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Impact of the use of electric vehicles in collaborative urban transport networks: A case study

Andrés Muñoz-Villamizar [a], Jairo R. Montoya-Torres [b,*], Javier Faulin [c]

[a] Escuela Internacional de Ciencias Económicas y Administrativas, Universidad de La Sabana, Km 7 autopista norte de Bogotá, D.C., Chía, Cundinamarca, Colombia
[b] School of Management, Universidad de los Andes, Calle 21 # 1-20, Bogotá, D.C., Colombia
[c] Department of Statistics and Operations Research, Los Magnolios Blg. First Floor, Campus Arrosadia, Public University of Navarra, 31006 Pamplona, Spain

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A B S T R A C T

Transportation is one of the essential services in cities that contribute to the quality of life. As a result, efficient methods for transport planning have become increasingly important. Decision makers have considered collaborative strategies to reduce the overall cost of the supply process and to improve the efficiency and effectiveness of urban logistics systems. This paper assesses the implementation of an electric fleet of vehicles in collaborative urban distribution of goods, in order to reduce environmental impacts while maintaining a level of service. An approach using mathematical modeling with multiple objectives, for tactical and operational decision-making, is proposed to explore the relationship between the delivery cost and the sustainability impact. This approach has been validated using real-data taken from the city of Bogotá, Colombia. Similarly, theoretical experiments in other countries have been performed to analyse the impact of the use of electric vehicles in the configuration of the transport network.

1. Introduction

Urban transport plays a key role in the efficient and sustainable urban development of a city. In particular, an efficient freight transport system is required as it plays a significant role in the competitiveness of an urban area and represents an important element for the local economy regarding generated employment and income (Schliwa et al., 2015). Freight transport in urban and metropolitan areas concerns both pick-up and delivery in retail, parcel and courier services, waste transport, transport of equipment for the construction industry and a broad range of other types of transport (Russo and Comi, 2010). Despite the benefits of transportation activities in urban areas, negative externalities are also originated by these activities. For example, while overall CO_2 emissions are falling in many other sectors, emissions from transportation are still expected to rise in the future as freight transportation activity is expected to expand further over the next decades (ITF, 2015).

Freight transportation is essential for economic development, but it is also harmful to the environment and to human health (Demir et al., 2014b). The planning of freight transportation activities has mainly been focused on cost minimization. However, with an increasing worldwide concern for the environment, logistics providers and freight carriers have started paying more attention to the negative externalities of their operations. These include pollution, accidents, noise, resource consumption, land use deterioration, and risk of climate change (Demir et al., 2014a).

* Corresponding author.
E-mail addresses: andres.munoz1@unisabana.edu.co (A. Muñoz-Villamizar), jr.montoya@uniandes.edu.co (J.R. Montoya-Torres).

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In the last years, several strategies and logistics schemas have been developed in order to increase the effectiveness of freight transportation, and more precisely in the context of city logistics planning and management (Gonzalez-Feliu and Salanova, 2012). Some of the largest goods production industries, major manufacturers have started to collaborate with (direct) competitors to reduce transport cost, increase the delivery frequency and meet higher sustainability requirements. At the same time, they have improved other important transport performance issues such as reliability, transport management, the resources needed to process goods and environmental impact (Ankersmit et al., 2014).

The environmentally sensitive logistic policy itself requires changing the transportation scheme and shifting it onto a sustainable distribution network with fewer negative impacts on the environment (Lin et al., 2014). This situation and the increase of the environmental and social awareness have triggered numerous green initiatives at companies, such as the promotion of next-generation electric vehicles. In the logistics field, electric vehicles are now considered a serious alternative to conventional combustion vehicles (Juan et al., 2014, 2016; Davis and Figliozzi, 2013). Electric vehicles have no direct CO_2 emissions and produce only minimal noise; however, they are more expensive and less commercial than combustion vehicles. Nevertheless, several companies have started to employ electric vehicles in their last-mile delivery operations and governments and private companies are starting to provide the required infrastructure to further boost this electrification trend (Goeke and Schneider, 2015).

The aim of this paper is to evaluate the impact of using electric vehicles in collaborative freight transport networks from a multi-objective perspective; that is to say, presenting a holistic view of the problem and not only considering economic issues. Thus, this study seeks to provide support to the understanding of the relationship between delivery cost and environmental impact in different cities transport systems. To do so, a formal mathematical modeling approach is employed within a framework that allows characterizing both the city under study and the implemented freight transportation system. This framework and the multi-objective mathematical modeling approach are validated using real-life data from a large city in an emerging country.

The rest of this paper is structured as follows. An overview of related literature is presented in Section 2. Section 3 describes in detail the problem under studyl. Section 4 sets out the proposed approach, followed by an application and analysis of results in Section 5. Finally, Section 6 presents some concluding remarks and research perspectives.

2. Literature review

This section briefly reviews related literature about the problem under study. Two main subjects are analyzed related to city logistics (Savelsbergh and Van Woensel, 2016) goods distribution in urban systems with horizontal cooperation and environmental impact of transport systems.

Over recent years, several strategies and logistic models have been developed in order to increase the supply chain efficiency, where collaboration is one of the most promising areas of study in supply chain management (Gonzalez-Feliu et al., 2013). In the academic literature, collaboration is commonly seen all along the supply chains (Montoya-Torres and Ortiz-Vargas, 2014). In general, two types of collaboration can be distinguished: between actors in a supply chain at different stages (vertical collaboration) and between actors of the supply chain at the same level having analogous needs (horizontal collaboration) (Gonzalez-Feliu et al., 2013). This collaboration in urban logistics can take place at several stages and with different levels of interaction (Gonzalez-Feliu and Morana, 2011): transactional, informational, and decisional. Decisional dimension concerns the collaboration at different planning horizons of logistics and transportation activities: (a) operational planning, related to daily operations that can be coordinated or shared (goods transportation or cross- docking); (b) tactical planning, related to middle-term planning stage regarding forecasting, shipping, inventory, production management and quality control; and (c) strategic planning (highest collaboration stage), related to long-term planning decisions such as network design, facility location, finance and production planning.

Various types and designations of horizontal collaboration have been discussed in both professional and academic literature. Cooperation, collaboration, alliances, and partnerships are all used to refer to concerted practices on horizontal supply chain links (Cruijssen et al., 2007). However, collaboration involves much more than cooperation, especially in terms of sharing information, risks, knowledge, profits, etc. The horizontal collaboration is a business agreement between two or more companies at the same level in the supply chain or network in order to allow ease of work towards achieving a common objective (Bahinipati et al., 2009). In the collaborative scenario, companies are incentivized to share trucks, routes and costumers in order to improve their individual turnovers by reducing transportation costs, or decreasing the number of necessary vehicles, and offering, in many cases, a better service to customers, along with reducing the environmental impact of the delivery activities (Muñoz-Villamizar et al., 2015).

The situation in which the goods distributions are done from some companies, each acting as a single depot where vehicles start and finish their routes, to final clients can be solved as multiple individual single-depot Capacitated Vehicle Routing Problems (CVRP). The CVRP model designs optimal delivery routes where each vehicle only travels one route, each vehicle has the same characteristics and there is only one central depot. On one hand, the objective of that problem is to find a set of routes for the vehicles that minimizes the total cost. In those routes, each customer is visited exactly once by one vehicle. Moreover, each vehicle starts and ends its route at the depot, and the vehicles capacity is not exceeded and customers' demands must be satisfied. On the other hand, collaborative transport network configuration can be performed through solving the variant of the CVRP known as Multiple Depots Vehicle Routing Problem (MDVRP) in which more than one depot