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A dynamic closed-loop location-inventory problem under disruption risk

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ABSTRACT

In this paper, a dynamic closed-loop location-inventory problem is addressed that optimizes strategic decisions (i.e., facility location in terms of contracting/selection of distribution centers and reworking centers) along with tactical ones (i.e., allocation of centers, inventory management) under facility disruption risks. The presented model seeks to minimize total cost as the first objective function, and time as the second one in the considered network. Due to the NP-Hard nature of the model, a hybrid meta-heuristic algorithm based on Multi-Objective Particle Swarm Optimization (MOPSO) and Non-dominated Sorting Genetic Algorithm-II (NSGA-II) is presented to solve the problem in large scales. Finally, applicability of the proposed model is tested via a real case study and the results are analyzed in depth.

1. Introduction

In today's competitive business environment, cost reduction and customer service improvement are the two major challenges for each company. Inventory management as one of the main tools to cope with such challenges, has been devoted to a great concern in recent years. This field has been further integrated with decisions like facility location in order to pursue a more efficient integrated strategic–tactical decision-making, which has resulted into an efficient (in terms of decreasing production costs, increasing customer satisfaction, etc.) holistic view in supply chains. Two major decisions which are mainly made in location-inventory problems are; first, location and allocation decisions which characterize the proximity of facility location and how to allocate the facilities to customers; second is related to inventory management which characterize responsiveness of the supply chain in terms of inventory serviceability (Gzara, Nematollahi, & Dasci, 2014).

In recent years, there is an increasing attention to green supply chains which integrate value-adding operations of business environments with the aim of minimizing negative effects such as water and air pollution, and a reduction in natural source level (Abdallah, Diabat, & Simchi-Levi, 2012). Generally, product recovery is one of the most applied approaches for greening a supply chain which needs to make a closed-loop supply chain that we have utilized in our model. Possibility of implementation of reverse logistics is one of the most important requirements for achieving a closed-loop supply chain which is defined as operations related to damaged or unsold products and end-of-life products. Such operations are disposing, remanufacturing, reworking and return products reinforcing. Closed-loop supply chain management is an integration of forward logistics as a traditional process and reverse logistics as a modern process; in forward logistics, manufactured products transfer to the customers and in reverse logistics, remanufactured products which maybe have the same quality with original products re-enter the supply chain as original products or even spare parts which are further being sold to a secondary market. However, a common proposed assumption in the literature which states that the returned products combined with subassemblies to enter the secondary market as a spare part is not an applicable assumption in real world. Therefore, a new different approach has been presented in this study in comparison with similar studies. It has been assumed that returned products can re-enter the forward logistics after the completion of operations needed to reach an acceptable quality. In this regard, ordering pattern of the DCs and retailer demands can be influenced by this strategy. As a result, by using this approach closed-loop supply chains concentrate on resource level reduction. Finally, according to mentioned importance for both location-inventory and closed-loop supply chain, it seems a problem by the topic of integrated closed-loop location-inventory approach has special position in the literature and helps in strategic decisions relating to supply chains.

Facility disruption is another important issue that should be addressed. In the traditional view, an established facility is considered as an ever-available one; however, sometimes many facilities would be out of reach due to the risk of the disruptions (Chen, Li, &

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Ouyang, 2011). These operational disruptions may originate from natural disasters, strikes and recession, terroristic acts, etc. (Hatefi & Jolai, 2014). Both negative financial effects and operational outcomes, i.e., high transportation costs, delay in orders, inventory shortages, etc. may be originated from these risks (Peng, Snyder, Lim, & Liu, 2011).

In this paper, a dynamic closed-loop location-inventory supply chain network design problem, in which inventory decisions have been integrated with location–allocation decisions in a multi-product dynamic closed-loop supply chain under the risk of facility disruption is considered. It should be mentioned that the location decisions are related to contract with the facilities in order to find their optimum locations.

Based on before-mentioned descriptions, the contributions in this study that differentiate it from the other relevant works are:

- Presenting a novel bi-objective dynamic closed-loop location-inventory problem
- Considering the risk of probabilistic facility disruption
- Considering the effectiveness of returned products in a period on DCs' ordering pattern and retailers demand in the next period
- Presenting a developed hybrid multi-objective meta-heuristic algorithm based on Multi-Objective Particle Swarm Optimization (MOPSO) and Non-dominated Sorting Genetic Algorithm-II (NSGA-II)
- Applying the presented model in a real case study in Iran

The rest of this paper is organized as follows. Section 2 addresses a comprehensive literature review of the previous related research efforts. In Section 3, mathematical formulation of proposed problem is presented. Section 4 addresses two meta-heuristic algorithms, namely NSGA-II and MOPSO which have been proposed to solve the model. In Section 5, evaluation of the meta-heuristic algorithms is discussed. Section 6 presents a real case study and some sensitivity analyses. Finally, conclusions and future research directions are discussed in Section 7.

2. Literature review

The literature in the area of efficient supply chain design can be divided into 3 categories: (i) inventory theory, (ii) traditional forward logistics location theory, and (iii) reverse logistics theory (Diabat, Abdallah, & Henschel, 2015). In addition, we import one novel discussion as facility disruptions to the mentioned categories. In recent years, Daskin (1995) and Drezner (1995) addressed traditional forward logistics that concentrate on determining both location and the optimal number of DCs which consider only the costs of delivering from plant to the retailer. Unlike traditional forward logistics theory, reverse logistics has recently been addressed. More precisely, reverse logistics is the development of traditional forward logistics location theory so that the collection centers have been opened for remanufacturing, reworking, recovery, and disposal.

Closely related to the recent studies, integration of location and inventory is becoming an increasingly important issue, whose first idea was proposed by Baumol and Wolfe (1958). A number of integrated location-inventory models which has studied by Barahona and Jensen (1998), Erlebacher and Meller (2000), Miranda and Garrido (2006) and Teo, Ou, and Goh (2001), have chosen heuristics or approximations to solve nonlinear optimization problems. Barahona and Jensen (1998) applied Dantzig–Wolfe decomposition to solve the linear relaxation of the location problem which has fixed inventory cost. Erlebacher and Meller (2000) developed a heuristic algorithm based on analytical model for stylized version. Nozick and Turnquist (2001a) considered inventory, transportation and customer responsiveness costs in addition to facility costs, and Nozick and Turnquist (2001b) presented a model for optimizing the location of inventory for individual products in a multi-product inventory system which is two-echelon. Freling, Romeijn, Morales, and Wagelmans (2003) modeled a single sourcing multi-period problem considering inventory and transportation costs in a dynamic environment; the problem was formulated as a Generalized Assignment Problem (GAP) with a convex objective function. Teo and Shu (2004) presented a model to minimize inventory, transportation and facility location costs in a multi-echelon supply chain and solved it by using Column Generation (CG). Shu, Teo, and Shen (2005) studied inventory-transportation network design problem in an uncertain environment existing one supplier and multiple retailers with the assumption of keeping safety stock. Shen and Daskin (2005) implemented weighting method on location-inventory cost-based model; furthermore they proposed a heuristic solution approach based on Genetic Algorithm. Huang, Romeijn, and Geunes (2005) proposed a problem with integration of allocation, production and inventory and CG was utilized for solving the problem. Eskigun et al. (2005) assumed the lead time as a function of volume of demands assigned to the DCs in a location-inventory model. Miranda and Garrido (2006) considered a nonlinear mixed-integer model for simultaneous inventory and location decisions and solved the problem by using heuristic algorithm based on Lagrangian Relaxation. Finally, Kumar et al. (2015) developed production and pollution routing problem with time window in a VRP model, in which the location and inventory decisions are considered and has been solved by a new hybrid Self-Learning Particle Swarm Optimization (SLPSO) algorithm.

Recently, Daskin, Coullard, and Shen (2002) and Shen, Coullard, and Daskin (2003) adopted a new approach of inventory and location decisions considering (Q, r) policy. Miranda and Garrido (2004) considered the main problem as a series of capacitated location problems. In this area, Ozsen, Coullard, and Daskin (2008) formulated a capacitated location problem using risk pooling. Qi and Shen (2007) added routing cost to inventory and location costs in a stochastic supply chain, You and Grossmann (2008) used a heuristic method and developed decomposition algorithm based on Lagrangian Relaxation, and in this way they both helped to develop the location-inventory literature. Finally, Diabat, Richard, and Codrington (2013) studied a multi-echelon location-inventory model which was formulated as a nonlinear mixed-integer problem, and was solved by using Lagrangian Relaxation.

The next stream of related research efforts to our work is the closed-loop supply chains. Fleischmann and Minner (2004) considered the inventory management problem related to closed-loop supply chains and concluded that inventory decisions should integrate to some other businesses. Savaskan, Bhattacharya, and Van Wassenhove (2004) was the first to study the choice of reverse channel structures for collecting returned products from consumers. They concluded that reverse channel structure with collecting policy at retailers is optimal to the manufacturer. Lieckens and Vandaele (2007) studied reverse logistics network efficient design and created a nonlinear mixed-integer model for involving the queuing relationships. Chung, Wee, and Yang (2008) developed a multi-echelon closed-loop model with remanufacturing capability. Jaber and El Saadany (2009) developed a model under lost sale condition. Chung and Wee (2011) and Wee, Lee, Yu, and Edward Wang (2011) addressed supply chain inventory system considering deteriorating green products. Abdallah, Farhat, Diabat, and Kennedy (2012), Kannan, Diabat, Alrefaei, Govindan, and Yong (2012) and Diabat, Abdallah, Al-Refaie, Svetinovic, and Govindan (2013) studied impacts of forward and reverse logistics on carbon emissions. Kaya and Urek (2015) developed a novel closed-loop supply chain by considering the location, inventory and pricing decisions simultaneously in a