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A stochastic model for forward–reverse logistics network design under risk

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ABSTRACT

Attention with reverse logistics networks has increased during the last decade since their economic impact has been increasingly important and as environmental legislation has been becoming stricter. In this paper, *A multi-period multi-echelon forward–reverse logistics network design under risk model* is developed. The proposed network structure consists of three echelons in the forward direction, (suppliers, facilities and distribution centers) and two echelons, in the reverse direction (disassembly, and redistribution centers), first customer zones in which the demands are stochastic and second customer zones in which the demand is assumed to be deterministic, but it may also assumed to be stochastic. The problem is formulated in a stochastic mixed integer linear programming (SMILP) decision making form as a multi-stage stochastic program. The objective is to maximize the total expected profit.

1. Introduction

A reverse logistics network establishes a relationship between the market that releases used products and the market for "new" products. When these two markets coincide, then it is called a closed loop network, otherwise it is called an open loop network (Salema, Barbosa Póvoa, & Novais, 2007a). Very few optimization models for the design of supply chains with reverse flows are available in literature under uncertainty using scenarios to solve the model as uncertainty makes MILP models very hard to solve (Salema, Barbosa Póvoa, & Novais, 2005).

A facility location-allocation model for the collection, reprocessing and redistribution of carpet waste was presented by Louwers, Bert, Edo, Frans, and Simme Douwe (1999) to determine the locations and capacities of the regional recovery centers to minimize investment, processing, and transportation costs.

A generic stochastic model for the design of networks comprising both supply and return channels, organized in a closed loop system was presented by Listes (2002). This model considers one echelon forward network combined with two echelon reverse network. The uncertainty is handled in a stochastic formulation by means of discrete alternative scenarios.

A cost-minimization model for a multi-time-step, multi-type hazardous-waste reverse logistics system was presented by Hu, Sheu, and Huang (2002).

A stochastic programming model and solution algorithm for solving supply chain network design problems of a realistic scale was proposed by Santoso, Ahmed, Goetschalckx, and Shapiro (2005). The proposed solution methodology integrates a recently proposed sampling strategy, the sample average approximation scheme, with an accelerated Benders decomposition algorithm to quickly compute high quality solutions to large-scale stochastic supply chain design problems with a huge (potentially infinite) number of scenarios.

A strategic and tactical model for the design and planning of supply chains with reverse flows was proposed by Salema et al. (2007a). The authors considered the network design as a strategic decision, while tactical decisions are associated to production, storage and distribution planning.

A general reverse logistics location allocation model was developed by El Saadany and El-Kharbotly (2004) in a mixed integer linear programming (MILP) form. The model behavior and the effect of different reverse logistics variables on the economy of the system were studied. Demand in this proposed model is deterministic.

A carpet reverse logistics supply chain was simulated by Biehl, Edmund, and Matthew (2007) and used a designed experiment to analyze the impact of the system design factors as well as environmental factors impacting the operational performance of the reverse logistics system.

A stochastic approach to the case study of recycling sand from demolition waste was proposed by Listes and Dekker (2005). In this approach, the uncertainty is related to the demand sources and quality, i.e. from which locations the sand to be recycled is originated and its characteristics.

A MILP model for the design and planning of an integrated forward and reverse chain was proposed by Salema et al. (2005).

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Salema, Barbosa Póvoa, and Novais (2007b) studied the design of a reverse distribution network and found that most of the proposed models on the subject are case based and, for that reason, they lack generality. The model contemplates the design of a generic reverse logistics network where capacity limits, multi-product management and uncertainty on product demands and returns are considered. A mixed integer formulation is developed. This formulation allows for any number of products, establishing a network for each product while guaranteeing total capacities for each facility at a minimum cost. But the inventory was not taken into consideration. An illustrative case is presented, which allowed the model generality to be corroborated within very satisfactory computational times.

In present work, a multi period multi echelon forward–reverse logistics network model is developed for design purposes under risk. The problem is formulated in a stochastic mixed integer linear programming (SMILP) decision making form as a multi-stage stochastic program. The objective of the model is to maximize the total expected profit. Decisions are taken to determine the following:

- Suppliers, facilities, distribution centers, disassembly, and redistribution centers locations,
- Production at each location (what and how much to produce),
- Transported quantity of goods between locations, and
- Quantity of goods to hold as inventory at each period.

2. Model description

The model is a formulation for the forward–reverse logistics network design problem. The network is a multi-period multi-echelon, where it consists of suppliers, facilities, distributors, and first customers in the forward direction. In the reverse direction it consists of disassembly, disposal, redistribution locations and second customers, as shown in Fig. 1.

Costs incurred at different nodes are as follows:

(1) Suppliers:
These include investment fixed costs, materials costs, recycling costs, and transportation costs.
(2) Facilities:
These include investment fixed costs due to the opening of each facility, manufacturing costs, remanufacturing costs, non-utilized capacity costs, storage costs, and transportation costs.

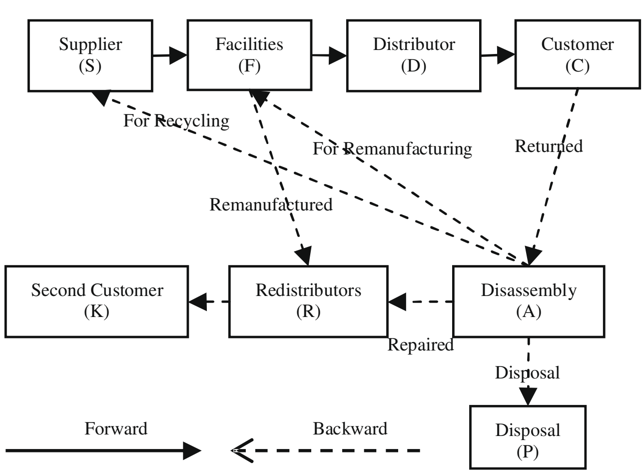

Fig. 1. The proposed forward–reverse logistics network.

(3) Distributors:
These include investment fixed costs due to the opening of each distributor, shortage costs, storage costs, and transportation costs.
(4) Disassembly locations:
These include investment fixed costs due to the operation of each disassembly location, returned price, disassembly, inspection and sorting costs, repairing costs, and transportation costs.
(5) Redistribution centers:
These include investment fixed costs due to the opening of each redistribution center, and transportation costs.
(6) Disposal locations:
These include investment fixed costs due to the opening of each disposal center, and disposal costs.

3. Model assumptions and limitations

The following are the assumptions considered in the present model:

1. The model is a multi-period.
2. Customers' locations are known and fixed with stochastic demands.
3. The returned quantities are stochastic and depend on the first customer demand.
4. The quality of remanufactured and repaired products is different from the new ones.
5. The potential locations of suppliers, facilities, distributors, disassemblies, and redistributors are known.
6. Costs parameters (fixed, material, manufacturing, non-utilized capacity, shortage, transportation, holding, recycling, remanufacturing, disassembly, and disposal costs) are known for each location and time period.
7. Capacity of each location is known for each time period.
8. The shortage cost depends on the shortage quantity and time.
9. The holding cost depends on the residual inventory at the end of each period.
10. Integer number of batches is transported.

4. Model formulation

The model involves the following sets, parameters and decision variables:

Sets:
S: potential number of suppliers, indexed by s.
F: potential number of facilities, indexed by f.
D: potential number of distributors, indexed by d.
C: potential number of first customers, indexed by c.
A: potential number of disassembly locations, indexed by a.
R: potential number of redistributors, indexed by r.
P: potential number of disposal locations, indexed by p.
K: potential number of second customers, indexed by k.
T: number of periods, indexed by t.

Parameters:
D_{ct} demand of first customer c in period t,
μ_{ct} demand mean of first customer c in period t,
σ_{ct} demand standard deviation of first customer c in period t,
D_{kt} demand of the second customer k in period t,
P_{ct} unit price at the first customer c in period t,
P_{kt} unit price at second customer k in period t,