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Retail supply chain network design under operational and disruption risks

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ABSTRACT

Designing robust and resilient retail networks under operational and disruption risks can create substantial competitive advantage. In this paper, a deterministic multiple set-covering model is first proposed. Then, it is extended to a possibilistic scenario-based robust model by scenario generation and disruption profiling to design a robust and resilient retail network. The developed models are validated through randomly generated examples and a real case study in retailing. Numerical results demonstrate that designing retail chains without considering operational and disruption risks is really misleading. Also, multiple covering of retail stores as the measure of redundancy increases the network's resilience significantly.

1. Introduction

The Supply Chain Network Design (SCND) problem involves several strategic decisions such as determining the number, location, and capacity of required facilities to provide requested supplies to given customer zones in a timely and efficient manner. When designing a Supply Chain Network (SCN), the anticipation of production, warehousing, distribution, transportation and demand management decisions (associated with costs) as well as the revenues and service levels are required (Klibi et al., 2010).

One of the main factors contributing to the complexity of the SCND problems is the long-term impact of design decisions. Supply facilities in SCNs are selected to last for several years. Therefore, it is not sufficient to consider parameters, especially critical ones (such as demands), only in business-as-usual situations. Additionally, extreme events caused by natural or man-made disasters might have serious effects on the capabilities of a SCN (Klibi and Martel, 2011). Tang (2006) defines two categories of risks in supply chains. The first is operational risks arising from business-as-usual incidents, such as machine breakdowns and power outages which lead to uncertainties in matching supply and demand. Operational risks are usually captured through incorporating such inherent uncertainties in the input data (e.g. uncertain customer demand, uncertain supply capacity, and uncertain costs) due to dynamic and fluctuating nature of these parameters over the time. The second category is disruption risks, which arises from natural and man-made disasters such as earthquakes, floods, hurricanes, terrorist attacks, etc. Disruption risks are usually captured by incorporating disruption scenarios in the model formulation of

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underlying decision problem since they are unlikely to occur, but have a high impact when they do occur. However, accounting for possible variations in the critical data over a long term horizon (i.e. operational risks) as well as disruption risks is essential to make the designed SCN viable in the competitive environment (Bashiri et al., 2012).

Retailing is one of the main business sectors in urban areas whose business continuity (BC) is crucial, especially during emergencies. Unexpected disruptions, such as those that might occur during natural disasters in incoming shipments to stores, may impose ever-lasting detrimental effects on the continuity of retail networks (Oke and Gopalakrishnan, 2009). In these situations, it is critical for retailing managers to be able to distribute supplies rapidly from their unaffected supply facilities to undisrupted retail stores, especially those in affected areas, in an efficient and effective manner. However, the optimal retail network under normal operating conditions may not be optimal or even feasible under these circumstances. This motivates the need to optimize a retail network under uncertain input data and disruption risks.

The retail SCND problem is a complex optimization problem. In order to ensure having an efficient and effective supply flow along the network, the supply facility locations and demand coverage pattern must involve several factors and criteria, such as capacity, reliability, and accessibility of supply facilities, while accounting for uncertainties in parameters and possible partial or complete disruption of the network's facilities, vehicles, etc. In this paper, a mixed integer linear programming model (MILP) is developed for making the best decisions about the locations of supply facilities (which will supply several retail stores), demand coverage pattern (i.e., allocation of retail stores to supply facilities), and the number of required vehicles of different types (such as trucks, vans and helicopters) in the retail chain. Moreover, robustness and resilience measures are incorporated in the formulated model.

The remainder of this paper is organized as follows. In Section 2, the literature on the retail SCND problem is reviewed. Section 3 provides the problem description and formulation. In this section, a deterministic version of multiple set-covering model (MSCM) is first developed and then it is extended to a possibilistic scenario-based model in order to incorporate mixed possibilistic-random uncertainties of input data in the original MSCM. In Section 4, a hybrid solution procedure is proposed to solve the extended MSCM under mixed uncertainty. In Section 5, the developed models are validated through randomly generated test problems and a real case study in retailing. Managerial insights evolved from this study are provided in Section 6. Finally, Section 7 concludes the paper and introduces avenues for further research.

2. Literature review

A review of SCND problems by Klibi et al. (2010) shows that although disruptions are the main source of most SCN deficiencies; they have been ignored by most businesses in the past. However, the current literature trend shows a growing interest in the effect of disastrous events on SCND problems (Kleindorfer and Saad, 2005; Sheffi and Rice, 2005; Wagner and Bode, 2008; Wagner and Neshat, 2010; Chopra and Sodhi, 2012). Craighead et al. (2007) discussed that the severity of disruptions is directly related to the supply chains' density, complexity and nodes criticality. Furthermore, the complex nature of supply chains as well as dynamic and chaotic business environment in which supply chains operate impose a high degree of uncertainty in supply chain planning decisions which significantly affects their overall performance (Klibi et al., 2010). Also, in the most recent classification of SCND problems by Farahani et al. (2014), lack of incorporating uncertainties in SCN models is criticized. To address the aforementioned gaps in the retail supply chains, a novel decision model is developed at this paper in which operational and disruption risks are simultaneously taken into account.

Several research works have used different SCN measures, including robustness (Dong, 2006; Snyder et al., 2006) and resilience (Sheffi and Rice, 2005; Gong et al., 2014), to value network stability in a perturbed business environment. According to Klibi et al. (2010), robustness is "*the quality of a SCN to remain effective for all plausible futures,*" and resilience is "*the capability of a SCN to avoid disruptions or quickly recover from failures.*" To the best of our knowledge, there is no SCND model in the literature that considers these two measures concurrently. By incorporating robustness and resilience measures in the decision model we aim to fill this gap.

The concept of robustness in SCND is concerned with solution and feasibility robustness. A generic definition found in the literature defines robustness as the ability of a SCN to function in a variety of future scenarios (Dong, 2006; Snyder et al., 2006). Recently, Baghalian et al. (2013) have developed a model for designing a robust multi-product supply network that considers uncertain capacities of producers, distributers, and retailers in the marketplace. Solution robustness and model robustness as the two important features of a robust model are used in this paper to enhance the functionality of the model against possible future scenarios.

Resilience strategies aim to mitigate the operational and disruption risks that are threatening the structure and continuous operations of a SCN. There are several proactive and reactive strategies to improve supply chain resilience including incorporating of backup and redundancy measures, investing in the reliability improvement of existing facilities (i.e., fortification), and assuring rapid post-disruption recovery through implementing Business Continuity Management Systems (BCMS) (Li and Savachkin, 2013; Torabi et al., 2014; Sahebjamnia et al., 2015). Investing in flexible network structures by incorporating redundancy measures is one of the most commonly used strategies. An example of this is the selection of backup suppliers used if primary suppliers are disrupted. The trade-off between supply chain resilience and cost efficiency is also well acknowledged in the literature (Sheffi and Rice, 2005). For example, it is often costly to keep flexibility and redundancy through prepositioned safety stocks (Sawik, 2013, 2014), backup suppliers (Meena and Sarmah, 2013), and extra backup sites. On the other hand, a lack of enough resilience may lead to several difficulties including interruptions in supply