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Vehicle relocation and staff rebalancing in one-way carsharing systems

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ABSTRACT

A solution to the imbalance of vehicles in one-way carsharing systems is vehicle relocation which involves staff members to redistribute the vehicles between stations. Vehicle relocation, however, can lead to an imbalance of staff members between stations. Thus, staff members, themselves, need to be relocated between stations to perform the vehicle relocations. This study addresses the joint optimization of vehicle relocation and staff rebalancing using two integrated multi-traveling salesman formulations. Results show that fleet size is more sensitive to demand than staff size, staff size is inversely related to vehicle cost, and that vehicle relocation time increases with vehicle cost.

1. Introduction

CarSharing Organizations (CSO) are an alternative to private vehicle ownership that provides individuals access to a fleet of shared-vehicles available at designated stations. CSO members (hereafter referred to as users) generally pay a subscription fee and are charged on hourly or minute-by-minute rate. Over the last two decades, CSOs have grown in North American, Asian, and European Cities. In North America, the number of carsharing members has raised from 905 in 1998 to 208,584 in 2012 (Shaheen et al., 2012). Such growth has contributed to urban sustainability. For instance, City Carshare in San Francisco released an environmental report in 2013 emphasizing the company's role in reducing a total of 25 million vehicle miles, and 85 million pounds of CO_2 emissions (City Carshare, 2013).

CSOs are generally classified as one-way and round-trip systems. Round-trip systems (e.g. Zipcar and Autoshare) require users to return the rented vehicle to the same station from which it was picked up (Costain et al., 2012). One-way systems (e.g. Car2Go), on the other hand, are flexible about the drop-off station and do not impose any restrictions. According to their definitions, round-trip systems are a special case of one-way systems with drop-off station constraints. This extra constraint can be unappealing to users who have longer activity durations or those who do not need the return trip at all. For instance, a user going to work in the morning would be charged for the entire work period up until the vehicle is returned to its original station. Hence, a one-way trip would be more engaging. Realizing this shortcoming of round-trip systems, some prominent

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CSOs are considering the addition of the one-way option. This is an essential transformation as 94% of all North American CSO memberships belong to round-trip systems (Shaheen et al., 2006). In May 2014, Zipcar, a round-trip CSO with 12 years of experience, 10,000 vehicles, and 850,000 users, announced a new one-way carsharing option. In Montreal, Canada, Communauto, a round-trip system with 29,000 users and a fleet of 1200 vehicles announced a one-way carsharing pilot project in 2013 (Woodland, 2013).

One-way CSOs are further divided into free-floating and station-based (non-free-floating) systems. In free-floating systems, users are allowed to park the vehicles at any location of choice but generally within some predetermined boundary whereas in station-based systems users are obliged to park the vehicles at designated parking stations. Despite their many benefits, one-way systems pose some challenges. As users freely move vehicles between stations, an imbalance of vehicles can occur. To relieve vehicle imbalance, one-way CSOs relocate vehicles between stations (Kek et al., 2009; Nourinejad and Roorda, 2014), impose parking reservation policies (Kaspi et al., 2014), and balance their station capacities (El Fassi et al., 2012). Among these, vehicle rebalancing is imperative as it entails a tradeoff between fleet size and staff size. Roughly speaking, CSOs with relatively large fleet sizes require few relocation operations and consequently few relocating staff whereas CSOs with smaller fleet sizes require more extensive relocation operations and consequently more staff members to perform them. Alternatively, as the staff are relocating vehicles, an imbalance of staff can also occur. Hence, three sets of problems are at hand: (i) given a database of user reservations, which we assume to be given, what is the required fleet and staff size in order to serve all users with the objective of cost minimization, (ii) how should the vehicles be relocated in the network, and (iii) how should staff be assigned to different vehicle relocation tasks. In answering the three proposed questions, this study presents a joint optimization model of vehicle relocation and staff rebalancing. While vehicle relocation has been studied before, staff rebalancing requires further research. Most available models assume that a vehicle can be relocated from any station to any other station regardless of whether a staff member is present to perform the relocation task or not. This oversight of staff members weakens applicability of any model.

The remainder of this paper is as follows. A literature review on vehicle relocation and staff rebalancing in one-way CSOs is presented in Section 2. A fleet and staff size optimization model is provided in Section 3. Model analysis on a case study of Car2Go is performed in Sections 4 and 5. Conclusions are presented in Section 6.

2. Literature review

The following terms are defined to avoid any confusion in the remainder of this paper:

Vehicle relocation: A vehicle is relocated when a staff drives it from one station to another.
Staff rebalancing: A staff member is rebalanced between stations to perform two separate relocation operations.

Examples of vehicle relocation and staff rebalancing are provided in Fig. 1 for two scenarios. While a vehicle is relocated only when a staff drives it, staff rebalancing can be done via various modes such as biking or taking public transportation. That is, if a staff has two relocations to perform, he/she can bike after finishing the first relocation to start the second one. Biking as a mode of staff rebalancing is possible if each vehicle has a bike rack. This allows staff members to carry their vehicles as they are relocating vehicles.

We divide the following literature review into two subsections pertaining to (i) vehicle relocation and (ii) staff rebalancing in one-way CSOs.

2.1. Vehicle relocation

In a comprehensive literature review on carsharing systems, Jorge and Correia (2013) identify vehicle relocation as one of the fundamental strategies for reducing costs in one-way systems. Among the first to consider vehicle relocation are Dror et al. (1998) who propose using a fleet of finite capacity tow trucks to redistribute a fleet of electric vehicles. This problem is modeled as a pickup and delivery problem and a mixed integer linear programming formulation is provided. Barth and Todd (1999) develop a simulation model with three main components: (i) a stochastic trip generator which produces origin–destination pairs and inter-request times (i.e. time between two requests), (ii) a traffic simulator which takes trip generation inputs and simulates each vehicle in the network according to trip features such as departure time and origin–destination zones, and (iii) a relocation mechanism which can be static, predictive, or exact. Static relocation is based on the immediate relocation need at a station where a request has occurred but no vehicle is available, predictive relocation uses knowledge of expected vehicle demand in the future, and exact relocation assumes that perfect knowledge of future demand is available. Their study shows that vehicle relocation is minimized when there are 18–24 vehicles available for every 100 users. However, it is not clear whether an optimization approach would provide lower operating costs. In another simulation-based research, Wang et al. (2010) present a forecast-based relocation model with the following three major components: (i) macroscopic traffic simulation, (ii) forecasting model, and (iii) inventory replenishing model. In the forecasting model an estimate of aggregate origin–destination demand is obtained which is passed on to the inventory replenishing model where relocations are composed. In the inventory replenishment model, stations holding excessive or too few vehicles are labeled overstocked and understocked, respectively. The relocation process involves moving vehicles from overstocked