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An integrated optimization-simulation framework for vehicle and personnel relocations of electric carsharing systems with reservations

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ABSTRACT

One-way electric vehicle carsharing systems are receiving increasing attention due to their mobility, environmental, and societal benefits. One of the major issues faced by the operators of these systems is the optimization of the relocation operations of personnel and vehicles. These relocation operations are essential in order to ensure that vehicles are available for use at the right place at the right time. Vehicle availability is a key indicator expressing the level of service offered to customers. However, the relocation operations, that ensure this availability, constitute a major cost component for the provision of these services. Therefore, clearly there is a trade-off between the cost of vehicle and personnel relocation and the level of service offered. In this paper we are developing, solving, and applying, in a real world context, an integrated multi-objective mixed integer linear programming (MMILP) optimization and discrete event simulation framework to optimize operational decisions for vehicle and personnel relocation in a carsharing system with reservations. We are using a clustering procedure to cope with the dimensionality of the operational problem without compromising on the quality of the obtained results. The optimization framework involves three mathematical models: (i) station clustering, (ii) operations optimization and (iii) personnel flow. The output of the optimization is used by the simulation in order to test the feasibility of the optimization outcome in terms of vehicle recharging requirements. The optimization model is solved iteratively considering the new constraints restricting the vehicles that require further charging to stay in the station until the results of the simulation are feasible in terms of electric vehicles' battery charging levels. The application of the proposed framework using data from a real world system operating in Nice, France sheds light to trade-offs existing between the level of service offered, resource utilization, and certainty of fulfilling a trip reservation.

1. Introduction

The emergence of carsharing as a new transportation mean between public and private transport is quite recent. People benefiting from this service have to register and then can use vehicles located within a designated service area. Carsharing

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is an approach to increase vehicle utilization while decreasing the cost encountered to each user. Expenses associated to car ownership are nowadays quite high linked to purchase, gasoline, insurance, parking and maintenance. Avoiding these expenses may be a motivation for a driver to adopt carsharing as a regular transportation mean if the system is able to provide high quality of service (accessibility and availability of vehicles both at origin and destination of his/her trip at reasonable cost). In addition to users' benefits, carsharing systems are producing broader societal and environmental benefits such as reduction of congestion, air pollution, and the urban space needed for parking.

Carsharing systems can be classified in different categories according to the rental conditions. Free-floating systems allow people to park the vehicles anywhere in the covered area, whereas non-floating impose restrictions to users to park the vehicles at stations with limited number of parking spots. Another differentiating feature is the "one-way/round-trip" characteristic: Round-trip systems force the user to return the car to the location where it was picked-up whereas one-way systems allow drop-off at any station. The type of vehicle (combustion, electric, etc.) affects also the system's use.

Rental operations naturally induce imbalances in the spatial and temporal distribution of vehicles of one-way carsharing systems. To maximize the demand served, vehicle distribution needs to be rebalanced by performing relocations to maximize vehicle availability. There may be a wide variety of demand types depending on their reservation pattern: some reservations are made at the last minute while others are made long time in advance when a vehicle is needed for a scheduled activity. Both types of demand introduce constraints for the operator. Thus, the operational management of carsharing systems is complex due to the stochastic and dynamic nature of demand in time and space, and the limited availability of information. The operator of such a system has to manage it in a way that maximizes the use of the system while at the same time all operational and business constraints are satisfied.

We focus in this paper on non-floating one-way electric carsharing systems because of their increased flexibility towards the user compared to round-trip systems and their eco-friendly characteristics. In particular, the objective of this paper is to develop and apply an integrated framework for optimizing operational decisions related to vehicle and relocation personnel relocation decisions. The developed framework could be extended to free-floating one-way systems.

2. Previous related research

Carsharing systems have been studied intensively in recent years. The existing body of literature addresses issues related to carsharing systems characteristics and types, assessment of carsharing system impacts, and modelling of strategic, tactical and operational decisions. For a more comprehensive literature review the reader refers to Jorge and Correia (2013), Shaheen and Cohen (2013) and Boyacı et al. (2015). Given the focus of this paper on operational decisions we limit our literature review to papers that are mostly relevant to the modelling of operational decisions for one-way carsharing systems. These decisions relate to the allocation and re-allocation of carsharing vehicles and relocation personnel to stations. Optimization and/or simulation are the methodological approaches that have been used to support one-way carsharing operational decisions.

Barth et al. (1999) developed a queuing based discrete event simulation model to evaluate operational decisions for a shared vehicle system of a resort community in Southern California. The types of decisions addressed include vehicle availability, vehicle distribution, and energy management. This model uses a variety of performance measure, such as total average wait time, number of customers waiting, number of relocations, and average battery state of charge, to assess the performance of the system.

Kek et al. (2006) introduced a time-stepping simulation model for assessing relocation operations using shortest time and inventory balancing criteria. Zero-vehicle time, full-port time, and number of relocations were the three indicators used to assess the performance of the relocation operations. Kek et al. (2009) used a three-phase optimization-trend-simulation (OTS) approach to develop a decision support system (DSS), for relocation operations. The optimization phase is based on a mixed integer programming (MIP) formulation which is used to determine the resources needed to operate the carsharing system at minimum cost. In the second phase the output of the optimization phase is "filtered" to produce the parameters needed to simulate the operation of the carsharing system. The simulator developed in Kek et al. (2006) is used in the third step of the proposed DSS.

Nair and Miller-Hooks (2011) proposed a stochastic mixed integer programming (MIP) model to generate minimum cost vehicle redistribution plans to satisfy a proportion of the near-term stochastic demand of the carsharing system. The proposed model was demonstrated on a real-world carsharing system in Singapore.

Correia and Antunes (2012) developed an optimization approach for station location and trip selection schemes to maximize profit for one-way systems with stations. This work showed that offering a high level of service to one-way systems without involving relocation requires a very large fleet to cope with the demand and high involved cost. Thus, integrating a relocation module is necessary to deal with spatial and temporal asymmetry of demand. Correia et al. (2014) considered how information about vehicle availability in stations and flexibility of users in renting from a station nearby, but not the closest station, can improve the demand served. No relocation strategies have been integrated in this formulation.

Relocation strategies and inventory management for bike-sharing systems already exist in the literature (Benchimol et al., 2011; Nair et al., 2013; Raviv and Kolka, 2013; Raviv et al., 2013; Sayarshad et al., 2012). While bike- and carsharing systems share plenty of similarities both at the tactical and operational level, a significant difference is that relocation is usually performed with trucks that are able to reposition simultaneously a large amount of bicycles, while for carsharing systems, these actions are more time- and personnel-consuming.