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Integrated forward and reverse supply chain: A tire case study

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ABSTRACT

This paper attempts to integrate both a forward and reverse supply chain to design a closed-loop supply chain network (CLSC). The problem in the design of a CLSC network is uncertainty in demand, return products and the quality of return products. Scenario analyses are generated to overcome this uncertainty. In contrast to the existing supply chain network design models, a new application of a CLSC network was studied in this paper to reduce waste. A multi-product, multi-tier mixed integer linear model is developed for a CLSC network design. The main objective is to maximize profit and provide waste management decision support in order to minimize pollution. The result shows applicability of the model in the tire industry. The model determines the number and the locations of facilities and the material flows between these facilities.

1. Introduction

With the rapid changes in technology and the subsequent reduction in the life cycle of products, consumers produce more wastes and disposable products. This has led to serious environmental problems, such as rapid depletion of resources, production of more toxic and non-toxic waste, air and water pollution, and climate change. To highlight the waste and environmental problems and propose a solution for such problems, tires are used as one of the main sources of waste generation. Statistics show that over 1,000,000 tons of scrap tires are disposed off annually throughout the world; for instance over 600,000 tons per year in Germany (Lebreton and Tuma, 2006) and the equivalent to 250,000 tons per year in France (Ferrer, 1997), which indicates the potential for an enormous disposal problem that causes health hazards and environmental damage (Jang et al., 1998). The carbon black and rubber, which are part of tire contents, make tires unfit for landfill disposal.

A deeper look into the tire structure reveals great opportunities for retreading. A generic tire is composed of two parts: the casing and tread (Fig. 1). With prolonged usage, the surface of tire or tread wears out and tends to become flat as a result of being in contact with the road surface. This makes the tire unsuitable for road use because of reduction of brake performance and adherence. The casing of returned tires is less likely to have significant damage. Thus, there are opportunities for replacing the worn tread with a new one and reducing waste. In addition, a life cycle assessment of new tire production and tire retreading highlights the fact that production of new tires consumes four times more materials than the production of retreaded tires. Furthermore, energy usage for producing a new tire is three times higher than that for a retreaded tire (see Table 1). Therefore, retreading is a key to reducing waste and consumption of non-renewable raw material.

Managing new tires and used tires effectively as well as harmonizing the forward and reverse logistic networks are challenging tasks in a value chain for the tire industry. Therefore, an appropriate logistic network is a must for this type of industry. Designing an economically optimized CLSC network is a prerequisite for tire manufacturers not only to earn profit, but also to decrease waste, with the ultimate goal of sustainable development.

In addition, nowadays companies in the competitive market are seeking optimal configuration of their supply chains (Christopher, 2007). In fact, supply chain network design, i.e. defining number, size and location of supply nodes (Abdallah et al., 2012), has attracted great importance and companies are trying to have a robust and agile logistics network, which can be configured or redesigned easily and precisely (Creazza et al., 2012).

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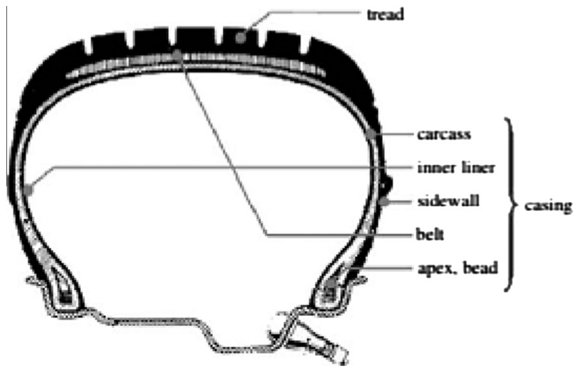

Fig. 1. Tire structure. Source: Lebreton and Tuma (2006).

Table 1
Energy and material usage for the manufacture of a car tire. Source: Ferrer (1997).

Type of tire	Materials consumption (in kg)	Energy usage (in kJ)
New tire	8	72,000
Retreaded tire	1.9	19,000

1.1. Product recovery and life cycle analysis

Product recovery is a process aiming at reusing the collected used products from the user with the purpose of minimizing the amount of waste that is sent to landfills. One type of product recovery process is remanufacturing, which provides a situation in which old products can be used as new, by means of carrying some necessary operations such as disassembly, refurbishing and replacement operations. In this context, Thierry et al. (1995) studied strategic production and operations management to determine recovery options such as repair, refurbishing, remanufacturing, and recycling. Their product recovery management model provided a system to recover economic value of the used products as reasonably as possible to reduce the quantity of waste as much as possible. Jayaraman (2006) suggested that manufacturers need to have a clearly thought-out strategy to collect products from the end-user. He proposed Remanufacturing Aggregate Production Planning (RAPP) in the form of a linear programming model to minimize the total remanufacturing cost taking into cognizance the incoming distribution of nominal quality. Boyer et al. (2013) developed a mathematical model for hazardous material. Dehghanian and Mansour (2009) designed a recovery network for end of life tires and addressed life cycle analysis (LCA) in order to highlight the environmental impact factors of different end of life options. Ferrer (1997) studied retreading of the tire for remanufacturing process and provided a simple rule to decide how many times a tire can be retreaded to reach its maximum utilization. Torretta et al. (2015) provided a review and compared the ways used tires were disposed and recovered in Europe, particularly in Italy and Romania which are two countries with high rate of waste disposal. In their study, various aspects of waste and their potential recovery options, such as the reconstruction of tires and material recovery, were taken into account. In addition, life cycle analysis has been used as a decision supporting tool in the literature. Dhouib (2014), for instance, proposed multi-criteria decision analysis to choose among different reverse logistics options for waste tires. Guide et al. (2008) provided an analytical model to help managers decide which products should be accepted for remanufacturing. In line with Guide et al. (2008), Jayaraman et al. (2008) identified the challenges in the collection of the used products and discussed how information technology can ameliorate many of these difficulties. de Souza and D'Agosto (2013) provided value chain analysis to assess the likelihood of distributing financial benefits for scrap tire reverse logistics.

1.2. Network design

Salema et al. (2008) developed a both strategic location-allocation and tactical decision model for CLSC. Easwaran and Üster (2010) developed a multi-product CLSC network design model to minimize the total cost of the model. They formulated the model as a mixed-integer linear programming problem, where hybrid manufacturing/remanufacturing facilities and a hybrid distribution/collection center with limited capacity was considered to serve retailers. Shekarian et al. (2016) developed a reverse logistics inventory model for a recoverable manufacturing process. Pishvaee et al. (2010) presented a bi-objective mixed-integer linear programming model for CLSC with a similar concept to that of Easwaran and Üster (2010). However, their model contained a disposal center. They maximized the responsiveness of the logistic network in addition to the total costs. Later, Pishvaee et al. (2011) solved the CLSC model given in Pishvaee et al. (2010) with robust optimization methods.

Amin and Zhang (2011) proposed a mixed-integer linear programming model to configure CLSC. They maximized profit by determining parts and products in the CLSC network. Pishvaee and Torabi (2010) proposed a CLSC network to minimize total costs including opening, transportation and processing cost and minimizing total tardiness. Gomes et al. (2011) developed a mixed-integer linear programming model for recovery of waste electrical and electronic equipment (WEEE).

Abdallah et al. (2012) presented an un-capacitated closed-loop location -inventory model with the assumption that a single plant shipped one type of product through the distribution center to the retailers, and the retailer, in turn, has the responsibility to collect the returned products. The remanufacturing center is an intermediary facility between recovery and market.

Zhou et al. (2007) studied the battery recycling and reverse logistics practice in China. They identified the obstacle and the weakness of the existing system in China and proposed a solution for the battery recycling logistics. Next, Kannan et al. (2010) provided a single objective, multi-echelon, multi-period, and multi-product CLSC network model for secondary or "rechargeable" (Zhou et al., 2007) lead/acid batteries. The proposed mixed integer linear programming model used genetic algorithm to determine the optimum cost. Moreover, the solution was comparable with that from GAMS optimization software. Sasikumar and Haq (2011) designed a multi-echelon, multi-product CLSC network and also included the best third party reverse logistics provider into their model to achieve cost efficiency and delivery schedule in reverse logistic. Jayant et al. (2014) provided simulation modeling and analysis of CLSC network design for the battery industry. Their model calculated cycle time, transfer cost, resource utilization, and transfer time. Subulan et al. (2014b) developed a fuzzy multi-objective, multi echelon, and multi-product mixed integer linear programming model for a CLSC network. However, their model is subject to minimization of cost, maximization of coverage and maximization of flexibility. Ene and Ozturk (2015) developed a reverse network for end of life vehicles. They proposed a mixed-integer linear programming model in order to determine the numbers and locations of facilities in the network and the material flows between these facilities.

1.3. Uncertainty

Most of the real life applications involve uncertainty. Similarly, uncertainty is embedded in the supply chain. Uncertainties contribute adversely to the quality of decisions made in the strategic,