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A dynamic carsharing decision support system

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ABSTRACT

This paper proposes a dynamic optimization–simulation model as a decision support system for one-way carsharing organizations. To reduce the vehicle imbalance in one-way systems, a Vehicle Relocation Optimization model is solved successively in a discrete event simulation. Each event is the arrival of a new user. The model is compared to an a priori benchmark model. Autoshare is chosen as a case study. Results show that increasing the reservation time (time between requesting and picking up a vehicle) from 0 to 30 min reduces fleet size by 86%. The model captures a tradeoff between vehicle relocation hours and fleet size.

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1. Introduction

Urban carsharing services provide individuals with access to a fleet of shared-use vehicles without the costs and responsibilities of private vehicle ownership. Members of these services typically pay for subscription-access plans and are charged through hourly rates. Further benefits of carsharing are reduced parking costs, mitigated environmental impact, and availability of an alternative transportation mode (Katzev, 2003). City Carshare in San Francisco, the largest non-profit carsharing organization in North America, released an environmental report in 2013 outlining its role in reducing a total of 25 million vehicle miles, 85 million pounds of CO_2 emissions, and 4.3 million gallons of gasoline (City Carshare, 2013).

CarSharing organizations (CSO) are commonly classified based on configuration into one-way and two-way systems. Two-way systems (e.g., Zipcar and Autoshare) restrict vehicles to be picked up from and returned to the same station. One-way carsharing systems (e.g., ICVS and Praxitele), on the other hand, permit users to return the vehicle to a location of choice as long as the drop-off station and time is indicated in advance. While two-way systems are more common and account for 94% of all North American carsharing memberships (Shaheen et al., 2006), one-way systems are less adopted. This is mainly due to the issue of vehicle imbalance which happens when cars shift towards certain destinations in the network. Some CSOs such as Car2Go address vehicle imbalance by employing drivers to relocate the vehicles to high demand locations. Such relocation operations increase costs for the CSOs.

Despite high relocation costs, the number of one-way systems is rising. Communauto, a privately owned carsharing organization founded in city of Québec in 1994, has inaugurated the first electric one-way carsharing service in Canada (Communauto, 2013). This pilot project aimed to evaluate the benefits of one-way systems and was initiated due to public consultations that showed the demand for such systems. To complement such pilot projects, better dynamic vehicle relocation decision support tools need to be designed which consider dynamically the location of all vehicles in the fleet and locations of new user requests. Accounting for these two, the objective is to minimize total vehicle relocation costs. This

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tactical model differs from higher level decision making models which mainly focus on where to locate carsharing parking stations and what fleet size to use based on aggregate demand values.

The main objectives of this paper are as follows:

- Present a benchmark model that considers simultaneously the complete set of all user requests received in a particular day assuming user requests are known in advance.
- Propose a dynamic integrated simulation–optimization model which takes online user requests and acts as a decision support tool for CSOs to maximize system profit.
- Perform sensitivity analysis on the fleet size of each system configuration and highlight the important factors and policies which impact both the fleet size and vehicle relocation costs.

This paper is structured as follows. In Section 2, we describe the literature review of previous operational models on carsharing systems. In Section 3, we explain the user preferences, constraints, and problem assumptions. Sections 4 and 5 present the benchmark model and the dynamic model, respectively. In Section 6, we analyze both models for the case of Autoshare in Toronto. Finally, in Section 7, we highlight the major findings of the article.

2. Literature review

Previous research on carsharing mainly focuses on its environmental impacts (Steininger et al., 1996; Cervero et al., 2007; Firnkorn and Muller, 2011), market dynamics (Shaheen and Cohen, 2007; Shaheen et al., 2006; Vine et al., 2013), users' behavior (Celsor and Millard-Ball, 2007; Morency et al., 2010; Habib et al., 2009, 2012), and relationship with public transit (Stillwater et al., 2009). The core of CSO operations, however, has received less attention. Table 1 presents previous operations models of CSOs.

Barth and Todd (1999) develop a simulation model of carshare operations with inputs and measures of effectiveness that allow for scenario analysis. They conclude that a sufficient fleet size for satisfying customers is 3–6 vehicles for every 100 trips but that 18–24 vehicles per 100 trips are required to minimize relocation costs. Fan et al. (2008) propose a multi-stage stochastic linear integer model which attempts to capture system uncertainties such as carsharing demand variation. The objective function of their model maximizes the revenue obtained from servicing customers while minimizing the cost of vehicle relocation.

More recently, Kek et al. (2009) and Correia and Antunes (2012) propose two distinct mixed integer programming models (MIP) that aim at optimizing specific features of CSO operations. Kek et al. design a novel three phase optimization-trend-simulation (OTS) decision support system for CSOs to indicate a set of near-optimal manpower and operating parameters for the vehicle relocation problem. For a carsharing company in Singapore, they conclude that optimization of manpower can reduce staff expenses by up to 50% and zero vehicle time (duration of vehicle shortage at parking stations) by up to 13%. Correia and Antunes (2012), on the other hand, focus on the fleet size, number of vehicle relocations, depot size, and location of potential parking stations. Considering all these decision variables, the authors present a mixed integer optimization MIP approach to maximize CSO revenues while minimizing costs such as vehicle maintenance, parking provision, vehicle depreciation, and vehicle

Table 1
Classification of previous work on operational models of carsharing.

Authors (year)	Objective function	Main decision variables	Solution methodology	System configuration	Study area
Barth and Todd (1999)	Minimize average wait time, number of customers waiting, number of relocations	Effective fleet size	Simulation	One-way	Coachella Valley
Fan et al. (2008)	Maximize revenue, minimize vehicle relocations	Vehicle usage, fleet size	Stochastic programming	One-way	–
Kek et al. (2009)	Minimize vehicle relocation, minimize staff utilization cost, minimize demand rejection penalty	Crew size, staff waiting time, vehicle relocation	Mixed Integer Programming (MIP)	One-way	Singapore
El Fassi et al. (2012)	Maximize member satisfaction, minimize fleet size	Parking capacity, station locations	Discrete event simulation	–	Montreal
Correia and Antunes (2012)	Maximize revenue, minimize vehicle maintenance, relocation, and depreciation	Depot size, depot location, fleet size, vehicle relocations	Mixed Integer Programming (MIP)	One-way	Lisbon
Jorge et al. (2012)	Maximize revenue, minimize vehicle maintenance, relocation, and depreciation	Depot size, depot location, fleet size, vehicle relocations	Simulation – Mixed Integer Programming (MIP)	One-way	Lisbon
Correia and Jorge (in press)	Maximize total daily revenue, minimizing maintenance cost, operational cost of a vehicle, and vehicle ownership cost	Number of vehicles that are parked at each station, origin and destination stations of each trip	Mixed Integer programming (MIP)	One-way	Lisbon