The value of anticipating information in free-floating carsharing systems

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1 INTRODUCTION

Several studies indicate that a large fraction of the population does not use, or uses very rarely, public transport, and prefers to use a private car instead. As an example, according to a recent study on modal split for passenger transport in Europe[1], private cars accounted for 82.9% of inland passenger transport in the EU in 2016, whereas motor coaches, buses and trolley buses (9.4%) and passenger trains (7.7%) each accounts for less than a tenth of all traffic. The motivations of such low usage rates are mainly related to the fact that the traditional public transportation systems cannot satisfy the mobility needs of most users. The main drawbacks of public transportation systems are: lack of flexibility, frequent delays, long detours, lack of comfort. On the other hand, public transportation systems are known to inefficient, overcrowded during rush hours and under-used in off-peak hours. All the above reasons stimulated the design and implementation of new mobility systems, which aim at attracting users by offering a better and more flexible service. Carsharing systems are among those that report a high growing rate. The number of cities where at least one carsharing system is available is constantly trending upwards, as well as the number of users. The success of carsharing systems can be explained by multiple factors. Firstly, they enable users to travel directly to the desired destination, thus avoiding the delays experienced with public transportation systems with fixed itineraries and frequencies. Moreover, users have access to cars without several of the responsibilities and costs associated with car ownership, including the purchase and insurance costs. A recent survey conducted in Italy[2] shows that only 57% of car owners use their vehicle almost every day, whereas the remaining 43% use it 2-3 times per week or less frequently. Thus, the fixed costs associated with car ownership are hardly amortized. Some important benefits are also offered to carsharing users, such as the opportunity to travel in restricted traffic zones or to park in dedicated areas, often free of charge. In fact, when using private cars, the time required to find a parking spot close to the destination may be remarkable. Several studies have shown that this time is not

[1]https://www.sipotra.it/wp-content/uploads/2019/06/Passenger-transport-statistics.pdf
[2]https://www.statista.com/statistics/1122212/private-car-use-frequency-in-italy/

negligible, and contributes substantially to the overall travel time. A recent study[3] reports that in 2016 the average driving time was less than one fourth of the average parking time in different European countries.

Modern carsharing systems can be classified in different ways. The classification in two-way (also called round-trip) and one-way systems is related to the return location. In the former systems, users are required to begin (by picking up the car) and end (by returning the car) their trip at the very same location. In the latter systems, users are allowed to begin and end their trip at two different locations. Typically, in one-way carsharing systems operators are needed to relocate the cars from areas with an excess demand to areas with a shortage of cars. This is one of the major drawbacks of one-way systems, due to the cost associated with carrying out the relocating operations. A second classification is related to the degree of freedom given to the user in terms of parking the car. In station-based (or stationary) services, users are required to park the car at designated parking stations. In other systems users are allowed to park the car at any legal parking location within the geographical boundaries determined by the operator. One-way systems where cars can be freely parked are called *free-floating carsharing systems*. As far as the service model is concerned, carsharing systems can be classified into two main categories: *reservation-based* and *instant-access* systems. Reservation-based systems require customers to make reservations in advance and within a given deadline (e.g., one day before the vehicle usage). Conversely, instant-access systems do not require any reservation. In other words, if the car is available where requested, the user has instant access to it. In between, there are carsharing systems with *real-time reservations*, and those with *open-ended reservations*. Carsharing systems with real-time reservations are particularly relevant to our research. In these systems, users submit their request (through a mobile app or a web-based application) and receive immediately (i.e., in real-time) or within a very short time the notification of whether it has been accepted or rejected.

A recent survey by Ferrero et al (2018) analyzes and classifies 137 papers covering the last fifteen years of research on carsharing, and identifies some mainstreams based on the different carsharing services and the research questions that emerged from the papers. In the operations research literature many authors are concerned with the solution of operational problems, whereas a relatively small number of papers contribute to managerial and strategic decisions (see, e.g. Boyaci et al (2017). This paper aims at giving a contribution to the evaluation of different carsharing systems.

2 CONTRIBUTIONS OF THE PAPER

2.1 The carsharing system

In this paper, we propose and analyze a management strategy for free-floating carsharing systems with both instant-access and real-time reservations, where a user is allowed to place a reservation also when no car is available at the desired pickup location. The underlying idea is that it may be possible to assign to the user a car that is in use at the time of the reservation but will become available at the time the user will need it. The system, that we call *look-ahead free-floating carsharing system* or simply *look-ahead system*, aims at taking advantage of advanced information about when and where the cars will be returned. A user is allowed to directly pick up a car if available at the time and location desired (i.e., instant-access). In this case, we assume that to start the engine the user must indicate where the car will be returned, along with an estimate of the return time. If, instead, a user prefers to reserve a car in advance for future travel needs, a reservation is made through a time window for the pickup time. The acceptance or rejection of the reservation is notified to the user in real-time or within a very short time frame (e.g., 5 minutes). The acceptance/rejection decision is taken on the basis of the information on

[3] https://publications.jrc.ec.europa.eu/repository/handle/JRC77079

the cars parked and currently in use, and on other simultaneous reservations. To increase the probability to accept a reservation, users may be requested to walk for a certain distance to pick up the car at a location different from the desired one, but not too far. If a car is, or will become, available in the parking location recommended by a user, the request made is satisfied by assigning to it the corresponding car. If a car is, or will become, available at a parking location within a maximum walking distance from a user-specified location, the request is satisfied by assigning to it the corresponding car. In case no such car exists - i.e., no car is, or will become, available within the desired time window and at the recommended parking location or nearby - the request is rejected.

2.2 The analysis

In order to measure the benefits of the look-ahead system, we perform a simulation study based on real-world data from the city of Milan (Italy). We compare the look-ahead system with a system, called *current system*, that mimics the behavior of the main systems currently active in Milan. In the current system users pick up or reserve a car only if it is available at the time and location desired. As a reference, we also consider the case, called *perfect info system*, where all the information about the users requests (pickup and return locations, and time) is known in advance.

Note that to simulate the current system no optimization problem needs to be solved. In fact, after sorting chronologically all the requests based on the moment each of them is placed, each request at a time is analyzed to determine if it can be accepted or must be rejected. In case more than one car is available, the car located in the parking location closest to the one desired by the user is assigned. After accepting each request, the availability of the car assigned is updated accordingly.

To simulate the perfect info system, we present a *static optimization model*, which turns out to be a mixed integer linear programming model, based on the assumption that all the information is available to the decision-maker upfront. The main objective of the model is to maximize the number of satisfied requests. A second level objective is the minimization of the distance between the desired pickup parking location and the assigned one.

Finally, to simulate the look-ahead system we present an optimization model for the case where the information is revealed to the decision-maker dynamically over time. The optimization problem calls for determining an optimal assignment of requests to cars that are parked or in use, where each assignment will have to satisfy each request in terms of window of availability and parking location.

2.3 The computational environment

The data concerning the requests of cars made by users was simulated by exploiting real-world data for the city of Milan (Italy). The simulator was developed in MATLAB. The models were implemented in Java, and the LP relaxations of the optimization models were implemented by using the ILOG Concert Technology API (CPLEX version 12.10). All the experiments were conducted on a Workstation HP Intel(R)-Xeon(R), equipped with a 3.5GHz 64-bit processor, 64GB RAM, and Win 10 Pro as Operating System. The processor was equipped with 6 cores, but all the tests were performed by using only one thread.

We simulated the carsharing demand by exploiting the survey on the mobility of people conducted in the Milan area by the Agency for Mobility, Environment and Territory of the Municipality of Milan (AMAT). For administrative purposes, the city of Milan is divided into several census zones, where each zone has uniform environmental and socio-economic characteristics. The original data refers to private car trips from/to different census zones in Milan and is organized in an Origin-Destination (O-D) matrix. The trips are classified according to their scope (such as, business, study, and occasional) and three different time frames: morning (7:00

to 10:00; peak hours), off-peak (10:00 to 16:00), and evening (16:00 to 20:00; peak hours). We focused on the data describing the occasional trips, as they are the most representative of the carsharing users. Hence, from the original O-D matrix, we extracted the data concerning these occasional trips. To the sake of brevity, in the following the latter is simply referred to as the O-D matrix. The time horizon $[0, T]$ is discretized in time slots, of 1 minute each. For each census zone, given in input, we computed its centroid and the node of the road network closest to such centroid. Centroids and the corresponding nodes were determined by means of the ArcGIS software. We refer to the road network nodes as *centroid nodes*. We assume that the set of parking locations coincides with this set of centroid nodes. This assumption is motivated by the observation that in our case study the census zones are relatively small. Hence, the centroid nodes can be considered as good approximations of parking locations. In the simulation, we considered the 105 census zones located within the ring road of Milan since most of the carsharing trips occur in this area.

2.4 The results

The results of the computational experiments show that the look-ahead system outperforms considerably the current system in terms of various performance indicators, particularly the acceptance and the utilization percentages. The results also indicate that the performance of the look-ahead system is only slightly worse than the benchmark produced by the perfect info system.

The main insights are as follows:

- The average value of the acceptance ratio achieved by the look-ahead system is more than twice that of the current system;
- The average value of the acceptance ratio achieved by the look-ahead system is only slightly smaller than the benchmark value provided by the perfect-info system;
- As expected, the longer the maximum walking distance a user is available to walk, the better the performance of each carsharing system is, both in terms of acceptance and utilization ratios.

3 REFERENCES

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