah [10] first developed a VMI model for a multi-retailer single-vendor supply chain problem with a similar interval of consumption, and then applied a heuristic algorithm to solve the problem. Next, Pasandideh et al. [36] studied a VMI model with several constraints for a single-supplier single-retailer in which shortages were backordered. They proposed a genetic algorithm (GA) with tuned parameters to find a near-optimum solution of the problem. However, they did not concentrate on the maximum available inventory level in their modeling. As a result, Cárdenas-Barrón et al. [4] first extended their model to contain the maximum available inventory, and then used a better heuristic algorithm to solve the problem. Nonetheless, both ignored a closer to reality assumption on the replenishment frequencies. Since the vendor replenishes the retailers based on certain frequencies, Sadeghi et al. [39] improved the model