Computers & Industrial Engineering 119 (2018) 338–352

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

A location-inventory supply chain network model using two heuristic algorithms for perishable products with fuzzy constraints

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ARTICLE INFO

Keywords:
Location-inventory
Supply chain network
Two heuristic algorithms
Perishable products
Fuzzy

ABSTRACT

Supply chain network is very important to the development of industries. This paper integrates a location-inventory problem into a supply chain network and develops an optimization model for perishable products with fuzzy capacity and carbon emissions constraints. This model is formulated a mixed integer nonlinear programming model. In order to solve this model, hybrid genetic algorithm (HGA) and hybrid harmony search (HHS) are put forward to minimize the total costs. Instances under different situations are calculated using these two algorithms and Lindo (optimization solver). The impacts of some factors such as the number of facilities, intact rates, and demand on the total costs are investigated. The results of numerical experiments demonstrate that the proposed algorithms can effectively deal with problems under different conditions and these two algorithms have their own advantages. Specially, the quality of HHS's solution is higher than that of HGA's solution, whereas HGA is faster than HHS.

1. Introduction

Supply chain network is crucial to the development of industries. To survive in today's market of intense competition, companies need to design an efficient, and responsive supply chain network (Friesz, Lee, & Lin, 2011; Shahabi, Unnikrishnan, Jafari-Shirazi, & Boyles, 2014). The costs of a supply chain network can be decreased by 60% through an appropriate design (Harrison, 2004). Decision in supply chain networks can be divided into three levels: strategic, tactical, and operational (Shen & Qi, 2007). Strategic decisions involve the number and location of facilities. Tactical decisions deal with the location and quantity of inventory. Operational decisions include the quantity of shipment, fleet and routing management (Berman, Krass, & Tajbakhsh, 2012). In the traditional setting, strategic level decisions are made without considering the tactical and operational decisions. Furthermore, the strategic decision is made before the operational and tactical decisions are determined (Shahabi et al., 2014).

However, this method of decision-making may not result in the most effective structure and it could incur additional costs according to Snyder, Daskin, and Teo (2007). In recent years, a trend of integrating the strategic, tactical, and operational decisions has arisen through the establishment of location-inventory network models. There are two major problems in the location-inventory models. The first one is the location and allocation problem; the second one is the inventory management problem (Gzara, Nematollahi, & Dasci, 2014). According to Diabat and Richard (2015), in general, location models focus on maximizing the efficiency of the supply chain while inventory decisions focus on improving the responsiveness of the supply chain. These two problems are interdependent and should be handled simultaneously to minimize the total costs or maximize the profits. Moreover, it is possible to model real-world business problems as location optimization problems, without involving any "real" location decisions for opening or constructing new facilities (Diabat & Richard, 2015). In this paper, we introduce a location-inventory supply chain network model and provide an integrated framework for solving the proposed model. A supply chain network is considered that involves a set of potential plants, a set of potential warehouses, and a certain amount of retailers. Warehouses replenish the retailers and receive supplies from plants. The objective of the proposed model is to minimize the total cost by identifying the number and location of warehouses and plants, the shipments between plants and warehouses, and the quantity of perishable products between warehouses and retailers.

Traditional supply chain network models often assume that the lives of products are unlimited. Nevertheless, the assumption does not always conform to the actual situations, for example, meat, green vegetables, human blood, medicine, flowers, films, alcohol, and gasoline.

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https://doi.org/10.1016/j.cie.2018.04.007
Received 27 May 2017; Received in revised form 8 October 2017; Accepted 3 April 2018
Available online 05 April 2018
0360-8352/

Some products have perishability, i.e. they lose all or part of their value as time goes by (Levina, Levin, McGill, Nediak, & Vovk, 2010). These products can be divided into two groups: perishable products and decaying products. Meat, green vegetables, human blood, medicine, flowers, and films are perishable products (Mirzaei & Seifi, 2015). Alcohol and gasoline which have no shelf-life are known as decaying products (Goyal & Giri, 2001). The sale of perishable products accounts for half of whole sale of retail industries in US (Ferguson & Ketzenberg, 2006). About 10% of the perishable goods become wastes before they are purchased by customers (Roberti, 2005). Therefore, the costs caused by deterioration, corruption, and degradation should not be ignored. In this paper, the losses and costs of perishable products during transit will be considered. In addition, the papers which consider capacity constraints are not many, for example, Miranda and Garrido (2008), and Atamtürk, Berenguer, and Shen (2012).

Most studies assume the capacity of warehouses is infinite. However, in fact, the quantity of products supplied by plants is often limited by the capacity of the warehouses. In order to fill this gap, this paper put forward a location-inventory model with fuzzy capacity constraints to account for storage space limitations, finite resources for processing and handling, manpower limitations, or a combination of these factors (Easwaran & Üster, 2009). Furthermore, because environmental policies of governments become more and more severe and public environmental awareness continues to grow, companies and firms begin to concern about the environmental impact of their own activities (Hammami, Nouira, & Frein, 2015). Several traditional location-inventory problems have been reconsidered with environmental factors (Arikan & Jammernegg, 2014; Konur & Schaefer, 2014). In particular, transportation is one of the main sources of carbon emissions. Thus, researchers associate carbon emissions with the decisions of facility location or supplier selection (Dekker, Bloemhof, & Mallidis, 2012; Tang & Zhou, 2012). In our supply chain network model, we also consider carbon emissions, which are produced in the process of transportation.

In the end, supply chain network is limited by many factors, such as capacity and carbon emission, which are uncertain because they are affected by many known and unknown factors. For example, new or old trunks and tires, the quality of gasoline, and pavement smoothness of road will affect the carbon emissions. The quality of tools and skill - proficiency of workers will affect the capacity. However, decision makers have a very limited understanding of these known factors, not to mention those unknown factors. Therefore, decision makers have psychological expectations for carbon emissions and capacity. In other words, decision makers hope the actual value is lower than the expectations and hope the actual value is as low as possible. It is a problem to be solved that how to integrate the subjective intention and the expectations of the decision makers. This problem is described by some vague language. With the increasing perfection of fuzzy theory proposed by Zadeh (1965), more and more researchers use fuzzy theory to solve practical matter. For example, Pai (2003) solved a capacitated lot size problem on the basis of the assumption that the capacity is fuzzy. Qu and Li (2014) explored the impact of carbon trading mechanism on the carbon emission control and cost optimization of inventory management under fuzzy environment. In this paper, the constraints of fuzzy capacity and fuzzy carbon emissions are proposed. By means of the fuzzy theory, fuzzy constraints are transformed into equivalent crisp forms.

On the basis of the above discussions, a location-inventory supply chain network model for perishable products with fuzzy capacity and carbon emission constraints is presented. The supply chain network is composed of three echelons, that is, plants, warehouses, and retailers. The objective of the proposed model is to minimize the total cost (TC), which includes warehouse holding cost (HC), warehouse ordering cost (WOC), fixed cost (FC), transportation cost (TRC), loss cost of perishable products (LC), and penalty cost (PC). The decisions need to be made are: location and number of plants and warehouses, allocation of retailers to warehouses and warehouses to plants, and inventory control decisions of each warehouse. The assumptions of the model include: (1) fixed costs of warehouses and plants are predetermined, (2) transportation costs are proportional to distance, quantity of perishable products, and unit freight, (3) each retailer is assigned at least one located warehouse. If supply exceeds the demand of retailer or supply is less than the demand of retailer, penalty costs will arise, (4) inventory costs including holding costs and ordering costs occurs only at warehouses. The optimal order quantity is based on the economic order quantity. In addition, different perishable products have different unit holding costs and ordering costs, (5) perishable products deteriorate during transit from warehouses to retailers. No degeneration occurs at other times. Once the time of transportation from warehouses to retailers exceeds the critical time, the perishable products cannot meet the demand of the retailer and be discarded. Deterioration rate of perishable products follows three-parameter Weibull distribution. Moreover, multiple perishable products are considered, (6) warehouses are subjected to capacity constraint. Supply chain network is subject to carbon emissions constraint. Carbon emissions and unit capacity for perishable products are fuzzy variables, (7) there are no lead time and no product shortages for warehouses.

The proposed model is a mixed integer nonlinear programming model which is difficult to solve using exact solution methodologies. Therefore, hybrid genetic algorithm (HGA), hybrid harmony search (HHS), and an optimization solver Lindo are used. In order to handle the uncertainties caused by fuzzy numbers, a fuzzy programming approach is applied.

We summarized the main novelties of this article that differentiate this paper from the existing ones in the related literature are as follows. First, we integrate a location-inventory problem into three-echelon supply chain network model, which is composed of plants, warehouses, and plants. Second, we assume each retailer is assigned to at least one opened facility. Previous studies often assume that each retailer is assigned to one opened facilities. Third, different perishable products with different unit holding costs and ordering costs are considered. Fourth, we take into account the losses and costs during transit for multi-perishable-product. Fifth, this paper includes capacity and carbon emission constraints using fuzzy programming approach. Sixth, we develop and compare hybrid genetic algorithm (HGA) and hybrid harmony search (HHS) with Lindo. Computational experiments show that the quality of HHS's and HGA's solutions is higher than that of Lindo.

The paper is organized as follows. Section 2 reviews the existing literature related to location-inventory models of supply chain networks. Section 3 elaborates fundamental concepts and operations. Mathematical formulation is presented in Section 4. In Section 5, two novel algorithms are proposed. In Section 6, numerical experiments are provided. Finally, conclusions are made in Section 7.

2. Literature review

In this section, we discuss the literature related to location-inventory modeling of supply chain networks and associated constraints and solution methods. The section is divided into three subsections. The first subsection presents the literature related to location-inventory models. The second subsection discusses the literature on the inventory management of perishable products. The third subsection reviews the studies on inventory problems with constraints.

2.1. Location-inventory problem

Yao, Lee, Jaruphongsa, Tan, and Hui (2010) proposed a location-allocation and inventory problem which includes many sources of warehouses. The study determines the locations and number of warehouses, quantity of products shipped to the customer, and warehouses' inventory levels to minimize the expected total cost. In order to solve