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Technical paper

A stochastic optimization model for integrated forward/reverse logistics network design

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ABSTRACT

In this paper, we develop a stochastic programming model for an integrated forward/reverse logistics network design under uncertainty. First, an efficient deterministic mixed integer linear programming model is developed for integrated logistics network design to avoid the sub-optimality caused by the separate design of the forward and reverse networks. Then the stochastic counterpart of the proposed MILP model is developed by using scenario-based stochastic approach. Numerical results show the power of the proposed stochastic model in handling data uncertainty.

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1. Introduction

Nowadays, the emphasis on productivity and customer satisfaction leads firms to focus on the supply chain and integrated logistics. Thus, an effective, efficient and robust logistics network becomes a sustainable competitive advantage for firms and helps them to cope with increasing environmental turbulence and more intense competitive pressures.

Along the same lines, because of legal requirements, environmental protection and also related economic benefits, an increasing number of companies such as General Motors, Kodak and Xerox focused on reverse logistics and recovery activities and they have achieved significant successes in this area [1,2].

One of the most important and strategic issues in supply chain management is the configuration of the logistics network that has a significant effect on the total performance of the supply chain. A logistics network is a network of suppliers, production, distribution centers and the channels between them and customers organized to acquire raw materials, convert these raw materials to finished products, and distribute final products in an efficient way to customers. Logistics network design decisions include determining the numbers, locations and capacities of facilities and the quantity of flow between them [3].

In most of the past researches the design of forward and reverse logistics networks is considered separately, but the configuration of the reverse logistics network has a strong influence on the forward logistics network and vice versa. Separating the design may result in sub-optimality, therefore the design of the forward and reverse logistics network should be integrated [4].

Another major drawback in most past researches is the assumption that the critical parameters such as demand and returned products are deterministic, whereas the design and establishment of the logistics network is a strategic decision whose effect will last for several years, during which the parameters of the business environment (e.g. demand of customers) may change [5]. Thus some critical parameters such as customer demand are quite uncertain. Especially in reverse logistics the quantity and quality of returned products have a high degree of uncertainty even in a short period of time. Therefore, the logistics network should be designed in a way that it could handle the uncertainty in parameters; otherwise the impact of uncertain parameters will be larger than necessary.

This paper offers an efficient stochastic MILP model for single period, single product, multi-stage integrated forward/reverse logistics network design that could support both recovery and disposal activities to cope with the uncertainty in the quantity and quality of returned products, demands and variable costs. Numerical tests show the power of the proposed stochastic model in handling uncertainty in parameters.

The remainder of this paper is organized as follows. After systematically reviewing the literature in Section 2, the problem is defined and an efficient MILP model is developed in Section 3. The stochastic counterpart of the proposed model is developed in Section 4 and the numerical results are reported in Section 5. Section 6 concludes this paper and presents directions for further research.

2. Literature review

Many models are developed for logistics network design based on facility location theory. These models range from simple uncapacitated facility location models (e.g. [6]) to complex

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Table 1
Review of some existing models.

Reference articles	Uncertain parameters	Type of network			Modeling				Objectives		
		Forward	Reverse	Integrated	MILP	MINLP	SMILP	MIGP	Min cost/Max profit	Max responsiveness	Others
Krikke et al. [10]	–		•		•				•		
Jayaraman et al. [11]	–		•		•				•		
Yeh [6]	–	•			•				•		
Listes and Dekker [12]	I, QnR		•				•		•		
Amiri [3]	–	•			•				•		
Altiparmark et al. [9]	–	•				•			•	•	
Üster et al. [2]	–		•		•				•		
Salema et al. [13]	D, QnR, TC		•				•		•		
Ko and Evans [14]	–			•					•		
Lee and Dong [4]	–			•	•				•		
Du and Evans [7]	–		•		•				•	•	
Patia et al. [15]	–		•					•	•		•
Aras et al. [17]	–		•			•			•		
El-Sayed et al. [16]	D, QnR			•			•		•		
Our work	D, TC, QnR, QlR			•			•		•		

D: Demand; TC: Transportation Costs; QnR: Quantity of Returns; QlR: Quality of Returns; I: Income.

capacitated multi-objective models (e.g. [7]). Melo et al. [8] present a comprehensive review on logistics network design to support a variety of future research directions. In this paper, we survey specific network design problems for forward, reverse and integrated logistics network design problems. A large part of the literature in logistics network design is related to forward logistics network design aimed to determine the configuration of a directed network from suppliers to customers, including production and distribution centers. A smaller part of the literature is associated with reverse logistics network design aimed at determining the number of collection, recovery and disposal centers, their location and capacities, and the optimized reverse flow from customers to recovery and disposal centers. Also, in recent years a few papers have attended to integrated logistics network design. In the integrated paradigm, the objective is to integrate the forward and reverse network design decisions to avoid the sub-optimality resulting from separated design.

In the area of forward logistics network, as a traditional part of logistics network design problems, many models have been developed for various kinds of networks. Yeh [6] proposes a MILP model for a production–distribution network. An efficient hybrid heuristic is developed to solve the intractable model. Most of research in logistics network design was often limited to considering a single capacity level for each facility and often did not address how capacity levels can be determined. Amiri [3] develops a MILP model for a multi-stage forward network and also considers multiple capacity levels for each facility. Besides determining the number and location of facilities, the model is able to find the optimal capacity level for each facility.

The increasing importance of network responsiveness in recent years caused a significant tendency to responsive logistics network design. To this aim Altiparmak et al. [9] develop a multi-objective MINLP model for forward logistics network design. They propose a multi-objective genetic algorithm based on a priority-based encoding method to solve the model.

In the context of reverse logistics various models have been developed in the last decade. Krikke et al. [10] designed a MILP model for a two-stage reverse supply chain network for a copier manufacturer. In this model processing costs of returned products and inventory costs are noticed in the objective function for minimizing the total cost. Jayaraman et al. [11] developed a model to solve the single product two-level hierarchical location problem involving the reverse supply chain operations of hazardous products. They also developed a heuristic to handle relatively large size problems.

Demand uncertainty and also uncertainty in the quantity and quality of returned products is an important factor in designing reverse supply chain networks. According to this fact, Listes and Dekker [12] proposed a stochastic mixed integer programming (SMIP) model in a sand recycling network to maximize the total profit. They developed their model for different situations regarding several scenarios. Salema et al. [13] developed a stochastic model for multi-product networks under demand uncertainty using stochastic mixed integer programming.

In recent years a few researchers aimed to develop models for integrated logistics network design to avoid the sub-optimality associated with separate design of forward and reverse networks. Ko and Evans [14] presented a MINLP model for the design of a 3PL dynamic integrated forward/reverse logistics network. They developed a genetic algorithm-based heuristic to solve the complex developed model. Lee and Dong [4] developed a MILP model for integrated logistics network design for end-of-lease computer products. They considered a simple network with a single production center and a given number of hybrid distribution–collection facilities to be opened which they solved using tabu search. Patia et al. [15] proposed a mixed integer goal programming (MIGP) model to assist in proper design of a multi-product paper recycling logistics network. The model studies the inter-relationship between multiple objectives of a recycled paper distribution network. The considered objectives are reduction in reverse logistics cost; product quality improvement through increased segregation at the source; and environmental benefits through increased wastepaper recovery. Finally, El-Sayed et al. [16] present a SMILP model for integrated forward/reverse logistics network design under demand and return uncertainty. The objective is maximizing total profit.

A more detailed classification of the literature is illustrated in Table 1 by considering three characteristics: uncertainty in parameters, type of network and modeling. The characteristics of the problem that will be discussed in this paper are presented in the last row of Table 1. As shown in Table 1 the main differences of the problem in question compared to those discussed in the literature are the integrated design of forward and reverse logistics and also considering uncertainty in the quality of returned products besides in the quantity of them.

3. Problem definition and formulation

The integrated logistics network (ILN) discussed in this paper is a single period, single product, multi-stage logistics network

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