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Determining time windows in urban freight transport: A city cooperative approach

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ABSTRACT

Many cities have implemented delivery time windows, which limit city center access for freight vehicles. Each city determines its time windows independently. However, time window restrictions of one city also affect store deliveries in neighbouring cities, since retailers combine deliveries to customers in different cities in a single trip. We develop a cooperative game-theoretic approach to find better time windows than those currently used. A study of three cities and three retail chains illustrates the approach. Compared to the current situation, we find time windows that improve all the city satisfactions, while they hardly impact the retailers' efficiencies.

1. Introduction

Due to the increase in population and economic growth in urban areas, the demand levels for urban freight transport (UFT) activities are increasing (Cherrett et al., 2012). Although urban freight is very important to the functioning of the urban area by providing accessibility to goods and services, UFT has various unsustainable effects that threaten the livability and accessibility in the urban areas. Freight vehicles emit both local and global pollutants and cause significant environmental problems. The transport sector is responsible for around a quarter of greenhouse gas emissions (European Commission, 2015). According to ALICE, ERTRAC (2015), urban freight alone would already account for 25% of CO_2 emissions and 30%–50% of other transport-related pollutants. Furthermore, freight transport reduces traffic safety, causes other problems such as road congestion, noise disturbance, and physical hindrance.

Various measures have been implemented in different countries in order to reduce the negative economic, social and environmental impacts of UFT and to create more efficient UFT operations. Russo and Comi (2011) classify such urban transport measures into four classes: (a) *material infrastructure measures* which aim to increase sustainability by taking actions to optimize freight transport (e.g., loading and unloading zones and developing an urban transportation subnetwork) (b) *immaterial infrastructure measures* which support vehicle routing and scheduling and include policies that enable the exchange of information between stakeholders (e.g., telematics in intelligent transportation systems (ITS)), (c) *equipment measures* which are related to the development of sustainable-friendly devices that improve pick-up and delivery (e.g., new low emission vehicles, electric engines) (d) *governance measures* that include transport regulations imposed by the national or local governments (e.g., time window restrictions, imposing a minimum load factor, road pricing and taxes). Stathopoulos et al. (2012) additionally distinguish (e) *management measures* where collaboration between logistics providers is encouraged through initiatives such as freight quality partnerships. Quak and De Koster (2014) have classified such UFT sustainability initiatives, with respect to drivers of the initiative and success rate.

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Municipalities in Western Europe and some Asian countries typically try to solve urban freight problems by implementing measures such as access-restricting delivery time windows for trucks, vehicle size and weight restrictions, noise regulations, and environmental zones. Time window measures are probably the most frequently used (Quak, 2008). They allow environmentally sustainable solutions to urban freight transport problems (Lindholm and Blinge, 2014). Time windows limit the periods during which freight vehicles are allowed to enter city centers (usually outside shopping hours). The prime objective is to reduce inconvenience for residents and the shopping public by increasing store accessibility during shopping hours, and thereby making the city more attractive for the shopping public (Quak and De Koster, 2007).

As stated by OECD (2003), in most countries, UFT is considered as a local problem and local authorities are responsible to establish transport regulations including time windows. Since local authorities determine time window restrictions without considering other cities' objectives, time window restrictions in a country may vary from city to city and even within a city from area to area. Nuzzolo et al. (2016) compare the characteristics of UFT in Rome, Barcelona, and Santander and point out that each city implements measures without considering the actors in neighboring areas. They emphasize the importance to achieve uniformity in implementing measures at the local and larger scale. Dablanc and Frémont (2012) also mention the lack of uniformity in truck access and delivery regulations in the Paris region and state that since the regional local rules are unharmonized, it becomes difficult for truck companies to comply with all of them.

As the time window pressure increases, the number of store deliveries that can be combined in one roundtrip decreases, i.e., the retail chain (who stores and sells the goods) is forced to use extra trucks and cover longer distances to accomplish the store deliveries which results in an increase in the retailer's cost. Furthermore, time windows change over time, and for a retailer it is difficult and costly to accommodate to all these changes. For this reason, many retailers consider time window policies as one of the major problems in UFT (Quak, 2008).

In practice, the retailers comply with the restrictions applied. However, in some cities in Europe such as in Amsterdam, retailers that use less polluting, or low noise trucks can obtain exemptions so that they are allowed to enter the central city areas in an extended time window period, or they have to pay a small penalty for violating the time window restrictions (Qureshi et al., 2009). In many cities, e.g. Utrecht, The Hague, or Amsterdam, the time windows are enforced through movable bollards placed under the ground which go down when the time window starts and go up when the time window ends. Using a chip-card (e.g. in Berlin) and via number plate recognition (e.g. in Enschede), retailers with an exemption can enter and leave the city centers outside time windows for allowed extended hours (BESTUFS, 2006).

Considering the possible exemptions given to the retailers, in this paper, we consider two different cases: *Case 1*) retailers comply with the restrictions and, *Case 2*) retailers have an agreement that allows them to violate time windows by paying a small penalty. For each of the two cases, we aim to find the best time windows taking into account the joint objective of the municipalities and the retailers.

In determining the time windows, we use a game theoretic collaborative approach where a coalition of the cities cooperate to jointly determine their time windows. This type of cooperation between the municipalities can be considered as an example of horizontal cooperation. Cooperation between the cities can bring advantages to both the cities, but also to the retailers. As a result, each retailer may be able to more easily combine trips that visit more than one city, which lowers its cost. In addition, it may lead to less violation of time window restrictions and therefore, a potentially higher satisfaction for the cities.

Cruijssen et al. (2007a) defines horizontal cooperation as identifying and exploiting win–win situations among companies at the same level of the supply chain in order to improve performance. In this study, we consider horizontal cooperation between municipal authorities who jointly determine their time windows, in a game theoretic sense. Such an approach has not yet been applied in municipal policy making. We develop a framework to represent the city satisfactions which depend on the time windows of other cities through the retailers' choice of delivery moment. The local authority decision makers can use the proposed framework to organize their time windows in cooperation with other cities, or to establish the added value of such cooperation.

Next to retailers and municipality time-window decision makers, many other stakeholders are involved in UFT. Taylor (2005) classifies the main actors in shippers, residents, freight carriers, planners and regulators. Holguín-Veras et al. (2015) distinguish producers/manufacturers, shippers, freight forwarders, third party logistic providers, warehouse operators, carriers, and receivers. All of them have different interests related to UFT that are worth being analysed. Marcucci et al. (2012) investigate these stakeholders' preferences with respect to urban freight policies using a survey instrument. These stakeholders interact with each other in their responses to e.g. time windows, which has led to different modelling approaches to represent the diversity of roles and functions of actors in the freight system (e.g. Roorda et al., 2010, Anand et al., 2016, Marcucci et al., 2017). We choose municipality time-window decision makers as the key representatives of the cities (planners, regulators) and retail chains as representatives of the shippers. The retail chains we chose are in full control of their store deliveries. Other stakeholders, such as residents and carriers are only included implicitly, via the city satisfaction function (residents) and the retailer delivery routes with minimum costs (carriers). However, we believe that the actors included are the main stakeholders in determining time windows and their effects: municipalities determine and retailers respond. Their actions impact all other stakeholders (e.g. transport providers, carriers) who may only have indirect influence on the decision process.

A case study comprising three cities and three fashion Dutch retail organizations is presented to illustrate the approach and the results. We develop a regression model to estimate the city satisfaction score, which takes into consideration the time windows of the city and its neighbouring cities, and the response of the retailers. We apply scenario analysis to generate the data to be used for the regression models. For each time window scenario, we optimize the vehicle routes of each retail organization for an average day of the week, resulting in a visiting pattern for each city involved and a satisfaction score of each city. In each coalition, we assume that different cities cooperate to determine their time windows together and from the solution of the mathematical models developed for