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Mathematical model for the study of relocation strategies in one-way carsharing systems

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Abstract

Carsharing is today considered as an ecological and innovative solution to improve urban mobility. The one-way version, where vehicles can be drop-off in any station, brings however some challenging open questions. The system has to be design as part of the global transportation one and vehicle relocation operations must be included to get the higher level of service.

In this paper, we consider a one-way carsharing system where stations and their location are fixed. The optimization problem consists in maximizing the total number of satisfied demands for a limited number of vehicles and relocation operations. We propose a formal definition and a mathematical model using Integer Linear Programming (ILP). We show that the problem size is strongly related to the number of possible relocation operations and a polynomial subcase is exhibited. Numerical results highlight that vehicle relocations can be drastically reduced without deteriorating the quality of solutions. Our method can thus be easily used in system management to evaluate possible implementation of vehicle relocation strategies.

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Keywords: one-way carsharing, vehicle relocation strategies, transport optimization, mathematical modelling.

1. Introduction

In recent years, many efforts have been dedicated to understand how to organize our transportation systems. Due to many externalities such as pollution, congestion or excessive energy consumption, new alternatives have to be identified. Although public transports are a relevant option for mass transit, they are facing drawbacks with respect to public perception and flexibility. Moreover, the network design has been often done many decades ago when the urban setting and the demand distribution were different. We are now facing with a critical point where the network appears completely saturated and presents difficulties to absorb the demand.

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Since the early 1990s, carsharing systems emerged in many cities as an ecological and innovative solution to this dilemma. From a social and ecological point of view, carsharing reduces the average number of vehicles per household (Martin et al., 2010; Ter Schure et al., 2012) and the total number of vehicles on the road. Shared vehicles have higher utilization rates and are used more efficiently than private ones (Litman, 2000; Schuster et al., 2005). Some studies observe that carsharing improves traffic fluidity and produces many positive environmental effects, such as CO2 reductions (Martin and Shaheen, 2011).

The carsharing principle is to make available a fleet of vehicles distributed over a set of stations that can be used by a wide group of users (Shaheen et al., 1999). The return station, where commuters can (or have to) drop-off a vehicle, divides station-based systems into two categories. Round-trip systems require users to return vehicles to the station they were picked up, whereas one-way systems allow a distinct return station. System flexibility has been identified recently as the critical factor to join a carsharing system (Efthymiou et al., 2012), making this criterion a strong development catalyst. Consequently, free-floating carsharing systems have came up a few years ago with a new feature. There are no station and users can pick-up and drop-off the vehicles freely within a predefined area (Weikl and Bogenberger, 2012). Of course, for one-way and free-floating systems, the higher the flexibility is, the harder it is to manage the system.

The uneven nature of the trip pattern in urban areas leads to unbalanced situations that causes hard operational problems. To ensure a good system efficiency, vehicle relocation operations have emerged as a good solution to balance vehicle stock. As such, they have to be part of the system design, as well as the system management, bringing then new research challenges.

The intuitive approach for solving the vehicle unbalance problem is to consider that periodic relocation operations can be done by the operator. Kek et al. (2006) and Kek et al. (2009) have used discrete event simulation models to help operators manage their systems while minimizing available resources (such as vehicles and staff members) and ensuring a certain level of service. Fan et al. (2008) introduced a trip selection approach, deciding which vehicle reservations should be accepted or denied and how many vehicles should be relocated or held to maximise profit. More recently, Correia and Antunes (2012) developed a station location approach. The goal was to study the effect of stations' location on capturing more favorable trip pattern to balanced the vehicle distribution in the network. The idea was to transfer the system unbalance to the clients by decreasing their possibility of accessing this system. The authors concluded that the unbalance situation would lead to severe financial losses if all demand have to be satisfied, even if the trip is very expensive. They also found that financial losses could be reduced by making appropriate choices of the stations configuration (number, location and size), but profits could only be achieved with full control over trip selection.

In this study, we address an opened system design problem and an innovative approach to solve it. Considering potential one-way carsharing station locations and demands over time, what could be the optimal system configuration capturing the higher number of demands ? The paper is organized as follow. The next section introduces more precisely the optimization problem addressed in this work. Section 3 presents the problem modelling using time expanded graphs (TEGs). Section 4 formulates the problem as an Integer Linear Program (ILP). Section 5 is devoted to the study of a polynomial subcase. Section 6 is dedicated to experimentations and results on graph densities, solver computation times and optimal distances. Finally, section 7 finishes with some conclusions and directions for further research.

2. Problem definition

This section aims to present the optimization problem. Inputs, which consist mainly in the description of the travels and the demands, are first described briefly, followed by the objectives. The section ends with a formal definition of the optimal dimensioning problem.

2.1. Inputs

Let $\mathcal{N} = \{1, \cdots, N\}$ be the set of $N \in \mathbb{N}^\star$ stations. Since they are usually located in dense urban areas, their respective number of parking spaces are considered limited. Let $Z(i) \in \mathbb{N}^\star$ be the maximum station capacity of station $i \in \mathcal{N}$.