Applied Soft Computing 62 (2018) 328–346

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Full length article

# A tri-level location-allocation model for forward/reverse supply chain

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ARTICLE INFO

*Article history:*
Received 24 January 2017
Received in revised form 11 May 2017
Accepted 2 November 2017
Available online 8 November 2017

*Keywords:*
Tri-level programming
Location-allocation problem
*Stackelberg* game
Tri-level metaheuristic
Keshtel algorithm
Water wave optimization

ABSTRACT

The design of supply chain network usually directly influences the performance of location-allocation of facilities, especially for the main parties. This paper firstly addresses the tri-level location-allocation design problem which considers the forward and reverse network, simultaneously. The proposed problem is formulated on the static *Stackelberg* game between the Distribution Centers (DCs), Customer Zones (CZs) and Recover Centers (RCs) in the framework. The literature reports that most of previous works have utilized the various exact approaches which are not efficient and are so complex. In this study, three old and successful methods consist of Variable Neighborhood Search (VNS), Tabu Search (TS) and Particle Swarm Optimization (PSO), as well as two recent nature-inspired algorithms; Keshtel Algorithm (KA) and Water Wave Optimization (WWO) are utilized. Besides, according the nature of the problem, this study proposes a simple nested approach named as tri-level metaheuristic for the first time in order to solve the large scale problems. The performances of the algorithms are probed by using Taguchi experimental method to set the proper values for the parameters. Eventually, the efficiency of the algorithms is compared by different criteria and validated through a real case study. The obtained results show that tri-level metaheuristics are effective approaches to solve the underlying tri-level models in large scale network.



## 1. Introduction

The last decade has seen the rapid development of designing the location-allocation models in the term of Supply Chain Management (SCM) which utilizes some new approaches to uniform the different parts of supply chain network [1–3]. The main process of a forward/reverse supply chain is happened on the allocation of customers to distribution centers, the allocation of recovering centers to customers in order to guarantee the used products, and also the location of these facilities. All of them follow a distinguished manner to reduce the transportation cost in each section [4]. In the real world, the management of these mentioned sections are separated and determined in different levels [5]. Customers select the services of DCs from their benefit and behavior. So, the multi-level programming is the useful way to simulate these parts of network, simultaneously.

Multi-level programming (or multi-level decision-making) is addressed by the game theory of *Van Stackelberg* [6]. It aims to apply comprising between the different decision levels which are distributed through a hierarchy. In the preliminary of multi-level programming as bi-level programming, the upper level is known as a *leader* and the lower level is defined as a *follower*. Their individual decision is made in sequence with the goal of optimization [6]. Usually, one of the important assumptions in these models is that the follower has full knowledge about the leader decisions. In this way, the reacts of follower depends on the used strategy of leader. The bi-level and tri-level programming models are two famous, typical and special of multi-level programming which have motivated a lot of researchers to use the application of these models in different topics, such as, location-allocation design, reliability, vulnerability of power system, interdiction facilities and military applications. Table 1 summarizes the related papers in the application of multi-level programming models. This table is developed according the Mahmoodjanloo et al. [44].

As can be seen in the table, these NP-*hard* problems have been considered and highlighted in the recent decade by researchers. As mentioned earlier, this paper firstly addresses the tri-level location-allocation design problem which considers the forward and reverse network, simultaneously. All parts of a supply chain act in a cooperative manner to decide the best strategy [50]. As illustrated in Fig. 1, the Distribution Centers (DCs) as the top-level leader takes decisions to receive products from manufacturers and to select the suitable facilities to be located among all potential facilities. This level is mainly focused on the forward network. According to the

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https://doi.org/10.1016/j.asoc.2017.11.004
1568-4946/

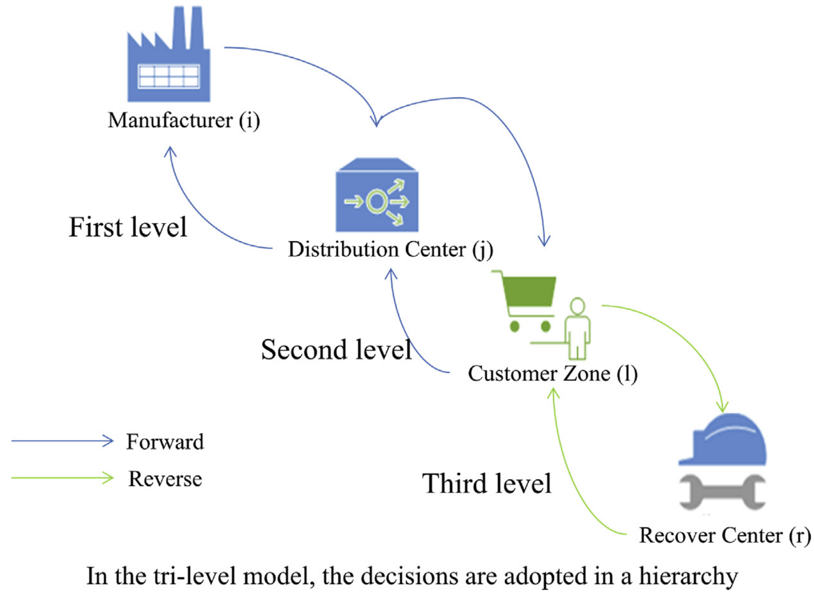


**Fig. 1.** The graphical structure of a simple tri-level model for forward/reverse network utilizing in this study.

**Table 1**
The application of multi-level programming models.

| Application | References |
|---|---|
| Location-allocation of supply chain and logistic network | [7–20] |
| Reliability | [21–27] |
| The vulnerability of power system | [28–33] |
| Interdiction facilities of supply chain network | [34–44] |
| Military applications | [45–49] |

decisions made by DCs, the Costumer Zones (CZs) as the middle-level follower make decision to choose the DCs in order to reduce the transportation and allocation cost. Lastly, the bottom-level follower considers the reverse network with the Recover Centers (RCs) to ensure the flow of used products from customers. In this level, the number of facilities to be established and allocation of customers to these centers will be specified.

To cope with the described problem, the main contributions of this paper can be outlined as follows:

- Developing a tri-level programming model for the location-allocation design problem for the first time.
- Proposing a new nested approach, tri-level metaheuristic for the developed tri-level model.
- Introducing the advantages and disadvantages of solution methods in multi-level programming.
- Comparing the metaheuristic methods by different criteria
- Keshtel Algorithm (KA) and Water Wave Optimization (WWO) as the recent metaheuristics, Particle Swarm Optimization (PSO), Variable Neighborhood Search (VNS) and Tabu Search (TS) as the traditional ones in this study.
- Validation of the proposed methodology through a real case study in Iran.

The following section describes the literature review of location-allocation design in supply chain network. Section 3 represents the proposed model in the mathematical tri-level programming. In Section 4, the proposed optimization techniques and characteristics of old and recent metaheuristics are explained, respectively. Experimental evaluations are conducted to evaluate the performance of the proposed algorithms against each other in terms of different criteria in Section 5. Finally, Section 6 presents the main findings and future lines of the research.

## 2. Literature review

Facility locations and allocations of demands are one of the research topics in designing a supply chain or logistic network. Some basic models of location-allocation design problem are summarized in Aikens [51]. These models are varied to uncapacitated and capacitated facilities besides the stochastic demands models. In such models, the aim of objective functions is to minimize the transportation cost of allocating and the fixed opening cost of locating a facility. In the literature, the stochastic and dynamic facility location-allocation problems during 1964–1977 were reviewed by Owen and Daskin [52]. They pointed out that stochastic models are divided into two categories: probabilistic and scenario-based. In this way, the input parameters are assumed to be uncertain. In the past, the supply chain configuration comprises two main parts: Manufactures to DC and DCs to Customers in the forward network [53]. But, recently, the flow of used products from Customers to RC as the reverse network is interested to be investigated by researchers [54–56].

It has been shown that location-allocation problem is NP-*hard* problem [57]. Hence, several heuristics and metaheuristics have been proposed to solve this problem [58]. Pirkul and Jayaraman [59] proposed the capacitated manufacture and warehouse models with multi-commodity as the parts of forward network. They developed a Mixed Integer Programming (MIP) by a heuristic method based on the lagrangian relaxation to solve the problem. In addition, in similar research, a branch and bound approach for a multi-commodity two-stage problem is used [60]. Zhou et al. [61] presented a Genetic Algorithm (GA) to address location-allocation problem via multiple distribution centers. Cross-dock scheduling is considered to from the DCs. In this term, the products are transformed to cross-docking DCs and distributed to CZ without handing in the inventory. Jayaraman and Ross [62] offered a Simulated Annealing (SA) algorithm to explore the cross-docking DCs in supply chain system. Sharma et al. [63] proposed the hierarchy process with multi-criteria to design the optimal distribution network with relevant selections for decision maker. Moreover, the location-allocation design problem for distribution network is solved via spanning tree-based GA by