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Flexible supply chain optimization with controllable lead time and shipping option

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ABSTRACT

In order to enhance customer's loyalty in a supply chain, many efforts could be done such as upgrading the service facilities and decreasing delivery time. Although these efforts need to extra-added cost, but we can reduce the shortage cost in supply chain. In this paper we consider a five-tier supply chain and assume that the lead time of manufacturers and warehouses can be shortened at an extra crashing cost, which depends on the length of lead time. Also we consider different options with different prices for product transportation between facilities. We formulate mixed integer non-linear model for a five-tiers supply chain with controllable lead time and multiple transportation options and develop a novel meta-heuristic method that combines the Taguchi's feature with Artificial Immune System (AIS) to solve the proposed model. The performance of the proposed solution method has been examined against a set of numeric instances and the obtained results are compared with those provided by AIS and the hybrid of Taguchi-genetic algorithm (GATA). Results indicate that the proposed method can provide better results than the previous solutions effectively.

1. Introduction

A significant issue in supply chain design is the foundation of proper indices to evaluate the performance of supply chain. A set of performance indices is used to determine effectiveness and robustness of an existing chain. These indices are categorized as qualitative and quantitative. Quantitative performance indices are also categorized based on cost or profit e.g. the total cost of supply chain, average time to response customers' demand [1]. In traditional supply chain the main focus of the problems was on cost or time component; for example, Amiri [2], Gen and Syarif [3], Truong and Azadivar [4] proposed mathematical models to minimize the total cost of supply chain. But in recent years many researchers such as Sourirajan et al. [5], Salema et al. [6], Panagiotis and Lazaros [7] and Tiwari et al. [8] proposed several models that consider total cost as a main index with combination of other indices such as transportation specification, supplier quality and customer waiting time.

Lead time as a quantitative performance index is an important specification for each facility in a supply chain. Researchers have investigated the lead time in several states. The lead time is more significant when demand is uncertain and effect of demand uncertainty can be decreased with effective lead time management. Therefore two opinion exist about lead time. In the first lead time is a parameter and in the second lead time is variable. If lead time is considered as variable, the models try to select the best value to minimize the cost and delivery time. Ouyang and Wu [9] emphasized that shortening the lead time can decrease the safety stock and stockout loss and increase the service level and the competitive ability. Ben-Daya and Raouf [10] presented review model that considers lead time and order quantity as decision variables. They obtain the best lead time and order quantity that minimize the crashing cost, ordering cost and holding cost. Ouyang and Chuang [11] proposed a mixture inventory model involving variable lead time and controllable backorder rate. They assumed that backorder rate is dependent on the length of lead time and proposed the best ordering policy. Lee [12] extended the work of Ouyang and Chuang [11] and proposed a model with combination of lead time and controllable backorder rate with the mixture of distributions.

As stated by Tersine [13], lead time usually consists of more than one component such as order preparation, order transition, supplier lead time, delivery time and setup time components. Considering this fact lead time can be reduced by decreasing the time of these components with crashing cost, that is to say the lead time is controllable. Many researchers utilize controllable lead time in supply chain design problem to reduce the customers waiting time and increase the service level. Lee et al. [14] proposed the continuous review inventory system with backorder discount and variable

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lead time, where capital investment leads to reduce the ordering cost and lead time can be shortened at an extra crashing cost. Their objective is to simultaneously optimize the order quantity, ordering cost, back-order discount and lead time. Ouyang and Chang [15] proposed a model deals with lead time and set-up cost reductions on the modified lot size reorder point. In the proposed model lead time can be shortened at an extra crashing cost the model objective is to optimize the lot size, reorder point, set-up cost and lead time. Pan and Hsiao [16] proposed an integrated inventory model with controllable lead time and backorder discount in which lead time crashing cost is a function of reduced lead time and orders quantities. Li et al. [17] investigated on a supply chain consisting of a vendor and a buyer with controllable lead time. They considered two scenarios such as complete information and incomplete information about buyer. Arkan and Hejazi [18] proposed a coordination mechanism based on a credit period in a two echelon supply chain with one buyer and one supplier that both lead time and ordering cost can be reduced at an added cost. Jha and Shanker [19] presented an integrated production-inventory model where a vendor produces an item and supplies it to a set of buyers. The buyer level demand is assumed to be independent normally distributed and lead time of every buyer can be reduced at an added crash cost. Yi and Sarker [20] also used controllable lead time in a buyer–vendor system.

Many supply chain models that focused on lead time and supply chain optimization are NP-hard and researchers utilized a heuristics or meta-heuristic method to find the optimal solution for them. Moncayo-Martınez and Zhang [21] proposed an algorithm based on pareto ant colony optimization as an effective method to solve multi-objective supply chain design problems. Gunnarsson [22] used two different heuristic approaches to optimize a supply chain problem. Melachrinoudis et al. [23] used multiple objective approaches to find a solution. Syam [24] applied Lagrangian relaxation and simulated annealing to a supply chain network with multiple levels and settings; minimization cost was the objective. Chang Ying [25] used genetic algorithms with optimum search features and combined the co-evolutionary mode, which is in accordance with various criteria and evolves dynamically, and constraint-satisfaction mode capacity to narrow the search space, which helps in finding rapidly a solution that, solves supply chain integration network design problems.

Taguchi method is a robust design method based on experimental design for assessment improvements in products, processes and equipment [26]. Taguchi methods have been also combined with heuristic algorithms and the results have shown efficient performance over an extensive range of problems [27,28]. In supply chain optimization by meta-heuristics, Taguchi method has been used to select the initial parameters of models [29] and this method did not have any role in solving stage of the model in most cases. On the other hand Taguchi method has been rarely utilized in order to select and reconstruct the population to produce the next generation or as a crossover operator in meta heuristics. Nevertheless there are some papers that used Taguchi method for selection stage in meta heuristic such as Tiwari et al. [8] that used the orthogonal array in order to find the best combination of parents' receptors for generating offsprings pool in their meta-heuristic solution.

In this paper we study an integrated supply chain with five tiers that delivers products from suppliers to customers. We assume that manufacturers and warehouses have controllable lead time that can be shortened to reduce delivery times. This advantage declines the inventory cost, transportation cost and backorder cost of entire supply chain. The objective function of this supply chain consists of six components such as purchasing raw materials, fixed cost, variable cost, transportation cost, holding cost and crashing cost. In the proposed model we find the best assignment of transportation options for each facility and determine which facility must be open or closed. To our knowledge there is no model and solution approach in the literature to find the optimum or near optimum combination of facility allocation, transportation selection and lead time duration setting in one problem, so we should restrain the complexity of this model and its solution. We first model a five-tier supply chain mathematically with controllable lead time and multiple transportation options and next propose a novel meta-heuristic method to solve this model effectively. We use Taguchi method and AIS to solve the model and also propose a particular type of antibody coding to find the best combination of receptors. In this study, to reduce computational efforts, Taguchi method is used to examine the important combinations of receptors in antibodies. To verify the effectiveness of the proposed meta-heuristic method, it has been compared with the previous methods.

The rest of the paper is organized as follows: Section 2 introduces the model assumptions. Section 3 describes the mathematical model for the considered supply chain. Section 4 introduces detailed description of the proposed method. Section 5 is devoted to the results and finally Section 6 concludes the paper.

2. Model assumptions

The model assumes that the customers' demand follows normal distribution and each customer has a maximum waiting time that his demand must be satisfied during this period. The proposed model determines which facility should be open or closed and also assigns transportation options to each facility. In each layer of supply chain there are different transportation options. For example, these options can be plane, truck or train, the price of these options is different in each layer. Raw materials are more than one type, for example if we have 2 types of raw material such as i_1 and i_2 the manufacturers need both of them to make the product, manufacturers can provide raw materials from different suppliers. Each manufacturer and warehouse has a controllable lead time that consists of some components and each component has several duration options and crashing costs. Lead time of these facilities can be shortened to satisfy customers' demand in their waiting time period. Other assumptions made in the proposed model are as follows:

- Transportation cost is nonlinear and we have several transportation options for each facility.
- Each supplier can fulfill the demand of more than one manufacturer.
- The demand of each facility is satisfied by one facility from upper layer.
- The lead time L for manufacturers and warehouses consists of I mutually independent components. The ith component has a minimum duration T_{i2}, normal duration T_{i1} and a crashing cost c_{i2}. Further, for our convenience, we rearrange c_i such that $c_{12} \le c_{22} \le c_{32} \ldots \le c_{n2}$. Then it is clear that the reduction of lead time should be first on the first component since it has a lower crashing cost, then second component and so on.
- Let $L_0 = \sum_i T_{i1}$ and L_k be the length of lead time that its first k components crashed to minimum duration. Then L_k can be expressed as $L_k = \sum_{i=1}^{I} T_{i1} - \sum_{i=1}^{k} (T_{i1} - T_{i2})$
- Crashing cost must be paid in all cycles, if a facility selects the crashed lead time.
- There is no shipment transfer between facilities of the same layer.
- Each manufacturer, warehouse and distribution center can fulfill the demand of more than one facility.
- The transportation options available to different classes of business entities are not the same.
- A periodic review inventory replenishment policy is assumed.