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A hybrid imperialist competitive-simulated annealing algorithm for a multisource multi-product location-routing-inventory problem

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ABSTRACT

This article studies a multi-product and multi-period location-routing-inventory problem in which location-allocation, inventory and routing decisions are to be taken in a three-level supply chain including suppliers, depots and customers. Products are distributed from depots to customers by a homogeneous fleet of vehicles. Backlogging is allowable on condition that the backlog quantity of each customer does not exceed a predefined fraction of his demand. A mixed-integer programming formulation is presented to describe the problem then a new hybrid heuristic algorithm based on the simulated annealing and imperialist competitive algorithm is designed to solve the model. Comprehensive numerical examples are presented to evaluate the efficiency of proposed algorithm. In addition, the proposed algorithm is compared with simulated annealing algorithm in small and large size instances. The results show that imperialist competitive-simulated annealing (IC-SA) algorithm outperforms simulated annealing (SA) algorithm in terms of solution quality and CPU time.

1. Introduction

Logistics management plays a pivotal role in enhancing the service level and competitiveness of companies as well as reducing operational costs. Distribution network design has a considerable importance in facilitating and accelerating efficient logistics management. Distribution network design problem (DNDP) consists of three major decisions: location-allocation, inventory and routing decisions. Location-allocation decisions involve facilities location and allocation of customers to facilities, recognized as location-allocation problem in the literature. In addition, inventory decisions (determining order quantity) and customers routing decisions have been studied by researchers as inventory control problems and vehicle routing problems, respectively.

It should be noted that integrated distribution network design in supply chains will bring about efficient logistics management. The higher level of integrity in designing a distribution network is, the better decisions could be made in a supply chain to decrease operational costs and raise customer service level (Javid & Azad, 2010). Initially, these decisions were considered separately in DNDP. However, the interrelation of these three problems prompted researchers to combine them. In the last two decades, pairwise integration, and more comprehensively, ternary integration of these three problems have been taken into account in DNDP. Pairwise integration problems are the forerunner of ternary integration ones involving location-routing, location-inventory and inventory-routing problems.

Liu and Lee (2003) proposed a heuristic method in order to solve a combined location routing and inventory problem. They showed the proposed heuristic method outperformed other heuristics not considering inventory control decisions. To solve the Liu and Lee's model more efficiently, Liu and Lin (2005) proposed a new heuristic method which was sequential in its improvement stage. Then Shen and Qi (2007) proposed a location-allocation model considering inventory costs and approximate routing costs which depended only on the locations of the opened depots. They studied the benefits of decisions integration in a supply chain and showed the total cost decreases as the degree of decision integration increases. Mete and Zabinsky also (2010) studied a DNDP of medical products for disaster management under a wide variety of possible scenarios. They proposed a two-stage stochastic programming to solve the problem. The location and inventory decisions were made in the first, and the routing decisions were made in the second stage according to the obtained results of the first one.

Finally, Javid and Azad (2010) were first to introduce location-routing-inventory problem (LRIP) which integrated location,

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inventory and routing decisions without any approximation. They substantiated that their model significantly outperformed Shen and Ki's in terms of solution quality. Sajjadi and Cheraghi (2011) and Nekooghadirli, Tavakkoli-Moghaddam, Ghezavati, and Javanmard (2014) presented a multi-product LRIP in a two-level supply chain.

Guerrero, Prodhon, Velasco, and Amaya (2013) presented a multi-period LRIP in a two-level supply chain in which customers face deterministic demands. They proposed a heuristic method to solve the problem and tested its performance for the three problems of location-routing-inventory, location-routing and inventory-routing. Granada and Silva (2012), Ahmad, Hamzah, Md Yasin, and Shariff (2014) and Nekooghadirli et al. (2014) also proposed a multi-period LRIP.

Ahmadi-Javid and Seddighi (2012) presented a LRIP model for designing multisource distribution networks. The model presented in this paper is also aimed at designing a multisource distribution network; however, it is multi-product, demands of customers are dependent on time and backlogging is allowed. Furthermore, each depot could be assigned to more than one supplier that seems more realistic assumption.

Abdelmaguid, Dessouky, and Ordóñez (2009) presented a multi-period inventory-routing problem with backlogging in a two-level supply chain. The causes of backlogging in their model were vehicle capacity restriction and transportation cost saving resulted from efficient use of vehicle capacity. However, in the model presented in this paper, backlog of orders could take place in two cases. The first is when there is an insufficient supplier capacity to satisfy customers' demands in a period. The second is due to transportation cost saving that is higher than the incurred shortage cost. An allowable backlog percentage for every customer is also considered in order to avoid accumulating backlog of orders of some customers with less backlog cost. Therefore, customers with less backlog cost are more likely to be confronted with backlog of orders although this amount is confined to a specific ratio.

Following all previous LRIP problems investigated in the literature, the problem in this paper is inspired by a real world problem in an automotive company which tries to determine the location of depots, inventory deliveries and routs of vehicles which distribute varied spare parts to some customers, widely distributed across the region. Each supplier has a limited capacity and one supplier may not be able to supply the demands of all customers assigned to a depot. In other words, split-sourcing may occur for each product which allows each depot to receive each type of product from more than one supplier. Suppliers are also distributed widely across the whole region. Transportation costs from suppliers to depots will influence on locating depots and selecting suppliers to supply the demands of customers. An allowable backlog percentage for every customer is considered in order to avoid accumulating backlog of orders of some customers with less backlog cost. To solve this problem, a model which combines location, routing and inventory decisions in a three-level supply chain is presented, the highest level of integrity in DNDP in the literature.

According to Javid and Azad (2010), LRIPs belong to the class of NP-hard problems. Therefore, a common way to solve such complex problems is to develop a heuristic method. In the current paper, an effective hybrid heuristic combining simulated annealing with imperialist competitive is proposed to solve the NP-hard problem. Then the obtained results of IC-SA algorithm are compared to that of SA algorithm.

To the best of our knowledge, there are two kinds of contributions in this paper, incremental and general contributions. Incremental contributions are as follows:

- A multi-product multisource distribution network is designed.
- Backlogging is allowable on condition that the backlog quantity of each customer does not exceed a predefined fraction of his demand in a period.
- Split-sourcing is permitted which allows each depot to select more than one supplier to provide its demands.

And, general contributions are as follow:

- A new hybrid IC-SA algorithm is proposed to solve the problem.
- The obtained results of IC-SA algorithm is compared with that of SA algorithm in terms of solution quality and CPU time.

The remainder of this article is organized as follows. In Section 2, the problem is described and formulated. Section 3 presents the proposed heuristic solution method to solve the problem, and Section 4 provides computational results to evaluate its effectiveness. Finally, Section 5 concludes the article.

2. Problem description and formulation

As mentioned in the previous section, this article considers a multi-product multisource LRIP in which customers' demands are dependent on time and backlogging is allowable. The goal of the proposed model is to determine the location of depots from a given set of candidate locations, assign some customers to each opened depot, determine inventory policy and route vehicles to transmit customers' demand such that the total system cost is minimized. The assumptions and notations are explained as follows.

2.1. Assumptions

- Split-sourcing is allowable.
- The possible capacity levels for each depot are known.
- Each supplier provides one or more than one product type.
- Each supplier has a periodic maximum supplying capacity for each product.
- Each customer could be assigned to only one depot.
- Backlog of orders is allowable and whenever a customer is confronted with backlog in a period, these unsatisfied demands must be met in the next period.
- Each vehicle has a maximum capacity and could be assigned to only one route.
- Total system costs consist of inventory holding costs, ordering costs, depots operating costs, inventory purchasing costs, inventory backlog costs and transportation costs (from suppliers to depots and depots to customers).

2.2. Index sets

I	the set of suppliers
J	the set of depots
K	the set of customers
N	the set of capacity levels available to depots
H	the merged set of customers and depots, i.e. $K \cup J$
T	the sets of periods
P	the sets of products
V	the sets of vehicles