Comparing optimal relocation operations with simulated relocation policies in one-way carsharing systems

Diana Jorge *

Department of Civil Engineering,

University of Coimbra, Coimbra, Portugal

Gonçalo Correia

Department of Civil Engineering,

University of Coimbra, Coimbra, Portugal

Cynthia Barnhart

Department of Civil and Environmental Engineering,

Massachusetts Institute of Technology, Cambridge, USA

***** Email: diana.jorge@student.dec.uc.pt

1 Introduction

Carsharing is a transport option that allows people using a private vehicle without having to own it. In what respects to type of trips, carsharing systems can be classified into: round-trip, in which users have to return the cars to the same station from where they departed; and one-way, in which users can pick up a car in a station and return it to another one [1]. This last type is more convenient for the users but it presents a system imbalance problem in vehicle stocks due to non-uniformity of trips between stations.

Previous research has proposed several approaches to solve this problem, such as: vehicle relocations [2,3,4]; pricing incentive policies for the users to relocate the vehicles themselves [5,6]; operating strategies designed around accepting or refusing a trip based on its impact on vehicle stocks [7,8]; and station location selection to achieve a more favorable distribution of vehicles [8].

Correia and Antunes [8] proposed a mixed integer programming model to locate one-way carsharing stations to maximize the profit of a carsharing company, considering the revenues (price paid by clients) and costs (vehicle maintenance, vehicle depreciation, and maintenance of parking spaces), and assuming that all demand between stations should be satisfied [8]. In applying their model to a case study in Lisbon, Portugal, tractability issues resulted and the model was only solvable with time discretization of 10-minutes steps.

In this paper, the same case study as the one in [8] is considered and station location outputs are generated using their model but with time discretizations of 1-minute. An approach to optimize relocation operations on a minute-by-minute basis is developed, given those outputs for station locations. These optimal vehicle relocations are compared to different real-time vehicle relocation policies implemented in a simulation model. This methodology should allow concluding on the influence of relocation operations on the profit of one-way carsharing and how to implement them.

2 Mathematical model

The objective of the mathematical programming model is to optimize vehicle relocation operations between stations. The decision variables of this model are: number of vehicles, number of parking spaces, and relocation operations. The objective function is the same as the one in [8], but including also the relocation costs.

3 Simulation model

In the simulation model, it is assumed that a trip will be performed only if there is simultaneously a station near the origin of the trip and a station near the trip destination. The environment is the case study city (Fig. 1), which influences the system through the effects of congestion on the road network with different link travel times throughout the day. These times were computed using the transportation modeling software VISUM (PTV).

In each minute, trips and relocation operations are triggered and the model updates a number of system attributes, including: number of completed minutes driven by customers and by vehicle relocation staff; vehicle availability at each station; total number of vehicles needed; and maximum vehicle stock at each station. These indicators are used to compute the objective function, which is the same used in the mathematical model.

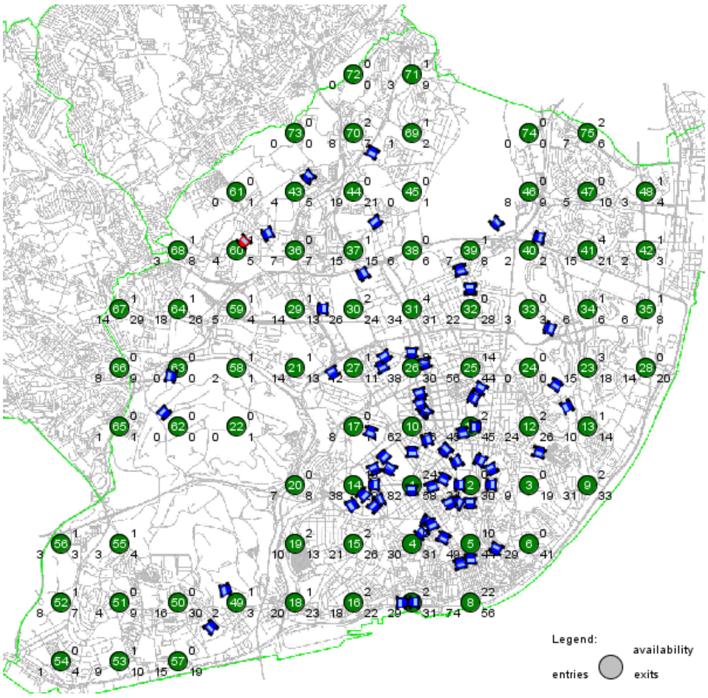

Fig. 1. Simulation visualization of the municipality of Lisbon with all the possible stations location

Two real-time relocation policies (1.0 and 2.0) were tested in the simulation. In the first one, it is determined for each minute of the day at each station *s* if the status of *s* is that of supplier or demander. A station *s* at time *t* is classified as a supplier if, on a previous day of operations, the average number of customer trips destined for that station at period $t+x$ exceeds or equals the average number of customer trips that depart that station at the same period. Note that only customer trips, and not repositioning trips, are included in this calculation. Each station that is not designated as a supplier is classified as a demander. If *s* is classified as a supplier, its supply is equal to the number of extra vehicles (those not needed for serving customer demand) at *s* at time *t*. If *s* is classified as a demander, its demand for vehicles is set equal to the number of additional vehicles needed to serve demand at time $t+x$. For relocation policy 2.0, *x* is set equal to 1 minute and the set of supplier stations and the associated supplies are determined as described for policy 1.0. The remaining stations are designated as demanders with the value of demand calculated as in relocation policy 1.0.

Using relocation policies 1.0 and 2.0 as a starting point, three variants of these two policies were developed. The first is that each supplier station is required to keep at least one vehicle at that station (policies 1.A and 2.A). The second is that the distribution of vehicles at each station at the start of the day is set to that generated by the mathematical model defined in the previous section (policies 1.B and 2.B). And the third is the same as the second with priority given to stations with the greatest demand for vehicles (policies 1.C and 2.C).

To decide how to distribute vehicles between suppliers and demanders, a typical transportation problem in Operational Research is solved where supply from *m* origins is distributed to *n* destinations minimizing the total travel time.

4 Results and conclusions

In Table 1, we show the best simulation results for each relocation policy.

Table 1. Results for the different relocation policy

Solution (stations)	Indicators	Optimization of the stations' location	Best results for each policy							
			1.0	2.0	1.A	1.B	1.C	2.A	2.B	2.C
69 (full demand attended)	Vehicles	390	264	273	262	264	257	267	318	222
	Parking spaces	739	533	490	550	412	409	480	415	334
	Time driven (min)	23711	23711	23711	23711	23711	23711	23711	23711	23711
	Time of relocations (min)	0	4008	2921	4800	4346	5169	2967	2661	9051
	Profit (€/day)	-1160.7	591.7	742.1	433.3	766.1	726.5	854.9	179.1	695.1
34 (free optimum)	Vehicles	121	121	121	121	126	125	121	126	126
	Parking spaces	241	241	241	240	195	195	241	195	195
	Time driven (min)	10392	10392	10392	10392	10392	10392	10392	10392	10392
	Time of relocations (min)	0	0	0	4	0	54	0	0	0
	Profit (€/day)	505.9	505.9	505.9	507.1	512.9(*)	519.1(**)	505.9	512.9(*)	512.9(*)
10 (small network)	Vehicles	22	22	22	22	22	22	22	22	22
	Parking spaces	42	42	42	42	29	29	42	29	29
	Time driven (min)	2125	2125	2125	2125	2125	2125	2125	2125	2125
	Time of relocations (min)	0	0	0	0	0	0	0	0	0
	Objective (€/day)	164.6	164.6	164.6	164.6	190.6(*)	190.6(*)	164.6	190.6(*)	190.6(*)

(*) no relocations occur, profit achieved only by bringing the initial availability from optimization
(**) this profit is achieved using relocations and bringing the initial availability from optimization

Analyzing Table 1, we can conclude that by using real-time relocation policies we reach higher profits compared to having no relocations. For instance, for the case of having all demand satisfied, we go from a situation in which there are losses of about 1160€/day to a situation where the profit is about 855€/day (best relocation policy found), even with increased costs due to relocations. This improvement was achieved through reductions in the number of vehicles needed to satisfy demand and the number of parking spaces needed at stations.

In Table 2, we compare the results for: the station location model, the relocations optimization model, and the best performing simulated relocation policies.

Table 2. Results for the different problems

Models	69 stations		34 stations		10 stations	
	Profit (€/day)	Improvements (€/day)	Profit (€/day)	Improvements (€/day)	Profit (€/day)	Improvements (€/day)
Optimization of station location	-1160.7	--	505.9	--	164.6	--
Optimization of relocation operations	3865.7	5026.4	1768.1	1262.2	322.0	157.4
Simulation with the best relocation policy	854.9	2015.6	519.1	13.2	190.6	26

Results for the simulated relocation policies are far from the optimal relocation solutions, showing that it is difficult to design effective real-time strategies based on fixed rules. A case in point is the 34 station scenario in which the optimized solution has an improvement in profit of about 1262 €/day, while the real-time relocation policies improve profit only to about 13 €/day.

Nevertheless, it is important to observe that the policies evaluated in this work were able to make profitable the 69 station scenario that serves all demand in the city. Concluding, real-time relocation operations influence significantly the profit of one-way carsharing and should be implemented to balance these systems.

References

[1] Shaheen, S., Cohen, A., and J. Roberts, “Carsharing in North America: Market Growth, Current Developments, and Future Potential”, {\em Transportation Research Record: Journal of the Transportation Research Board}, 1986, 116-124, 2006.

[2] Kek, A., Cheu, R., and M. Chor, “Relocation Simulation Model for Multiple-Station Shared-Use Vehicle Systems”, {\em Transportation Research Record: Journal of the Transportation Research Board}, 1986, 81-88, 2006.

[3] Kek, A., Cheu, R., Meng, Q., and C. Fung, “A decision support system for vehicle relocation operations in carsharing systems”, {\em Transportation Research Part E: Logistics and Transportation Review}, 45(1), 149-158, 2009.

[4] Nair, R., and E. Miller-Hooks, “Fleet management for vehicle sharing operations”, {\em Transportation Science}, 45(4), 105-112, 2011.

[5] Mitchell, W., Borroni-Bird, C., and L. Burns, “Reinventing the Automobile: personal urban mobility for the 21st century”, Cambridge, Massachusetts: MIT Press, (Chapter 8), 2010.

[6] Febbraro, A., N. Sacco, and M. Saeednia, “One-way carsharing: solving the relocation problem”, 91st Annual Meeting of the Transportation Research Board, Washington, D.C., 22-26 January, 2012.

[7] Fan, W., Machemehl, R., and N. Lownes, “Carsharing: Dynamic Decision-Making Problem for Vehicle Allocation”, {\em Transportation Research Record: Journal of the Transportation Research Board}, 2063, 97-104, 2008.

[8] Correia, G., and A. Antunes, “Optimization approach to depot location and trip selection in one-way carsharing systems”, {\em Transportation Research Part E: Logistics and Transportation Review}, 48(1), 233-247, 2012.