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Fleet size optimization in the discarded tire collection process

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ABSTRACT

Due to rapid growth in urban populations, waste collection in cities has become a topic of great concern, due to it impacts on environmental pollution. Regarding used tires, the effect on human health and the environment is a matter of great concern for urban authorities. Therefore, in this paper, we analyze the recovery process for discarded tires. In particular, we study a Reverse Supply Chain Network Design (RSCND), which is designed according to three fundamental echelons (i.e. waste collection, processing and customer zones). To this end, the simultaneous application of simulation techniques and optimization algorithms is proposed. Both approaches are framed within a general methodology, which has been taken from the Operations Research literature. We present a case study from a Colombian city. The combined algorithmic approaches, which include discrete simulation and multiobjective optimization, provide sufficient evidence regarding ways to optimally manage fleet size in the RSCND. Experimental results indicate that the discarded tire recovery process can be designed to be more profitable, as well as less environmentally harmful.

1. Introduction

According to Benjelloun and Crainic (2009), the term 'city logistics' highlights the importance of a systemic view of freight movements within urban areas. Since in urban contexts people are seeking for a higher quality of life, the aim of city logistics is to make these places more attractive and productive (Taniguchi, Thompson, & Yamada, 2014). City logistic and urban logistics refer to the same issues. Gonzalez-Feliu, Semet, and Routhier (2014), define urban logistics as "*the pluridisciplinary field that aims to understand, study and analyze the different organizations, logistics schemes, stakeholders and planning actions related to the improvement of the different goods transport systems in an urban zone and link them in a synergic way to decrease the main nuisances related to it*".

Several types of freight, such as consumer goods, materials, packages, and waste products flow through the city (Kim, Soon Ong, Heng, Tan, & Zhang, 2015). City logistics (or urban logistic) involves both forward and reverse logistics operations (Crainic, 2008), and therefore, it deals with material flows from producers to clients, and flows from clients to facilities for recycling or disposal. Therefore, waste collection becomes an important component in the logistic set-up of a city (Buhrkal, Larsena, & Ropkea, 2012).

Das and Bhattacharyya (2015), pointed out that the rapid and constant population growth in cities has increased the generation of municipal solid waste, which is becoming a crucial socioeconomic and environmental issue, contributing over 40% of the total cost of municipal solid waste management (Jaunich et al., 2016). From the city's logistics perspective, urban waste freight transport is a complex issue, due to particularities regarding collection operations (Behrends, Lindholm, & Woxenius, 2008). In particular, waste collection implies large expenditures and relevant operational, environmental, and social problems for municipal authorities (Faccio, Persona, & Zanin, 2011).

Various authors, such as Behrends et al. (2008), Macharis and Melo (2011), and Gonzalez-Feliu et al. (2014) have addressed the problem of reverse flows and waste transportation in urban contexts. In Gonzalez-Feliu et al. (2014), a conceptual framework for urban logistics planning and management, as well as some solutions for reduction of the main nuisances related to urban goods transport, are provided. Based on existing theories and concepts, Behrends et al. (2008) presents a definition of sustainable urban freight transport. Also, Macharis and Melo (2011) analyze multiple perspectives to deal with city distribution and urban freight transport. However, these authors mainly focus on descriptive issues regarding the waste collection problem.

The waste collection problem must be understood as a reverse logistics (RL) topic. RL emerges as a crucial strategy in addressing the challenges involved in urban waste collection operations. Also, RL has become one of the crucial activities in supply chain management and design (Govindan, Soleimani, & Kannan, 2015; Govindan & Soleimani,

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2017). Hence, RL is a supply chain management process involving several operations, such as product returns for direct reuse (resale), upgrade (repair, refurbishment and remanufacturing), recovery (cannibalization and recycling) and final disposal (incineration and landfilling) (Hanafi, Kara, & Kaebernick, 2008; Prahinski & Kocabasoglu, 2006). According to *The Reverse Logistics Executive Council*, RL can be defined as "*The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal*".

Supply chain design for reverse logistics operations has garnered great attention, due to the complexity of decision making (Kumar & Saravanan, 2014). Difficult situations frequently emerge when residual collection is planned by enterprises. For instance, the stochastic behavior of residual generation, fleet assignment (subject to vehicle breakdowns), and random transportation and pickup-delivery times represent the most common circumstances to be solved in a brief time period. For similar problems, simulation and optimization methods have been successfully applied (Garzón & Mendez, 2010; Lee & Farahmand, 2010).

Several models have been developed in order to achieve a proper balance between economic and environmental performance (Subulan, Tasan, & Baykasoglu, 2015). In the particular case of Reverse Supply Chain Network Design (RSCND), exact and approximate algorithms have been the most frequently utilized solution approaches. As far as approximate algorithms are concerned, numerous studies, addressing heuristic (Chen, Chou, & Chiu, 2007; Lu & Bostel, 2007) and meta-heuristic solutions, have been conducted (Cardona-Valdés, Álvarez, & Pacheco, 2014; Fakhrzad & Moobed, 2010; Ko & Evans, 2007; Lee & Chan, 2009; Pishvaee, Kianfar, & Karimi, 2010). However, few RSCN designs based on simulation approaches were found (Amin & Zhang, 2013; Suyabatmaz, Altekin, & Şahin, 2014; Tonanont, Yimsiri, & Rogers, 2009).

Regarding used tires, their harmful effect on human health and environment, derived from improper disposal, is a matter of great concern for municipal authorities (Subulan et al., 2015). As a consequence, several authors have stressed the importance of developing new supply chains which consider the manifold uses of tire components (Dehghaniana & Mansour, 2009; De Souza & D'Agosto, 2013; Dhouib, 2014). A tire contains 45% rubber (natural and synthetic), 26% carbon, 16% steel, and 13% other materials (Abdul-Kader & Haque, 2011).

An in-depth review, conducted by Amin, Zhang, and Akhtar (2017), indicates that although several papers addressing network configurations for closed-loop supply chains (forward and reverse flows) have been published, most of them proposed general networks and locations based on random numbers, showing a lack of realistic solutions. In the particular case of tire recovery and remanufacturing, a similar situation was also identified in Lebreton and Tuma's (2006) investigation.

In urban contexts, one major challenge in logistics network design is the pickup and transportation of used tires from various sources to the processing plants (Dhouib, 2014). Among others, collection activities involve visiting each generating source of used tires (e.g. car dealers). Each source, however, produces only a limited number of tires, which affects their operational profitability. According to Huang, Yang, Wuang, and Tsui (2010) and Lebreton and Tuma (2006), the collection process is a critical issue, due to the logistics costs involved. This situation requires proper vehicle routing, in order to achieve an economic balance via transportation cost reduction.

The vehicle routing problem is a topic that has gained popularity due to its importance in city logistics (Kim et al., 2015). According to Cattaruzza, Absi, Feillet, and González-Feliu (2017), "…*Vehicle routing problems define a class of combinatorial optimization problems that allow optimizing itineraries of a fleet of vehicles, when these vehicles operate round trips…*". Kim et al. (2015) state that "*City VRP mainly differs from conventional VRP in terms of the stakeholders involved, namely the shipper, carrier, resident, and administrator*". Focusing on the models and methods required for evaluation of city logistics systems and planning, Crainic (2008) presents an overview of city logistics concepts, issues, and challenges. From the operations research point of view, this author identifies research avenues and challenges, and states the need for more models and methodological developments that deal with new variants of routing problems in cities.

In Kim et al.'s (2015) investigation, an interesting literature review on city-VRP is presented. In this study, the city VRP literature was categorized, and constraints, models, and solution methods for VRP in urban areas were also identified. Through this review, several potential research directions for city VRP are proposed. Said authors suggest more work focused on the development of efficient solution methods, considering other computational paradigms, such as agent based, online optimization, and simulation approaches, among others. Another important contribution, addressing information and optimization models for routing in city logistics, can be found in Ehmke (2012).

An interesting overview of literature devoted to vehicle route optimization in cities is provided by Cattaruzza et al. (2017). These authors classify urban logistic flows into three main categories: Inter-Establishment Movements (IEM), End-Consumer Movements (ECM), and Urban Management Movements (UMM). Since UMM flows are related to the development, public maintenance, and functional needs of the city, waste collection flows are a sub-family of UMM. This study further analyzes a set of vehicle routing problems proposing directions for future research. In particular, new relevant models and solution methods are issues that require investigation.

The majority of solution alternatives dedicated to RSCND (for used tires) present a quantitative approach. Most of them emphasize environmental and economic aspects (Abdul-Kader & Haque, 2011). Others address technical aspects related to the recovery and remanufacturing processes (Uruburu, Ponce-Cueto, Cobo-Benita, & Ordieres-Meré, 2013). For instance, mathematical models which optimize supply chain profitability and total logistics costs are proposed by Lebreton and Tuma (2006) and Han, Ji, Wang, and Song (2009) respectively. Also in Dehghaniana and Mansour (2009) an optimization model is examined. However, these authors include environmental and social objective functions in discarded tire problem formulation. Heuristic and meta-heuristic algorithms have been utilized in used tire disposal problems. One good example is shown in De Figueiredo and Mayerle (2008). These authors contribute with a three-stage algorithmic solution, examining a case study in the recycling of unrecoverable tires in the southern states of Brazil.

Furthermore, a performance comparison of Genetic Algorithms (GAs) and Particle Swarm Optimization (PSO) is discussed in Kannan, Noorul Haq, and Devika (2009). In this contribution, the total supply chain cost obtained through GAs was lowered by 20% when compared with PSO. Moreover, the consideration of several conflicting objectives is recurrent in the discarded tire recovery issue. Therefore, Multiple Criteria Decision Analysis (MCDA) can be also found in the literature for resolution of used tire RSCND. Economic, environmental and government regulations are the most common criteria considered in this solution approach (Abdul-Kader & Haque, 2011; Dhouib, 2014; Huang et al., 2010).

According to the author's knowledge, the application of simulation techniques has been carried out poorly in the discarded tire collection process. Following a comprehensive literature review, only a simulation model reported by Abdul-Kader and Haque (2011) was found. This contribution presents a simulation-based agent for analysis of the tire remanufacturing industry. Obtained results indicated that 25% of market demand could be met with remanufactured tires. This outcome positively affects the environment, due to reduction of new tire consumption.

Based on the identified literature gap, in this paper we describe the collection process for used tires in the context of a case study. Specifically, we analyze the reverse system dedicated to collection of discarded tires in a city located in Colombia. Finding optimal truck fleet

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