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Network modeling for reverse flows of end-of-life vehicles

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ABSTRACT

Product recovery operations are of critical importance for the automotive industry in complying with environmental regulations concerning end-of-life products management. Manufacturers must take responsibility for their products over the entire life cycle. In this context, there is a need for network design methods for effectively managing recovery operations and waste. The purpose of this study is to develop a mathematical programming model for managing reverse flows in end-of-life vehicles' recovery network. A reverse flow is the collection of used products from consumers and the transportation of these products for the purpose of recycling, reuse or disposal. The proposed model includes all operations in a product recovery and waste management network for used vehicles and reuse for vehicle parts such as collection, disassembly, refurbishing, processing (shredding), recycling, disposal and reuse of vehicle parts. The scope of the network model is to determine the numbers and locations of facilities in the network and the material flows between these facilities. The results show the performance of the model and its applicability for use in the planning of recovery operations in the automotive industry. The main objective of recovery and waste management is to maximize revenue and minimize pollution in end-of-life product operations. This study shows that with an accurate model, these activities may provide economic benefits and incentives in addition to protecting the environment.

1. Introduction

Increasing environmental and social concerns worldwide are motivating manufacturers and consumers to implement environmental protection strategies such as product recovery, waste management, and the use of recycled materials. Additionally, companies in many countries are required by law to take responsibility for their products over the entire life cycle. Such regulations are relevant for the automotive industry, which is one of the largest industries in the world. The automotive industry involves a series of supply chain operations involving many international parties to produce and deliver vehicles (Chan et al., 2012). In the production and the use of automobiles, damage to the environment can be minimized with new technologies. In addition, the design and the production of new vehicles and their parts and materials should facilitate disassembly, re-use, recovery and recycling of used vehicles. A circular economy and the recycling of automotive products must be promoted for sustainable development, and reduction, reuse and recycling operations must be implemented (Tian and Chen, 2014). To protect the environment and human health, the waste generated from vehicles should be reduced. Recycling, re-use, recovery or disposal must be enacted for discarded or end-of-life vehicles to reduce the harmful effects on the environment. All of these activities are included in reverse logistics, which is part of the green supply chain. In the early 1990s, Stock (1992) provided one of the first definitions of reverse logistics: "...the term often used to refer the role of logistics in recycling, waste disposal and management of hazardous materials; a broader perspective includes all issues relating to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal". Reverse logistics encompasses the logistics activities from used products no longer required by the user to products that can be sold and used again (Fleischmann et al., 1997). The importance of reverse logistics has increased in recent years because of the necessity for managing product recovery operations. The value of recycled parts from used vehicles containing metallic and non-metallic substances has also increased because of the global shortage of raw materials (Chen et al., 2010). Network design is one of the most important decisions in reverse logistics and is essential for efficient recovery, recycling and waste management.

The purpose of this study is to develop a mathematical model for optimizing end-of-life vehicles' recovery and waste management operations within the framework of a reverse logistics network design problem. The network design problem comprises the collection of vehicles from customers and the shipment of the vehicles to dismantling facilities for fluid removal and disas-

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sembly operations, shipping the hazardous fluids from dismantling facilities to disposal centers, shipping the reusable vehicle parts from dismantling facilities to secondhand markets, shipping the dismantled vehicle bodies to processing facilities for shredding, shipping the shredded materials to recycling centers for material recovery, and shipping the shredded hazardous materials to disposal centers. The purpose of the proposed network model is to provide decision support to practitioners of end-of-life vehicle recovery for end-of-life vehicles' reverse logistics network design problem by determining the numbers and the locations of facilities to be opened and the material flows between these facilities for real case applications. The remainder of this paper is organized as follows: Section 2 provides a literature review of the reverse logistics network design problem; Section 3 defines the reverse network design problem for the automotive industry; Section 4 presents the mathematical formulation of the reverse logistics network design problem for the automotive industry; in Section 5, results are presented, including test cases and an actual case to demonstrate the model; and in Section 6, a summary and conclusions are given.

2. Literature review

A number of researchers have investigated reverse flows of products with reverse logistics network design. Most of these studies used operations research techniques and heuristics algorithms to obtain solutions. Some of these studies are summarized as follows. Jayaraman et al. (2003) proposed a mathematical programming model for the reverse distribution problem, and because of the complexity of the model, they developed a heuristic solution methodology. Li et al. (2006) considered the problem of determining the numbers and the locations of reverse consolidation points. They proposed a stochastic nonlinear mixed integer programming model and used a genetic algorithm and a Monte Carlo method to solve the proposed model. Ko and Evans (2007) proposed a mixed integer nonlinear programming model for the design of a dynamic integrated forward/return distribution network for 3PLs, and they presented a genetic-algorithm-based heuristic. Salema et al. (2007) developed a mixed integer formulation for the design of a "capacitated" (capacity-limited), multi-product reverse logistics network with uncertainty for product demands and returns. Lee and Dong (2009) developed a two-stage stochastic programming model for reverse logistics network design and proposed a heuristic solution based on simulated annealing. Lee et al. (2009) formulated a mathematical model of a three-stage reverse logistics network. They considered return, disassembly and processing stages and used a genetic algorithm with priority-based encoding to obtain solutions. Cruz-Rivera and Ertel (2009) presented a network design model for the collection of end-of-life vehicles in Mexico. Reverse logistics modeling was achieved through an "uncapacitated" (unlimited capacity) facility location problem. Mutha and Pokharel (2009) developed a mathematical model for a reverse logistics network for product returns. The model determines the locations, the numbers and the storage capacities of reprocessing and remanufacturing facilities and the allocation of material flows between facilities and includes all network costs. Achillas et al. (2010) presented a decision support tool for optimizing a reverse logistics network for waste electrical and electronic products. The tool is based on a mathematical model in which the existing infrastructure consisting of collection points and recycling facilities is included. Pishvaee et al. (2010) developed a mixed integer linear programming model to minimize the transportation and fixed opening costs in a multi-stage reverse logistics network. The network included customer, collection/inspection, recovery and disposal stages and was designed for one product type. Sasikumar et al. (2010) developed a mixed integer nonlinear programming model for maximizing the profits of a multi-echelon reverse logistics network and presented an actual case study of truck tire remanufacturing for the secondhand market. Gomes et al. (2011) studied a recovery network for electrical and electronic products in Portugal and developed a mathematical model based on graph theory. Alumur et al. (2012) proposed a mixed integer linear programming model that maximizes reverse logistics network profits. Dat et al. (2012) developed a mathematical programming model that minimizes the total processing cost in a reverse logistics network for electrical and electronic products. The model determines the optimal locations of facilities and material flows in the network. Kannan et al. (2012) presented a mixed integer linear programming model for the design of a reverse logistics network based on the "carbon footprint". The objective of the model was to minimize both the total cost involved in the reverse logistics network and the emissions produced in processing and shipping. Das and Chowdhury (2012) developed a mixed integer programming model to maximize profit in modular product design by considering the collection of returned products, the recovery of components and the proportion of the product mix at various quality levels. Assavapokee and Wongthatsanekorn (2012) proposed a mixed integer linear programming model for designing the infrastructure of a reverse production system to support product recovery activities. The model was applied to a case study of end-of-life electronic products recovery in the state of Texas. Listeş and Dekker (2005) presented a stochastic programming based approach and applied the stochastic models to a case study concerning the recycling of sand. Dowlatshahi (2005) identified strategic factors that are necessary and critical for effective design and implementation of reverse logistics systems through the use of case studies. Several studies have used fuzzy set theory or analytical hierarchy processes for making reverse logistics decisions. Pochampally and Gupta (2008) proposed a three-phase fuzzy logic approach to the reverse supply chain network design problem. The authors selected the product to reprocess using fuzzy logic and employed an analytical hierarchy process (AHP) and fuzzy set theory for selecting the operating regions for recovery facilities, and they developed a mathematical model for a single-period, single-product network design. Tuzkaya et al. (2011) developed a multi-objective model and a two-stage methodology for the reverse logistics network design problem. In the first stage, an analytical network process (ANP) and a fuzzy TOPSIS methodology were used to evaluate centralized return centers. In the second stage, the reverse logistics network design problem was solved via a genetic algorithm. A number of studies have addressed forward and reverse supply chains with the closed-loop supply chain concept. Some examples are presented as follows. Lee and Dong (2008) considered the design of a logistics network for end-of-lease recovery of computer systems, and they developed a deterministic programming model for forward and reverse logistics flows and a two-stage heuristic solution method. Demirel and Gökçen (2008) developed a mixed integer programming model for designing a reprocessing system with forward and reverse flows. The system included collection, distribution and disassembly stages. Ramezani et al. (2013) developed a stochastic multi-objective model for forward and reverse logistics network design. They considered three echelons in the forward direction – suppliers, plants, and distribution centers and two echelons in the reverse direction – collection and disposal centers assuming an uncertain environment. Özkır and Başlıgil (2012) proposed a mixed integer linear programming model for optimizing the design of a closed-loop supply chain, and they performed a sensitivity analysis and Monte Carlo simulations to determine the quality and the quantity of returned products. Özceylan and Paksoy (2013) proposed a mixed integer linear programming model for multi-period and multi-part