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Responsive and resilient supply chain network design under operational and disruption risks with delivery lead-time sensitive customers

Mohammad Fattahi [b], Kannan Govindan [a,*], Esmaeil Keyvanshokooh [c]

[a] Center for Engineering Operations Management, Department of Technology and Innovation, University of Southern Denmark, Campusvej 55, Odense, Denmark
[b] School of Industrial Engineering and Management, Shahrood University of Technology, Shahrood, Iran
[c] Department of Industrial and Operations Engineering, The University of Michigan, Ann Arbor, MI, USA

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ABSTRACT

We address a multi-period supply chain (SC) network design where demands of customers depend on facilities serving them based on their delivery lead-times. Potential customer demands are stochastic, and facilities' capacity varies randomly because of possible disruptions. Accordingly, we develop a multi-stage stochastic program, and model disruptions' effect on facilities' capacity. The SC responsiveness risk is limited and, to obtain a resilient network, both mitigation and contingency strategies are exploited. Computational results on a real-life case study and randomly generated problem instances demonstrate the model's applicability, risk-measurement policies' performance, and the influence of mitigation and contingency strategies on SC's resiliency.

1. Introduction

Over the recent years, a large number of corporations have respected responsiveness goals besides economic ones while designing their supply chain (SC) network. In accordance with Gunasekaran et al. (2008), a responsive SC is able to adapt itself to the alteration of customer needs and fluctuations of target market. In order to design a responsive SC network, most optimization models defined some objective functions related to SC responsiveness such as minimizing lateness of products' delivery, minimizing customers' service time, and maximizing fill rate of customers' demands in addition to economic objectives. However, in this paper, we extend the responsive supply chain network design (SCND) problem in such a way that customers are sensitive to the delivery lead-time.

Our responsive SCND framework can apply to a company that operates a set of facilities including manufacturing plants and warehouses. Assuming a multi-period planning horizon, each customer zone should be allocated to one facility at the beginning of each time period. A facility serving a customer zone directly affects the delivery lead-time of products, which contains processing time at this facility and transportation time of products to the customer. Thus, the customers' demands are dependent on the facilities to which the customer zones are assigned. Accordingly, the responsiveness of a SC is defined as a percentage of potential demands of customer zones, which can be satisfied by the SC.

* Corresponding author.
E-mail addresses: mohammadfattahy@shahroodut.ac.ir (M. Fattahi), kgov@iti.sdu.dk (K. Govindan), keyvan@umich.edu (E. Keyvanshokooh).

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The critical motivation of our study is its broad applications in several manufacturing industries (e.g., automobile, cellphone, and computer) and on-line retail companies for which one of the most important issues is the response time to customers, which affects directly their demand quantity. Practical surveys demonstrated that delivery lead-time between the placement of an order and its delivery has key influence on the purchase of automobile (Holweg and Pil, 2001). In this regard, in the UK, more than 60% of customers would prefer their automobile to be delivered within 14 days of their order. Moreover, in many industries the customers of a company are the other manufacturing corporations, which utilize the final products of the company in their production processes. In such a situation, if these manufacturing firms have small storage capacity, they would prefer to meet their needs from the suppliers with shorter delivery lead-time. Cheong et al. (2005) highlighted the significance of this issue for the textile dye companies whose customers are textile mills. In making the inventory decisions in particular when many entities of SC coordinate with each other, the importance of delivery lead-time has been addressed broadly in the literature of tactical supply chain planning (see e.g., Bandaly et al., 2016; Heydari, 2014). However, the main purpose of this study is strategic supply chain planning when the demand of customers depends on the delivery lead-time. In such a business environment, proposing a model to simultaneously make location, capacity and distribution decisions would be useful for today's companies. Recently, Correia and Melo (2016) considered the impact of customer sensitivity to the delivery lead-time in a multi-period facility location problem. To this aim, they divided customers into two segments based on their sensitivity to the delivery lead-time. Further, the significance of the delivery lead-time on customers' motivation to buy at on-line retail companies and their willingness to pay has been described by Agatz et al. (2008).

On the other hand, strategic decisions such as location and capacity for a SC network should have a well performance for many years or decades under uncertain environment (Snyder, 2006). Tang (2006), according to the source of uncertainties, categorized existing risks in SCs into operational and disruption. Inherent uncertainties in some parameters such as demand, supply, costs, and lead-time cause the operational SC risks. Nonetheless, the disruption risks are caused as a result of man-made or natural disasters. It is worth noting that functionality of SC components such as facilities and transportation links can be affected by disruption risks, either partially or completely over an undefined time (Snyder et al., 2016). In this paper, both operational and disruption risks are considered in designing a responsive SC network, which has been rarely addressed in the related literature. Here, the potential demands of customer zones for different products are stochastic. Further, the capacity of SC warehouses varies randomly due to a variety of possible disruptions.

As pointed out by Heckmann et al. (2015), the literature on SCND with disruptions has not yet addressed time-aspects of this issue in depth. Nonetheless, disruptions affect the performance of a SC for a long time. Hence, in this paper, a generic approach for modeling the impacts of disruptions on the facilities' capacity is developed, which takes into account the required time for recovery of facilities after the occurrence of disruptions. Further, a multi-stage stochastic program (MSSP) is presented, with the help of which not only the strategic design decisions can be made, but also the affected SC network can respond to disruption events and preserve the SC responsiveness as well. It should be mentioned that since the uncertainty related to stochastic parameters has been realized progressively in each time period, multi-stage stochastic programming is utilized as a suitable optimization tool (Laporte et al., 2015).

One of the major challenging issues in MSSPs is generating a multivariate scenario tree for stochastic parameters and obtaining associated probabilities of scenarios. On the other hand, a large number of scenarios can lead to a large-scale optimization problem. Even if a small set of scenarios is chosen, this results in limited situations under which decisions are evaluated. In this perspective, there exist different types of scenario generation and reduction techniques in Stochastic Programming community that have not been applied yet in the area of SCND. In this paper, scenarios are generated using a simulation approach and then a forward scenario construction method, presented by Dupačová et al. (2003), is used to create an appropriate scenario tree. This procedure leads to an efficient set of scenarios with the in-sample and out-of-sample stability.

Several assorted sources of uncertainty can be included in SCND models. Uncertainties in data and parameters require decision makers to determine robust design decisions and/or find a way to measure and optimize the related risks corresponding to these decisions. In the relevant literature, a few papers (e.g., Govindan and Fattahi, 2017; Nickel et al., 2012) utilized well-known risk measures for alleviating the risks based on SC economic objectives, such as SC cost or profit. However, in this paper, the risk associated with SC responsiveness as a strategic goal is measured by using a well-known risk measure. Additionally, we limit the level of responsiveness risk by adding risk constraints into our optimization model.

Further, there are a number of strategies utilized by SCs to manage the risk associated with major disruptions and obtain a resilient SC. These strategies can be classified into two groups. Mitigation strategies are preventive activities performed in advance of a disruption no matter a disruption happens or not. However, when a disruption occurs, contingency strategies are conducted to return the SC to its initial condition (Tomlin, 2006). To this aim, we consider a mitigation strategy in which some SC facilities are chosen during the design phase to be fortified against disruptions. In addition, as a contingency strategy, allocation decisions of customers to facilities can be modified after a disruption occurrence to maintain SC responsiveness level using the multi-stage stochastic programming. We examine the performance of these strategies through extensive computational studies.

In this paper, a three-level SC network including production plants, warehouses and customer zones is presumed. We develop a novel MSSP in which the location of warehouses is determined at the beginning of a multi-period planning horizon and then allocation decisions of customers to warehouses/production plants as a tactical decision are made before realization of uncertainty at each time period. The goal is to minimize SC costs and limit the responsive risk of SC via imposing some constraints as well. To demonstrate the applicability of our proposed optimization approach from different perspectives, a