Transportation Research Part C 86 (2018) 407–424

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Integrating operational decisions into the planning of one-way vehicle-sharing systems under uncertainty

Yinghan Deng, Michel-Alexandre Cardin*

National University of Singapore, Department of Industrial Systems Engineering and Management, Block E1A 06-25, 1 Engineering Drive 2, 117576, Singapore

ARTICLE INFO

Keywords:
Vehicle-sharing system
Discrete-event simulation
Particle swarm optimization
Optimal computing budget allocation

ABSTRACT

This study proposes a systematic approach for planning and operating a one-way vehicle-sharing system (VSS) under demand uncertainty. It investigates the distribution of parking spaces and vehicles considering stochastic demand and interactions with the major operational decisions, namely vehicle redistribution activities. An optimization model is formulated that aims to determine the best deployment strategy for minimizing overall cost while achieving a certain level of service (LoS). Then, a simulation-based solution approach based on a discrete-event simulator (DES), Particle Swarm Optimization (PSO), and Optimal Computing Budget Allocation (OCBA) is devised to solve the mathematical model. The methodology is then applied to a car-sharing system in Singapore. Results demonstrate that considering rebalancing activities is imperative in making deployment strategies. The case study also provides managerial insights regarding designing and operating one-way VSS.

1. Introduction

Rapidly growing populations, intensified land scarcity, and increasing environmental concerns pose unprecedented challenges to urban transportation systems. As a response to these ongoing challenges, vehicle-sharing systems (VSSs) have emerged in recent years. Vehicle systems are perceived as a promising alternative for urban transportation because of their ease of use and potentially large overall social benefits. For example, for car-sharing systems, users enjoy the convenience and comfort of private automobiles without the associated high cost, insurance requirements, need to refuel, service and repair demands, or parking problems (Mitchell, 2008). Substantial evidence suggests that encouraging people to use VSS is effective to alleviate people's reliance on private vehicles (Katzev, 2003). Therefore, more parking areas will be freed up for other public use and road congestion will be reduced.

A VSS involves a fleet of vehicles strategically located at stations across the transportation network. Vehicle fleets can comprise bicycles, low emission cars, or electric vehicles (Nair and Miller-Hooks, 2011). Stations in VSSs mainly consist of parking areas for cars or bikes, and charging facilities if electric vehicles are used. Existing VSSs can be categorized into two types, one-way or two-way. For two-way sharing systems, users are required to return the used vehicle to the station where it was picked up. Car-sharing systems are mostly two-way. Companies like Zipcar (http://www.zipcar.com) and Hertz (https://www.hertz.com) currently operate such systems. Compared with the two-way sharing systems, one-way VSSs are more flexible: users can walk to a nearby station to pick up a vehicle, and then drop off the vehicle at any station near their final destination. Initially, most one-way VSSs were bike-sharing systems that gradually became a popular choice for urban mobility, such as Vélib in Paris (http://www.velib.paris.fr) and Hubway in Boston (http://www.thehubway.com). Recently, more and more one-way car-sharing systems have been implemented, with the

* Corresponding author.
E-mail address: macardin@nus.edu.sg (M.-A. Cardin).

https://doi.org/10.1016/j.trc.2017.11.018
Received 5 December 2016; Received in revised form 20 November 2017; Accepted 20 November 2017

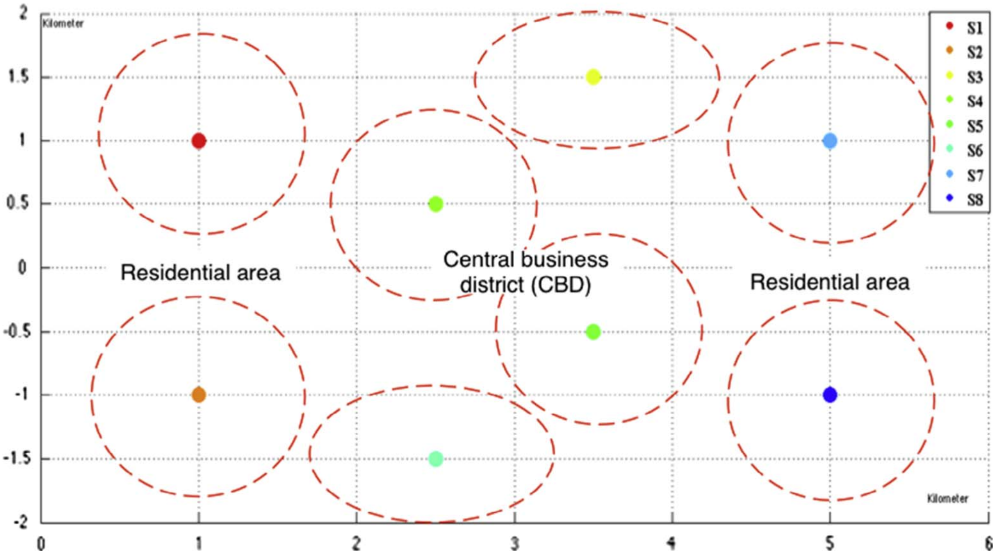

Fig. 1. Illustration of the target problem.

success of Car2go (https://www.car2go.com) in North America indicating the potential of such systems. Because of the usage mode, one-way VSSs are more likely to be utilized as a connection to existing public transport modes or as their substitute. The one-way VSSs can be further subdivided into station-based ones, where users need to return the vehicle to any parking areas rented by the company, and free-floating ones, where users have the freedom to drop off the vehicle anywhere within a certain area.

However, successfully deploying and operating a one-way VSS is even more difficult than two-way systems. In addition to the demand being difficult to predict and highly fluctuating, which calls for dynamic decision-making and prompt actions, the inherent imbalance of urban traffic flows frequently leads to an inefficient use of the system: areas with higher return rates may become overstocked with a large number of idle vehicles that could be better used if relocated to places in need of vehicles (Jorge and Correia, 2013). Moreover, the performance of a one-way VSS is largely influenced by the intricate interactions between different levels of decisions, among which the trade-offs may not be very explicit.

This paper targets the planning and operating issues of one-way station-based VSS. As compared with free-floating systems, more managerial and operational difficulties may be involved for operators of such systems. More specifically, it aims to assist stakeholders to determine the distribution of vehicles and parking spaces when faced with stochastic and imbalanced demand. More importantly, it investigates how such strategic decisions interact with operational decisions, namely vehicle redistribution activities. Take the problem illustrated in Fig. 1 as an example. The geographical region of interest is divided into eight zones with dots representing their centers. The zones represent clusters of adjacent parking spots, namely the maximum straight-line distance, namely the diameter of the circle, between parking spots located in the same subarea is within waking distance range. Therefore, within each zone, there is no difference for customers to pick up or drop off vehicles at any specific parking spot, but such difference does exist between zones. There are other studies utilizing complex models, e.g. clustering analysis Vogel et al. (2011), to understand how these zones can be more accurately defined. This study focuses more on how to plan and operate the whole system, however, and after the zones is already defined. Under such assumptions, this study intends to devise an approach to determine the following parameters for each zone: (1) the number of parking spots to be rented and (2) the number of vehicles to be placed at the beginning of the day.

The rest of the paper is organized as follows. The next section reviews the relevant literatures, identifies the research opportunity and explains the motivations for this study. Following this, the paper elaborates on the proposed methodology, including the models and the computational algorithm. Then, the methodology is further illustrated by a case study that demonstrates the effectiveness of the proposed analysis. Finally, the paper concludes by discussing the major findings and opportunities for future work.

2. Literature review and motivation

The literature on the quantitative planning and detailed operation of VSS was virtually non-existent until a few years ago, but has been growing rapidly in recent years. Existing studies can be roughly categorized into three sub-streams: data analytics, strategic planning, and rebalancing operations. Some of these studies address bike-sharing systems, while others pertain to car-sharing systems.

Authors in the area of data analytics focus on understanding and characterizing the usage patterns of VSSs. For example, Vogel et al. (2011) apply clustering analysis to riding data from Vienna's bike-sharing system, "Citybike Wien", identifying five distinct clusters based on pickup and return patterns over time. Borgnat et al. (2011) rely on non-stationary statistical modeling and data mining to describe the evolution of the dynamics of movements within the Vélib system in Paris. The spatial and temporary demand patterns are also described, and the social behavior of the users is explained. Using demographics and travel survey data, Ciari et al.