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Integrating the logistics network design with order quantity determination under uncertain customer demands

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ABSTRACT

This paper aims to design an optimal logistics network including suppliers and retailers by taking into account the order quantity of products under uncertain consumer demand pattern. This research proposes a mixed-integer bi-level programming model and employs the iterative-optimization method. In the bi-level programming, the upper model is the logistics network design (LND) problem, which is designed for suppliers and consists of the hub locations, wholesale price of the products as well as the transportation flow of the commodity. The lower model is the order quantity determination (OQD) problem for retailers. It processes a special case of inventory problem in which the customer demand is stochastic and follows a series of assumed probability distributions. By applying the proposed methodology in a computational experiment, this research shows that if there were a large number of suppliers in the logistics system, retailers could order the product with relatively low price and the largest profit belongs to the retailer who could sell the commodity at the highest price.

1. Introduction

The logistics network design (LND) problem has long been recognized as important issue in the literature. In the context of LND research, prior research has identified three distinct planning levels: strategic, tactical and operational (Shankar, Basavarajappa, Chen, & Kadadevaramath, 2013). Research on the strategic and tactical decision levels often address decisions from the supplier's perspective, such as decisions involved in the performance (e.g. the capacity of the plant, the price of goods) of commodity supply (Iyoob & Kutanoglu, 2013; Shankar et al., 2013), features (e.g. The number, location and capacities) of transportation hubs (Tancrez, Lange, & Semal, 2012), as well as the organization of commodity flow over the logistics network (Keskin & Uster, 2007; Qin & Ji, 2010). Melo, Nickel, and Saldanha-da-Gama (2009) suggested that "the terms network design and supply (or logistics) chain network design are sometimes employed as synonyms of strategic supply chain planning". On the other hand, research on the operational level decision has been largely focused on the order quantity, order price and issues related to the operation of logistics industry such as Level of Service (LoS) for the retailer. Moreover, besides a large number of research which focus on specific decision levels, there are issues related to multiple decision levels involved in LND, such as inventory control strategy (Ho & Emrouznejad, 2009), transportation flow assignment (Lee, Kang, & Lee, 2008), routing problem (Zolfpour-Arokhlo, Selamat, & Hashim, 2013), location (Sun, 2002) and capacity planning of the warehouse (Balcik & Beamon, 2008; Francas & Minner, 2009; Guener, Murat, & Chinnam, 2012).

Recently, the issue of designing an integrated logistics system (ILS) has received increasing attention in the literature (Cheong, 2005; Croxton & Zinn, 2005; Daskin & Coullard, 2002; Syarif, Yun, & Gen, 2002; Thanh, Bostel, & Péton, 2012). The development of the ILS, which refers to the incorporation of various operations, including manufacturing, processing, transportation and sales into a framework together, call upon researchers to incorporate new research approach in an attempt to overcome limitations in considering of integrated operations (Cheong, 2005; Lin, Gen, & Wang, 2009). One recent important issue in the ILS research is to find out the optimal network structure that can give the lowest cost of the physical distribution flow and efficient techniques for solving integrated logistics network design (ILND) problems for ILS. These problems were commonly modeled as combinational optimization formulations. The representative works in the design of ILS were done by Shen (2005, 2006) and by Daskin and Coullard (2002). Other researchers also made their contributions to the optimization of ILS (Cordeau, Pasin, & Solomon, 2006; Croxton & Zinn, 2005; Goetschalckx, Vidalb, & Doganc, 2002; Javid & Azad, 2010; Lin et al., 2009; Miranda & Garrido, 2004; Miranda & Garrido, 2009; Shu, Li, Shen, Wu, & Zhong, 2012). Detailed reviews of related problems could be accessed in (Miranda & Garrido, 2009; Shu et al., 2012). It is worth mentioning that, the idea of ILS operation has been applied in the commercial logistics company, which could help the customer in designing and implementing

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an integrated logistics network and try to provide a comprehensive, cost effective and reliable logistics service (Vasiliauskas & Jakubauskas, 2007).

Recent developments in the ILND problem have been centered on the cooperation of different operations in the logistics network (Cheong, 2005; Eksioglu, Song, Zhang, Sokhansanj, & Petrolia, 2010; Ho & Emrouznejad, 2009; Tsao & Lu, 2012). That is, by incorporating related decision-making processes (such as the facility location, the logistics price determination and the commodity transportation), decisions involved in the logistics network optimization were combined into an integrated framework.

Unfortunately, the extant research on ILND tends to treated the two issues separately: LND (on the supplier side) and the order quantity determination (OQD) on the retailer side. Further, majority of the exiting literatures has largely neglected the uncertain customer demand as well as its impact on the logistics operation (Crainic, 2009). In this paper, an ILND model with identical commodity is proposed, which embraces both the strategic and the operational decisions. The proposed formulation is incorporated into a bi-level programming framework, which simultaneously considers different time steps for strategic and operational decisions. Finally, this model makes decisions about transportation routing, transportation facility location for the production suppliers and decisions on order quantity and order price for the product retailer in a long-time horizon.

The contributions of this research is multi-fold: (a) we determine the optimal hub location, commodity transportation and wholesale price for suppliers and the order quantity for retailers simultaneously. These issues have not been integrated into an ILND framework and optimized simultaneously in prior literature; (b) we provide a bi-level formulation to model the decision planning issues of both the supplier and the retailer. The lower level problem for the retailer is continuous while the upper level problem for the supplier is discrete. Few formulations with bi-level framework could integrate two different kinds of mathematical problems together; (c) we use computational experiments on randomly generated data to verify the optimal decisions of suppliers and retailers. Our results show that our model could reflect the competence between the supplier, and that which kind of retailer could get the large retail profit.

2. Problem statement

Solutions for traditional LND problems often focus on how to minimize the sum of transportation and fixed warehousing costs, subject to capacity and demand constraints. The problem is usually modeled as a mixed-integer model and solved using a variety of optimization techniques, most frequently intelligent algorithms (Miranda & Garrido, 2009; Syarif et al., 2002; Thanh et al., 2012). It is assumed in standard models that inventory costs are independent of the network design. We integrated the inventory cost as well as the retail strategy into the logistics network design with hub location. The problem is detailed as follows.

As shown in Fig. 1, consider K retailers who sell identical commodity supplied from I different suppliers. Each supplier provides the retailer with identical commodity at a wholesale unit price. Assume that the customer at each retailer has uncertain demand with the known probability distribution. For retailer k, its objective is determining the optimal order quantity during the decision-making period. After each retailer order Q_k commodities from the supplier, the commodities would be transported directly from the i suppliers via a distribution center (DC) then to the retailer. During this process, the supplier would be involved in the following strategic planning issues: (1) determine which DC should be selected as the hub to reprocess the goods; (2) assign the commodity flow on the logistics network. That is, determine the commodity flow transported on the logistics network, x_{ijk}, which denote the amount of commodities transported from a supplier i to retailer k via DC (or) hub j; (3) determine different wholesale prices of the commodity to different retailers.

In general, some of the most important decisions in our model are as follows:

- Location of transportation hub (selection of DC as transportation hub).
- The commodity quantity to be supplied from each supplier.
- Commodity quantity to be transported from each supplier to each DC.
- Product quantity to be transported from each DC to each retailer.
- Order quantity as well as order price of each retailer with stochastic customer demand.

Moreover, some of the most important assumptions in the proposed model are as follows:

- The objective is to maximize the total supply chain profit.
- The customer demands are uncertain during the time periods.
- Both suppliers and retails are in an incomplete information circumstance.
- Each DC can be updated as a hub due to its physical condition.
- Each retailer has been equipped with an infinite-capacity warehouse.
- The distance between the warehouse and the retail store is zero.

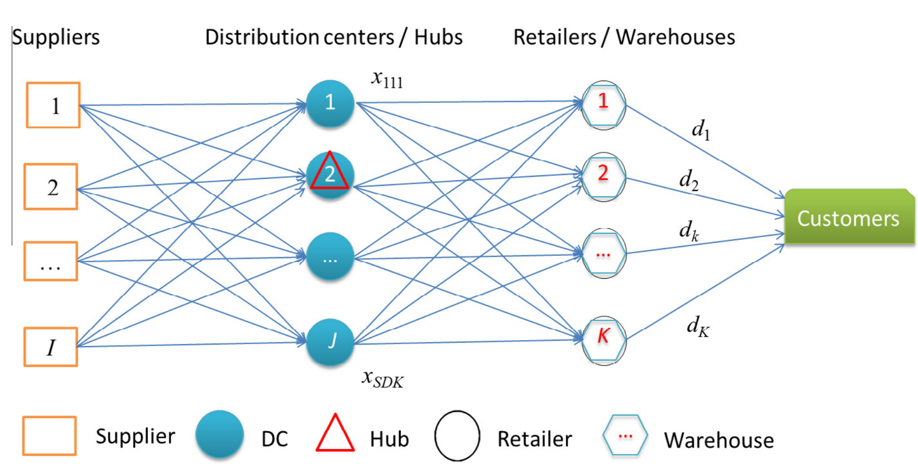

Fig. 1. A depiction of the logistics network structure.