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Urban consolidation solutions for parcel delivery considering location, fleet and route choice

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ABSTRACT

Consolidation schemes can reduce the negative impacts of urban freight movements. For this reason, in recent years several city authorities have promoted different measures to foster the implementation of urban consolidation centers. However, only a few real-world publicly promoted initiatives have succeeded due to several operational, financial, and regulatory issues. In this paper, we investigate different city logistics solutions for a mail delivery service in the city of Austin, Texas. We do that by using a model for the multi-depot vehicle routing problem with heterogeneous vehicle fleet for urban consolidation centers (UCCs) based on metaheuristics. The model considers the total costs and the environmental impacts of alternative UCC configurations and policy scenarios. According to the results, combinations of regulations and subsidies addressing both traffic inbound and outbound the facilities could be the most efficient and environmental friendly approaches. Factors like demand and traffic congestion have a significant impact on the overall performance of the solutions.

1. Introduction

Urban freight distribution plays a critical role in the sustainable development of urban regions as it determines up to 15–20% of vehicular traffic in cities (Dablanc, 2011). The negative effects of "last mile" freight distribution threaten the livability of cities and can outweigh the benefits of economic development and flourishing of commercial activities (McKinnon et al., 2015). Indeed, the presence of trucks in urban areas increases the use of nonrenewable resources and the levels of emission of associated pollutants (global and local), triggers traffic jams, and decreases the throughput of traffic. It can also lead to traffic accidents and can cause considerable noise and visual intrusion (Quak, 2008; Browne et al., 2012 Browne et al., 2012).

A particularly promising solution features urban consolidation centers (UCCs): transshipment points situated in the proximity of a city center, where deliveries from logistic companies are dropped off, sorted, and consolidated in smaller vehicles such as minivans, electric vans and cargo bikes (Crainic et al., 2004; Browne et al., 2005; Allen et al., 2007; Danielis et al., 2010). In addition to the opportunity of reducing emissions by using more environmentally friendly vehicles than trucks, another advantage of urban consolidation would be the higher load factors, and a decreased amount of traffic entering the city. Consequently, in recent decades a series of city logistics initiatives, including new regulations, infrastructure improvements, and measures concerning sharing space and time have been promoted in cities around the world, especially Europe and Japan (Muñuzuri et al., 2005).

UCCs can be beneficial for logistic companies and receivers too as they might reduce transportation in congested areas, and therefore increase delivery reliability and efficiency (Browne et al., 2011). Moreover, a series of additional logistics and retail services including off-site stockholding, consignment unpacking, preparation of products for display and price labelling can also be provided at the UCC (Huschebeck and Allen, 2005). On the other hand, among the operational barriers to the implementation of UCCs there are the extra costs of developing dedicated facilities for the transshipment of goods (and possibly added logistic services), operating these facilities, acquiring the fleet in charge of the last-mile deliveries, and providing the delivery service to customers (Verlinde et al., 2012). In addition, other operational issues, such as increased delivery time due to the transshipment and limitations of lower capacity, service range, and speed of vehicles like cargo bikes and electric vans, could arise when implementing UCCs. Most of these barriers have been thoroughly investigated in operations research, and in recent years also in city logistics. The interested reader can refer to Browne et al. (2005) and Allen et al. (2012) for a comprehensive review of UCC related initiatives.

A typical solution adopted by city authorities promoting UCCs consists of renting public spaces at reduced cost (Quak et al., 2008). Other possible city logistics initiatives aimed at supporting UCCs

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include the adoption of eco-friendly vehicles for the last leg of distribution, urban access regulations (concerning delivery times and typologies of vehicles), and pollution charges. While, it is generally agreed that, UCCs need to be financially viable without need of subsidies, it was often the only way to guarantee their survival. Still, some public authorities prefer to stimulate the development of self-sustaining privately run UCCs (Janjevic et al., 2016).

The engagement of both public and private stakeholders during the planning stage of city logistics projects is crucial for the successful development of city logistics initiatives (Lindholm and Browne, 2013). Several studies have investigated decision-making frameworks for freight partnerships such as "city logistics living lab" (Quak et al., 2016), and the "design and monitoring framework" (Österle et al., 2015). In the specific context of UCCs, having a clear picture of private and public implications of different design configurations, ancillary subsidies and regulations, is at the basis for fruitful collaborations.

The goal of this paper is to investigate potential city logistics solutions for the implementation of UCCs by means of a quantitative model that accounts for location, routing and fleet choice. Alternative potential scenarios and business models are investigated to identify the most suitable UCC configuration for the United States Postal Service (USPS) and for the city authorities of Austin, Texas. To the best of our knowledge, implementing UCCs as a city logistics measure is still a relatively unexplored concept in the context of US cities (Panero et al., 2011). Since the long-term survival of urban consolidation schemes depends on the viability of the underlying business model (Cherrett et al., 2012; Kin et al., 2016; Van Duin et al., 2016), we identify alternative measures and setups for the implementation of UCCs. We do that, by looking at different stakeholders' perspectives to adopt a more comprehensive planning approach as suggested by Ballantyne et al. (2013) and Janjevic et al. (2016).

In this paper, after a brief presentation of urban consolidation schemes, we provide the mathematical formulation of the problem and a description of a metaheuristic to solve it. The second part of the paper investigates a series of scenarios for the implementation of UCCs by USPS in the city center of Austin, Texas. Finally, based on the results, we present some policy considerations and the conclusions.

2. Urban consolidation schemes

In the last twenty years several urban consolidation schemes have been promoted by public authorities mainly in European cities (in the U.K., Italy, France, Germany and the Netherlands), but also in Motomachi in Yokohama, Japan. However, the majority of these projects did not last longer than a few years (Schoemaker, 2002; Browne et al., 2005). There are several reasons that can lead to the failure of consolidation schemes. Some failures can be ascribed to a lack of planning and to relatively ambitious forecasts in terms of public acceptance and carrier compliance (Van Rooijen and Quak, 2010). Other factors might be attributed to the initiatives' dependency on local authorities to subsidize the high investment and operating costs (Dablanc and Rodrigue, 2014). Finally, erroneous operational choices concerning the location of the facilities and the characteristics of the fleet in charge of the "last mile" deliveries may have led to eventual negative results of urban consolidation implementation. This is the case of Leiden, Netherlands, where the UCC was located relatively far away from the city center (Schoemaker, 2002) and Kassel, Germany where the additional operation costs outweighed the transportation savings (Browne et al., 2005).

Clearly, introducing consolidation centers involves extra costs, risks, and delays in the delivery process that could jeopardize the success of this measure. For this reason, identifying optimal solutions in terms of facility location, fleet, and delivery routes would be beneficial in the preliminary assessment of urban consolidation schemes, prior to financial and institutional considerations. To date, in the field of urban logistics, important studies have been conducted to determine efficient and sustainable configurations of urban distribution systems by identifying the best location of these facilities (Crainic et al., 2004; Muñuzuri et al., 2012) and the optimal fleet choice for the last-mile delivery (Figliozzi et al., 2011); more complex problems have also been investigated, including the optimal combination of "satellites" and delivery routes (Crainic et al., 2010), and the optimal configuration of routes and mix of vehicles (Van Duin et al., 2013).

Locating UCCs, which is a central aspect of the efficiency of the city distribution (Allen et al., 2007), relies on identifying the optimal sites where freight can be transshipped from trucks to smaller and more eco-friendly vehicles to accomplish the last leg of distribution. The problem has been traditionally formulated as an optimal location model for the multi-echelon distribution setting (Taniguchi et al., 1999; Crainic et al., 2004, 2010) where the main considered costs are those related to the investment and operation of the facilities and the transportation costs inbound and outbound the facilities. Different constraints concerning the capacity of facilities and budget conditions have been typically included to increase the realism of the models. Since each context represents a unique setting in terms of costs (rent, handling and transportation), accessibility of customers (traffic conditions), and urban morphology (land-use and road network layout), the optimal location model might yield to various results. For example, in a situation characterized by high infrastructure costs and limited available space in the city center, a few larger facilities in the periphery of the city would probably be a more desirable solution. Otherwise, in case of heavy traffic conditions, cargo bikes might demonstrate more advantages than larger vehicles because in these conditions larger vehicles (most often) cannot exhibit a speed advantage over cargo bikes. Interestingly, in most of the previous studies the adopted perspective was the one of local authorities, made in an attempt to minimize externalities, while the carriers' perspective has been usually neglected.

Another important tactical-operational matter arising when implementing urban consolidation schemes consists of the fleet of vehicles used for the last-mile distribution, as priorities as each typology of vehicle is characterized by specific strengths and weaknesses. In the last few years, in the field of city logistics, a growing number of studies have investigated the competitiveness of alternative modes, such as electric vans or cargo bikes (Browne et al., 2011; Conway et al., 2012; Feng and Figliozzi, 2013; Davis and Figliozzi, 2013; Tipagornwong and Figliozzi, 2014; Choubassi et al., 2016). Furthermore, different papers have combined this issue with the vehicle routing problem (VRP) and its extensions (with time windows restrictions, heterogeneous fleet and probabilistic demand), aiming to provide more accurate solutions (Ando and Taniguchi, 2006; Gonzalez-Feliu, 2008; Crainic et al., 2010; Figliozzi, 2012; Van Duin et al., 2013).This article follows similar lines, but aims to cover several of these aspects simultaneously, providing a broader perspective involving different policy goals. In this study we tackle both strategic (location and fleet choice) and operational issues (routing) for the implementation of UCCs in the multi-depot vehicle routing problem with heterogeneous vehicle fleet problem (MDHFVRP).

The MDHFVRP has received little attention compared to other logistic problems, with the exception of a few papers (Cordeau et al., 1997; Wu et al., 2002; Dondo and Cerdá, 2007; Salhi et al., 2014). A recent interesting extension of this problem has been proposed by Koç et al. (2016) who solved it including fuel and CO_2 emissions cost based on vehicles' travel speeds. In our paper, we independently solve a MDHFVRP using a novel metaheuristic approach, and we employ it to evaluate policies for the implementation of UCCs to serve the city center of Austin. The model is formulated as a mixed-integer linear program (MILP), where the decision variables are whether to use a facility or not, the number of certain vehicle types to be used, characterized by different capacities, speeds, costs, and emissions, and the routes to be taken to serve all customers. The model is decomposed into two sub-models solved sequentially: a facility location problem with capacity and budget constraints; and a mixed-vehicle routing problem