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Stochastic reverse logistics network design for waste of electrical and electronic equipment

Berk Ayvaz[a], Bersam Bolat[b], Nezir Aydın[c,*]

[a] Department of Industrial Engineering, Istanbul Commerce University, Küçükyalı, Istanbul 34840, Turkey
[b] Department of Management Engineering, Istanbul Technical University, Besiktas, Istanbul 34367, Turkey
[c] Department of Industrial Engineering, Yıldız Technical University, Besiktas, Istanbul 34349, Turkey

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ABSTRACT

In recent years, Reverse Logistics has received increasing attentions in supply chain management area. The reasons such as political, economic, green image and social responsibility etc. force firms to develop strategies to their current systems. The aim of this study is to propose a generic Reverse Logistics Network Design model under return quantity, sorting ratio (quality), and transportation cost uncertainties. We present a generic multi-echelon, multi-product and capacity constrained two stage stochastic programing model to take into consideration uncertainties in Reverse Logistics Network Design for a third party waste of electrical and electronic equipment recycling companies to maximize profit. We validated developed model by applying to a real world case study for waste of electrical and electronic equipment recycling firm in Turkey. Sample average approximation method was used to solve the model. Results show that the developed two stage stochastic programming model provides acceptable solutions to make efficient decisions under quantity, quality and transportation cost uncertainties.

1. Introduction

In recent years, product recovery has received growing attention in the world, due to driving factors such as social, environmental, and economic reasons. The factors such as regulation pressure, economic, green image and social responsibility force firms to evolve strategies to their current systems. Many manufacturers have adapted the practice of recovering value from returned products and integrated product recovery activities into their processes (Lee and Dong, 2009). Reverse logistics (RL) is the concept of reusing used products to reduce wastes and to increase an industry's environmental performance (Diabat et al., 2013). In term of sustainability, RL can be defined as a business strategy that acts as the driving force of putting recovery activities in action effectively in order to increase sustainability.

The recovery options in RL are remanufacturing, repairing, refurbishing, cannibalizing, and recycling (Zhou and Wang, 2008). It is widely applicable for the products like computers, vehicle engines, electrical appliances, electronic equipment, copiers, single-use cameras, cellular phones, paper, carpets, plastics, medical equipment, tires, and batteries (Srivastava, 2008a; Sasikumar et al., 2010).

The reason of product return in the supply can be listed such as; manufacturing returns, commercial returns (B2B and B2C), product recalls, warranty returns, service returns, end-of-use returns, end-of-life returns. (De Brito, 2002; Du and Evans, 2008).

Decisions in RL can be taken for long-term such as those about facility location, layout, capacity and design; or medium term such as those related to integrating operations or deciding about which information and communication technologies systems support the return handling or short-term decisions about inventory handling, vehicle routing, remanufacturing scheduling, etc. (Srivastava, 2008b).

Studies in the literature associated with RL have been concluded on different aspects such as network design, return forecasting, economic and environmental performance, lot sizing, vehicle routing, etc. The design of product recovery networks is one of the challenging RL problems (De Brito, 2002; Chanintrakul et al., 2009).

A Reverse Logistics Network Design (RLND) is complicated by the needs for testing and grading of return products, addressing uncertainty of return products in terms of quantity, quality and supply timing, integrating and coordinating different forward and reverse flows. A high level of uncertainty is one of the characteristics of RL networks (Fleischmann et al., 2000). Especially the impact of uncertainty in terms of quantity, quality and

* Corresponding author. Tel.: +90 212 383 3029; fax: +90 212 258 5928.
E-mail address: nzraydin@yildiz.edu.tr (N. Aydın).

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timing is the most popular issue in RLND (Chanintrakul et al., 2009). Deterministic models for RLND lack the ability to incorporate such uncertainty factors as variances of return amount, timing, and lead time through the network (Lee, 2009). Kall and Wallace (1994) claim that stochastic programming techniques present more flexibility to cope with uncertainty. So, in order to deal with this uncertainty, researchers developed various stochastic models (Ilgin and Gupta, 2010).

The aim of this study is to propose a RLND model under return quantity, quality, and transportation cost uncertainties and solve with a well-known solution algorithm, Sample average approximation (SAA), for Stochastic Programming (SP) problems. We present a multi-stage, multi-echelon, multi-product and capacity constrained two stage stochastic programing model to take into consideration uncertainties in RLND. We validate the developed generic model by applying to a real world case study of waste of electric and the waste of electrical and electronic equipment (WEEE) third party recycling company in Turkey. SAA schema is applied in solution process. The contributions of this paper are as follows: First, this study is the first appliance, in WEEE literature for RLND under uncertain parameters, such as, amount of WEEE, quality of collected WEEE and transportation costs. Second, the RLND network is modeled as a SP model and it is solved by SAA. Third, the proposed model is a generic RLND for third party reverse logistic companies. Lastly, the proposed model is easy and effective to support establishing RLND decisions for managers and decision makers.

In the literature, many researchers showed increasingly interest in the RLND problem. Some of the studies are briefly explained as follows:

Barros et al. (1998) presented a multi-level capacitated facility location problem for sand recycling in the Netherlands. They developed a mixed integer program (MILP) model when the volume and the locations of the demand are uncertain. They determined the optimal number, capacities and locations of the depots and cleaning facilities for recycling sand from construction waste. Krikke et al. (1999) developed a MILP model for a multi-echelon RLND for a copier manufacturer in the Netherlands. Shih (2001) developed a MILP model for design of an optimal collection and recycling system for end-of-life computers and home appliances. Jayaraman et al. (2003) developed an MILP model as a two-echelon capacitated facility location problem with limited collection and refurbishing facilities. Heuristic methods were also developed to solve the model. Min et al. (2006) addressed the multi-echelon RLND problem for product returns and developed a single-objective, nonlinear mixed-integer programming model that determines the optimal number and locations of collecting points as well as centralized return centers while taking the shipping costs, closeness of the collection points and in-transit inventory into consideration. A genetic algorithm is developed to solve the problem. Lu and Bostel (2007) addressed a two-level location problem with three types of facility to be located in a specific reverse logistics system. For this problem, they developed mixed integer programming model, considering simultaneously “forward” and “reverse” flows. They used langrage heuristic to solve the problem. Pati et al. (2008) developed a mixed integer goal programming model. The model addressed the inter-relationship between multiple objectives of a recycled paper distribution network. The objectives were the reverse logistics cost, a non-relevant wastepaper target and a wastepaper recovery target. Du and Evans (2008) presented a bi-objective MILP model for designing a closed-loop logistics network for third-party logistics providers. The objectives of the model are the minimization of total costs and the tardiness.

Kannan et al. (2012) presented a mixed integer linear model for a carbon footprint based RLND. The developed model aims to minimize the costs involved in the reverse logistics network model, and it considers the carbon footprint involved both in transportation and reverse logistics operations (collection) costs. It employs reverse logistics activities to recover used products, hence including the location/transportation decision problem. The presented model is applied to a plastic sector. Achillas et al. (2012) presented multiple objective linear programming (MOLP). The main goal of a MOLP model is the weighted optimization of different objectives. The developed MOLP approach minimizes total logistics costs, consumption of fossil fuel and production of emissions.

The uncertainty is an important characteristic of product recovery (Fleischmann et al., 2000). Design of reverse and closed-loop supply chain networks involves generally high degree of uncertainty, especially associated with quality and quantity of the returned products, as well as the time, delay and location of recovery and redistribution (Chouinard et al., 2008; Ilgin and Gupta, 2010; Pishvaee et al., 2011). The quantity and quality of used products are more difficult to control and estimate (Qin and Ji, 2010). Diabat et al. (2013) developed a multi-echelon reverse logistics network for product returns to minimize the total reverse logistics cost, which consists of renting, inventory carrying, material handling, setup, and shipping costs. In their study, a mixed integer non-linear programming (MINLP) model is developed to find out the number and location of initial collection points and centralized return centers. Two solution approaches, namely genetic algorithm and artificial immune system, are implemented and compared. The usefulness of the proposed model and algorithm are illustrated by an illustrative example.

Listes (2002) presented a generic stochastic model for the design of networks organized in a closed loop system. 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. Listeş and Dekker (2005) proposed two formulations using stochastic optimization for the network design of recycling sand under demand and supply uncertainties. The first formulation is a two-stage stochastic optimization with locational uncertainty of demand. The second formulation involves both demand and supply uncertainty via a three-stage stochastic optimization model. Listeş (2007) presented a generic stochastic model for the design of integrated real-world RL network. They considered uncertainty under return quantity. The objective is to maximize profit. Decomposition method based on the branch-and-cut known as the integer L-shaped method is developed to solve the problem. Salema et al. (2007) developed a generic reverse logistics network model which includes multi-product management and uncertain product demands and returns. A mixed integer formulation is developed. They solve their model with standard branch-and-bound (BB) techniques rather than using a decomposition method. Chouinard et al. (2008) considered the uncertainties related with recovery, processing and demand volumes in a closed-loop supply chain design problem by developing a stochastic programming model. Sample average approximation-based heuristic is developed to solve the problem. Lee and Dong (2009) considered a stochastic approach for the dynamic RLND under demand and return uncertainties. A two-stage stochastic programming model is developed by which a deterministic model for dynamic RLND can be extended to consider uncertainties. Pishvaee et al. (2009) presented a stochastic programming model for single period, single product, multi-stage integrated forward/Reverse Logistics Network Design to cope with the uncertainty associated with the quantity and quality of returned products, demands and variable costs. First, an efficient deterministic MILP 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.