A novel hybrid method for supply chain optimization with capacity constraint and shipping option

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Abstract In a modern market, supply chain network design is considered as a strategic decision that provides the proper platform for cost management and increases the competitive edge of enterprise. In a five-tier supply chain, there are several facilities such as suppliers, manufacturers, warehouses, distribution centers, and retailers or customers. For product transportation from one facility to another, different types of options may be used. These options have variety price and the manager should do the best assignment to reduce the total cost. In this paper, we formulated an integer programming model for a five-tier supply chain with capacitated facility and multiple transportation option with fixed lead time. We also proposed a novel meta-heuristic solution methodology that combines the Taguchi’s feature with artificial immune approach in order to solve the proposed model. The performance of the proposed solution methodology has been examined against a set of numeric instances and the obtained results are compared with those provided by hybrid genetic algorithm and Taguchi and artificial immune system. Results indicate that this methodology can make better results than previous solutions effectively.

Keywords Supply chain design · Taguchi design · Artificial immune system · Optimization

1 Introduction

The supply chain optimization problem is to utilize all sourcing units of chain with respect to satisfying all demands of end customers with minimum cost. The first problem of supply chain in location field was proposed by Weber [39]. He studied the problem of locating one facility among existing facilities, and this model was then developed by many researchers. Geoffrion and Graves [16] utilized the delivery constraints instead of service-level restriction in order to deliver products to customers in determined time. In the later years, researchers such as Francis et al., Aikens et al., and Brandeau [1, 5, 13] focused on facility and location problem. Pirkul and Schilling [28] further extended the maximal covering location problem with capacity limit constraint on the facilities.

According to Vidal and Goetschalckx [38], the supply chain optimization problem involves determining the number, location, capacity, and type of manufacturing plants and warehouses to use, the set of suppliers to select, the transportation options to use, the amount of raw materials and products to produce and ship among suppliers, plants, warehouses, and customers, and the amount of raw materials, intermediate products, and finished goods to hold at various locations of inventory. Special constraints of particular cases such as complex cost functions or logical constraints are not involved in the general definition of supply chain. Ganeshan et al. [14] studied on supply chain management to minimize the configuration cost. However Chong et al. [9] focused on the globalization and enlarged product variety in a supply chain that leads to product proliferation which complicates the supply chain structure and raises the cost. Beamon [4] proposed a general analysis of supply chain modeling. Pirkul and Jayaraman [27] extended the previous problem by considering locating also a given number of plants. They formulated the problem as a mixed integer model and developed a Lagrangian-based heuristic solution procedure.

The work of Goetschalckx was followed by Jayaraman and Pirkul [19]. They studied an integrated logistics model for locating production and distribution facilities in a multi-
echelon environment. Jayaraman and Ross [20] proposed a simulating annealing methodology to distribution network design and management. Yan et al. [40] proposed a strategic production–distribution model for supply chain design with consideration of bill of materials. Syam [33] extended traditional facility location models by introducing several logistical cost components such as holding, ordering, and transportation costs in a multi-commodity, multi-location framework. Amiri [3] focused on formulation and introducing an efficient solution procedure for a distribution network in a supply chain network to select the optimum number of locations and capacities of plants and warehouses to open so that all customers' demand are satisfied with minimum total costs. Gen and Syarif [15] and Truong and Azadivar [36] have also developed the work of Vidal and Goetschalckx [38] and proposed optimal design methodologies for configuration of supply chain. Li et al. [18] have developed a mixed integer strategic capacity allocation model for a complex supply chain in order to deliver the products to customers with minimum cost. Tiwari et al. [35] proposed a model for supply chain with multiple shipping and nonlinear holding cost and transportation cost.

Pontrandolfo et al., Goetschalckx et al., and Chan et al. [7, 17, 29] simulated the supply chain of a single channel logistics network incorporating order release theory. Chan and Chan [6] modeled the supply chain as a distributed constraint satisfaction problem and have used simulation method to verify the performance of proposed solution. Kumar et al. [23] utilized the simulation-based model to optimize a supply chain with different aspect variables such as delayed differentiation, information sharing, etc.

Although there are several researches that have focused on supply chain design with nonlinear variables, few researches especially the papers by Erlebacher and Meller, Daskin et al., Shen, and Shen and Qi [11, 12, 31, 32] have addressed the nonlinear holding cost. Erlebacher and Meller [12] formulated a nonlinear integer location model and used continuous approximation for solving the model. Shen [31] studied the joint location and inventory model. He combined the location, transportation, and nonlinear inventory costs in the same model and utilized an integrated approach to determine the number of distribution centers to establish.

Few researchers developed models with capacity constraint. Park [26] presented a method for integrated production and distribution planning with capacitated facilities.

Many researchers provided heuristics or meta-heuristic algorithms to find the optimal point of supply chain problems. For instance, Koray and Marc [22] proposed a multiple products mixed integer programming model to find the minimum cost that includes manufacturing cost, storage cost, and transportation cost. They used Bender's decomposition of integer programming to find the solution. Melachrinoudis and Min [24] used multiple objective approaches to find an optimal solution. Ross [30] employed a performance-based strategic resource allocation to solve supply network design problems. Syam [33] applied Lagrangian relaxation and simulated annealing to a supply chain network with multiple levels and settings that cost minimization was the objective. Altiparmak et al. [2] employed steady-state genetic algorithm to obtain the solution for the design of a supply chain network with multiple products and phases and compared their algorithm with linear programming, Lagrangian relaxation, and simulated annealing. This study aimed to minimize purchasing cost, transportation cost, fixed cost, and manufacturing cost. In the above literature, some studies take maximization profit as their objective, whereas most supply chain network models take minimization cost as their measure of performance and consider many costs, including purchasing cost, transportation cost, and storage cost. Chang [8] used genetic algorithms with optimum search features and combines 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.

In supply chain optimization by meta-heuristic, Taguchi method has been utilized in order to determine the best combination of input parameter such as cost level and service level [10, 37]. Taguchi is a method that uses orthogonal arrays in design of experiments to reduce the number of tests and costs. Taguchi et al. [34] utilized Taguchi method which is a robust design approach based upon statistical experimental design for evaluating and implementing improvements in products, processes, and equipment. Kumar et al. [23] proposed a model for supply chain optimization and utilized Taguchi for parameter setting. Tiwari et al. [35] also used the orthogonal array in order to find the best combination of parents for generating offspring pool in their meta-heuristic solution.

In this paper, we considered an integrated supply chain with five tiers that deliver product from suppliers to customers. The structures of transportation cost and holding cost are nonlinear. Capacity constraints also are considered for manufacturers, warehouses, and distribution centers; to handle these constraints, we should propose a particular type of coding in artificial immune system (AIS) to find the best combination of receptors in antibodies. In this study, to reduce computational efforts, Taguchi method is used to examine the important combinations of receptors in antibodies. Limits on the capacity reduce the feasible space and lead to the complexity of proposed meta-heuristic method. Because of capacity constraint of supply chain and using Taguchi immune approach, this paper is a novel matter in comparison with literature. To verify the effectiveness of the proposed meta-heuristic solution, it has been compared with the previous methods.

The rest of the paper is organized as follows: Section 2 presents the model assumptions and describes the