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Robust and reliable forward–reverse logistics network design under demand uncertainty and facility disruptions

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ABSTRACT

There are two broad categories of risk, which influence the supply chain design and management. The first category is concerned with uncertainty embedded in the model parameters, which affects the problem of balancing supply and demand. The second category of risks may arise from natural disasters, strikes and economic disruptions, terroristic acts, and etc. Most of the existing studies surveyed these types of risk, separately. This paper proposes a robust and reliable model for an integrated forward–reverse logistics network design, which simultaneously takes uncertain parameters and facility disruptions into account. The proposed model is formulated based on a recent robust optimization approach to protect the network against uncertainty. Furthermore, a mixed integer linear programing model with augmented *p*-robust constraints is proposed to control the reliability of the network among disruption scenarios. The objective function of the proposed model is minimizing the nominal cost, while reducing disruption risk using the *p*-robustness criterion. To study the behavior of the robustness and reliability of the concerned network, several numerical examples are considered. Finally, a comparative analysis is carried out to study the performance of the augmented *p*-robust criterion and other conventional robust criteria.

1. Introduction

The need for managing integrated logistics is widely recognized due to the importance of the productivity and customer satisfaction. Designing robust logistics networks helps firms to maintain and enhance the competitive advantages as they encounter with the growth of the environmental turbulence. To address this issue, a part of literature is focused on the configuration of a forward–reverse logistics network design because of the existing legal requirements, environmental protection and related economic benefits [1]. The activities and processes such as production and distribution are planned in the forward network, while the activities and processes like collection, inspection, recovery and disposal of the used products are carried out in the reverse network. Since the performance of both forward and reverse flows are interrelated, to avoid the sub-optimality arising from the separate design of forward and reverse networks, designing integrated logistics networks is highly recommended [1,2].

There are two wide categories of risk that impress the supply chain design: (1) the risk originating from the difficulties in coordinating supply and demand, and (2) the risk originating from a threat of disruptions to normal activities, which includes the issues related to the natural disasters, strikes, economic disruptions, and terroristic acts [3].

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The first category of risks is studied in the large body of supply chain literature. The existing uncertainties in the demand, lead times, transportation costs, the quantity and quality of returned products refer to this category of risks. The stochastic programing is an efficient tool used for considering the uncertain parameters [4]. For instance, a scenario-based stochastic programing and a multi-stage stochastic programing are developed to design integrated forward–reverse logistics networks [1,5]. A robust optimization (RO) can be considered as an alternative approach for dealing with the first category of risk in the case where there is no enough historical data to estimate the probability distribution of the uncertain parameters. Three of the most recent RO approaches are introduced by Mulvey et al. [6], Ben-Tal and Nemirovski [7–9], and Bertsimas and Sim [10,11]. Pishvaee et al. [12] and Hasani et al. [13] considered the RO approach developed by Ben-Tal and Nemirovski [7–9] to design robust closed-loop supply chain networks.

Kleindorfer and Saad [3] suggest that the second category of risks may originate from different sources. The authors categorize disruption risk sources in three groups: (1) operational contingencies, (2) natural hazards such as earthquakes, hurricanes and storms, and (3) terrorism and political instability. Most of the studies assume that facilities are always available. However, sometimes facilities may be unavailable due to the threat of the disruptions. As highlighted by Peng et al. [14], the disruption risks may lead to both negative financial effects and serious operational consequences, i.e., higher transportation costs, order delays, inventory shortages, loss of market shares, and, etc. Therefore, it is important that disruption risks be carefully considered when configuring of supply chain networks.

The existing studies just can cope with one category of risks, while this paper proposes a robust and reliable model for an integrated forward–reverse logistics network design that deals with both types of the supply chain risks. To the best of our knowledge this is a first attempt for doing so. Furthermore, it is worth pointing out that it is the first study which takes the issue of reliability into account for designing an integrated forward–reverse logistics network. The Bertsimas and Sim' RO approach [10,11] is applied to model parameters' uncertainty, and a robust optimization method with *p*-robust constraints is developed to deal with facility disruptions.

The rest of paper is organized as follows. The related literature is reviewed in Section 2. In Section 3, the studied problem is defined and formulated. The RO approach introduced by Bertsimas and Sim [11,12] is briefly explained in Section 4. The proposed robust and reliable model is elaborated in Section 5. The computational results are provided in Section 6. Finally, concluding remarks are discussed in Section 7.

2. Literature review

We review the concerned literature in two separate but complementary streams: robust logistics network design models and the models developed for dealing with disruption risks.

2.1. Robust logistics network design models

There are many logistics network design models inspired by facility location theory. Melo et al. [15] provide a comprehensive review on the facility location models in the context of strategic supply chain planning. A wide range of literature is concerned with the forward logistics network design problem. The forward network is configured from suppliers to customers through the direct and forward flows of goods among production and distribution centers, and customers. A small part of literature deals with the reverse logistics network design aimed to determine the collection, recovery and disposal centers and the optimal reverse flow among them. In order to avoid sub-optimality, designing integrated forward–reverse logistics networks are recommended [1,2].

All activities in both reverse and forward logistics are clearly subject to remarkable uncertainties. To deal with uncertainties, Listes and Dekker [16] propose a stochastic mixed integer programming model with several scenarios to design a reverse network. Listes [17] develop a stochastic model for a network design problem. Salema et al. [18] propose a stochastic mixed integer programming for multi-product networks to deal with demand uncertainty. Ding et al. [19] develop a stochastic simulation based optimization approach to design a production–distribution network. Lee and Dong [20] introduce a two stage stochastic programming to take uncertainty into account in a dynamic reverse logistics. A sample average approximation with a simulated annealing-based heuristic algorithm is adopted to solve the problem. A two-stage stochastic programming model is proposed for a paper recycling reverse logistics network design under uncertainty [21]. The authors use the commercial software to solve the proposed mixed-integer linear programming problem.

They are some research works addressing the problem of integrated logistics network design in which some parameters are subject to uncertainty. In this line of research, Pishvaee et al. [1] propose a scenario-based stochastic programming for an integrated forward–reverse logistics network design under demand, quantity and quality return rate and variable cost uncertainty. El-Sayed et al. [5] develop a stochastic mixed integer linear programming (SMILP) for designing a forward–reverse logistics under demand uncertainty. They consider a multi-period integrated network including suppliers, facilities and distribution centers in the forward flow and disassembly, and redistribution centers in the reverse flow. Ramezani et al. [22] introduce a multi-objective stochastic model for designing a forward–reverse logistic network, which optimizes three objective functions namely the profit, the customer responsiveness, and the quality level.