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Evaluating an innovative sub-leasing type of the round-trip carsharing

Samira Ziyadidegan*[a], Luca Quadrifoglio[a], Elena Floris[b], Matteo Gravellu[b], Eleonora Sottile[b]

[a] *Zachry Department of Civil Engineering, Texas A & M University, College Station, USA*

[b] *Interuniversity Economic Research and Mobility Center, University of Cagliari, Cagliari, Italy*

**Address correspondence to Samira Ziyadidegan, Email: samiraziyadg@tamu.edu*

Evaluating an innovative sub-leasing type of the round-trip carsharing

This paper introduces a sub-leasing type of round-trip carsharing to enhance its efficiency for both customers and companies. This innovative type of carsharing provides new temporary stations and allows customers to access both vehicles in the company's stations and vehicles already reserved but parked and unused in other locations. The evaluation is performed using simulation with available demand datasets. Results show that the proposed model significantly increases the acceptance rate of the reservations, enhances the availability and accessibility of the company's vehicles, and reduces the needed fleet size. Hence, it provides many benefits for both companies and customers. Sensitivity analyses quantify the expected improvement by assuming a higher acceptable walking distance for customers and by increasing flexibility of the customers' reservation time.

Keywords: round-trip; carsharing; sub-lease; sensitivity; simulation; spatial and temporal flexibility

Introduction and Literature Review

Carsharing, as an innovative type of mobility, was first introduced in Switzerland in 1948 (S. A. Shaheen & Cohen, 2007). In the late 1980s, carsharing services were developed in Europe, and then spread out in North America and Asia in the 1990s (S. A. Shaheen & Cohen, 2007). During years, the market of the carsharing system has been growing fast and getting more popularity. It is predicted that the number of carsharing customers and fleet size will be over 36,000,000 and 427,000 in 2025, respectively (Boyacı & Zografos, 2019).

A reason for this popularity is that carsharing is spreading in the range of shared mobility by combining features from private and public transports (Pinna et al., 2017). People can travel using a shared private vehicle owned by a carsharing company without the expenses and responsibilities of ownership, *i.e.*, a specific number of vehicles is shared with a large number of users (S. Shaheen et al., 2019; Uesugi et al., 2007). During the last years, carsharing has also gained much popularity as an effective and sustainable solution to reduce CO_2 emissions and to lower the consumption of public land by reducing the temporarily parked and unused vehicles (Firnkorn & Martin Müller, 2011; Heling et al., 2009; E. Martin & Susan Shaheen, 2011; E. W. Martin & Susan A. Shaheen, 2011; Rabbitt & Bidisha Ghosh, 2013). Moreover, carsharing gives a potential contribution to the creation of a sustainable transport system (Duncan, 2011). Firnkorn and Müller (Firnkorn & Müller, 2012) have conducted a survey study on carsharing customers to examine the environmental effects caused by the reduction in private vehicle ownership.

Worldwide, several carsharing business models have been built (Cohen & Kietzmann, 2014; Hampshire & Gaites, 2011; Remane et al., 2016) and its operational practices are divided primarily into two major categories: station-based carsharing (which includes round-trip carsharing and one-way carsharing), and free-floating carsharing. In the round-trip type, customers are required to return the reserved vehicles to the station from where the vehicle was picked up. Whereas, in the one-way type, customers can return the reserved vehicle to any company's station, which is not necessarily the pick-up station. In the free-floating type, customers can pick up vehicles from any point within the operational area of the company and return them to anywhere within that area (Alfian et al., 2015; Ferrero et al., 2018; Firnkorn & Martin Müller, 2011; Jorge & Correia, 2013; Nourinejad & Roorda, 2015).

One of the issues faced by carsharing companies in station-based types (e.g., round-trip carsharing) is determining the station locations and spatial distribution (Ciari et al., 2016; De Luca & Roberta Di Pace, 2015). Placing them within the customers' acceptable walking distance is an effective step in carsharing success (Celsor & Millard-Ball, 2007; Costain et al., 2012). Daniels and Mulley (Daniels & Mulley, 2013) have introduced a 400-meter walking distance or multiples (e.g., 800 meters) as rules of thumb for the key distance in a network. De Lorimier and El-Geneidy (De Lorimier & El-Geneidy, 2013) set the maximum acceptable walking distance to a station as 1.1 kilometers. Cervero *et al.* (Cervero et al., 2007) have determined a 0.5-mile distance.

Another specific known problem faced by the round-trip carsharing is that the station locations are fixed (unlike the free-floating type), and customers have to bring back the reserved vehicles to the pick-up station (unlike the one-way type). This decreases the popularity of round-trip carsharing in comparison to the other types of carsharing (Namazu & Dowlatabadi, 2018; Wielinski et al., 2017). Adding spatial and temporal flexibilities to the system is a good way to help resolve the issue (*2, 24*). Although these strategies have helped, they require some kind of compromise from either the company or the customers or both. Herrmann *et al.* (Herrmann et al., 2014) have introduced customer-oriented relocation ideas (spatial flexibility) and have determined that customers are willing to accept smart strategies with a discount rate to collaborate with the company. Ströhle *et al*. (Ströhle et al., 2019) have determined that using both spatial and temporal flexibilities would help optimize a company's resources.

A noticeable room for improvement for the carsharing operations can be identified since many of the reserved vehicles are potentially unused for hours during an ongoing reservation when they are parked at intermediate destinations of the primary reserving customers. This was noted also by analyzing our available data (see Data Description section). To the best of our knowledge, previous studies have not considered this matter, although it can potentially improve the service's efficiency. We are exploiting this gap and introducing a new type of spatio-temporal flexibility by proposing a sub-leasing type of round-trip carsharing with the intent to benefit both carsharing companies and their customers. This innovative type of carsharing can extend the operational area of the carsharing system, increase the availability and accessibility of carsharing vehicles and enhance the popularity of the round-trip system. In parallel, companies may benefit from an increased demand and reduced fleet size. Case studies, performance evaluations, and sensitivity analyses are conducted at the end.

Sub-leasing type

This paper analyzes the potential increase in the efficiency of the round-trip carsharing service by introducing an innovative sub-leasing feature to the model. New temporary stations, which are current customers' parking locations, are dynamically potentially utilized by future customers. A user will communicate the position and his/her preferred time frame (i.e., start-time and end-time of the trip). The company's reservation system, then, will search through the available options based on the reserved time frame and through the locations of available vehicles, and finally, assign him/her a vehicle from the nearest station. Then the user might decide to sell part of his/her reserved time by making the vehicle available to others in a specific time frame within his/her own reserved time. This means that the reserved vehicle can be reserved again from a new location (the customer's intermediate parking location). As Figure 1 shows, consider user X reserves a vehicle from 8 am from station A and will need to bring it back to A at 6 pm. User X will take the vehicle at 8 am and park it at location B (a parking location), and does not need the vehicle anymore until 4 pm. Hence, user X decides to sub-lease the vehicle availability from 10 am to 4 pm to another customer. User Y will take the vehicle from location B to location C after 10 am and bring it back to B before 4 pm. Besides, if user Y allows further vehicle availability, user Z can also reserve the vehicle parked at location C from any time within user Y's allowable time frame, etc. The described system takes the shape of a spiral.

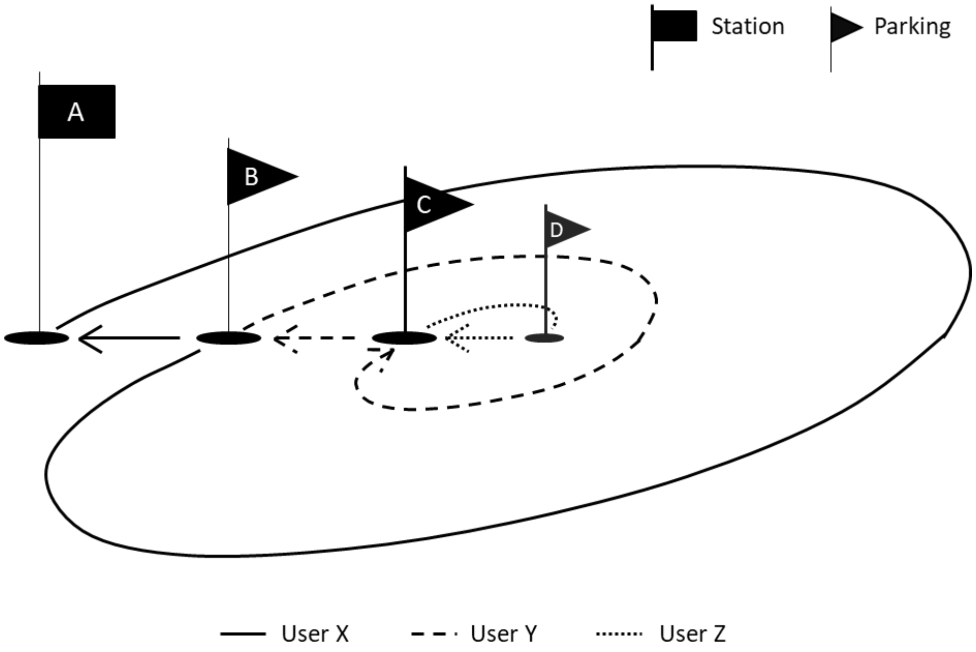


Figure 1 The spiral shape of the sub-lease carsharing system.

We are assuming that sub-lease customers are required to abide by the same rules of punctuality, cleanness and gas refill rules that are in place for regular round-trip customers.

Also, we are evaluating the feasibility and advantages of this new proposed system from an operational point of view. We are not focusing on legal aspects, which are certainly worthy of investigation, but are out of scope for this work.

Data Description

The study context is Cagliari, a city in southern Sardinia (Italy). The Cagliari municipality is about 85.3 km^2 wide and is inhabited by approximately 150,000 people. Playcar is a business company born in 2011, became a start-up in 2013 to introduce a carsharing system in the city of Cagliari, and finally, developed in 2014. Thanks to the in-depth knowledge of a previous rental company named "Mereu Felice Autonoleggio," Playcar is now one of the leading promoters of sharing mobility in the city of Cagliari. The company started its business with traditional round-trip carsharing and has introduced a free-floating fleet in the same area in 2019. Playcar Company has provided 54 vehicles used by 746 subscribers for their carsharing service since 2018.

To better understand the usage of carsharing in the city of Cagliari and to better define some of the input data of the algorithm described in the methodology chapter, an analysis has been conducted on a total of 13,762 reservation requests in 2018. Each reservation was related to a complete trip composed of a sequential series of sub-trips (each sub-trip started when the vehicle got moving and ended when it stopped). Table 1 shows the average and the corresponding percentile values of the three parameters. As they are described, 85 percent of customers' trip distance was less than 29 km with a vehicle speed of 20 km/h. Moreover, 15 percent of users booked a trip which is less than 30 minutes. The 85-percentile speed (20 km/h) is assumed as the average speed in this paper.

Table 1. Average and Percentile Values of Round-trip Reservations' Variables.

Variable	**Average**	**Percentile value**
Distance on board (km)	20.93	29 (85th percentile)
Reservation time (h)	3.22	0.48 (15th percentile)
Speed (km/h)	11.2	20 (85th percentile)

To test the algorithm (introduced later), a real dataset and a made-up dataset were used. The real dataset (Playcar) used in this study has been extracted from 13,762 round-trip reservations made with Playcar Company in 2018. These round-trip reservations consisted of a series of sub-trips (usually two, sometimes more) which started when the vehicle got moving and ended when the engine shut down during their reservation time frame. Most of them included at least an intermediate parking location where the vehicle was still and unused for hours. The data correction process consisted of i) filtering out the reservations without information about the parking locations reached in each sub-trip and ii) finding the primary parking location among all the destinations reached by the user, which was done by selecting the destination coinciding with a shutdown of the engine, closer to half the total distance travelled by the customer (this was done as a working assumption to detect the temporary stations used later in our simulations). Finally, 6,252 reservations have been chosen.

Additionally, a made-up (Casa_Lavoro) dataset (a combination of long and short trips) is composed using partial information of mandatory trips driven from a survey conducted in the municipality of Cagliari. This dataset contains 389 potential reservations carried out in one day. Both of the real and made-up datasets contain the following information:

User membership id number;

Reservation start time;

Reservation end time;

The origin of the trip (Companies' stations);

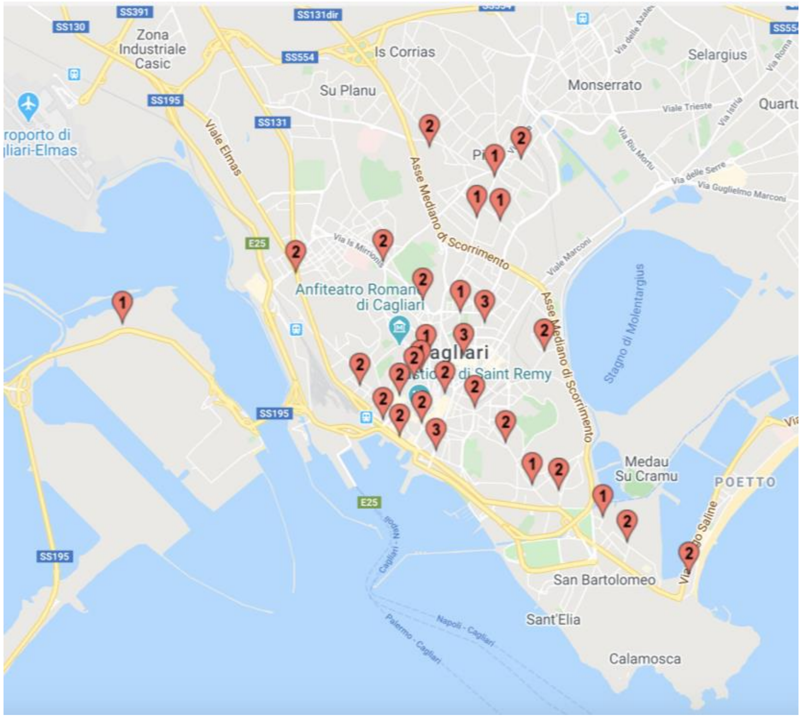
The destination of the trip (parking locations).

The following information of the company’s stations has also been provided (Figure 2):

Station id number;

Station locations;

The number of available vehicles in each station.



*Numbers on the map are the number of operational vehicles in each station

Figure 2. Carsharing stations managed by Playcar company in Cagliari (Italy).

Two different station datasets have been considered to test if a different number of operational vehicles in each station could change the results. The first one considers the exact number of operational vehicles of each station provided by the Playcar Company (Figure 2), which is 54 vehicles totally. The real station dataset indicated that the maximum number of fleets across all stations is three. So, a made-up station dataset is created considering three vehicles in each station (bringing the fleet to 90 vehicles) to compare the results between when the company uses the real fleet size and when the company uses the maximum capacity in each station.

Methodology

In order to test the feasibility of the new carsharing system and to verify the margin of the progress compared with the traditional round-trip type, an algorithm has been created and applied on both made-up and real datasets. Figure 3 shows the flowchart of this algorithm to assign vehicles to customers.

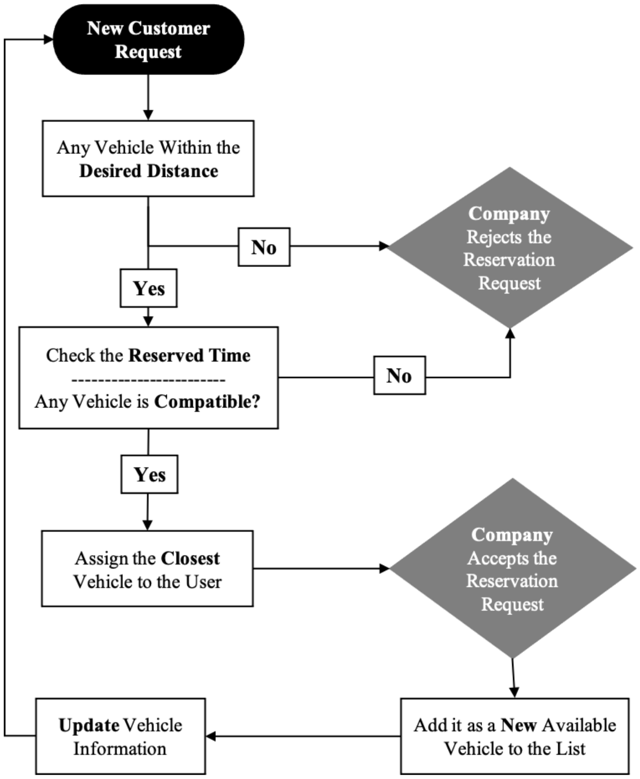


Figure 3 The flowchart of the innovative round-trip carsharing system.

As soon as a new request arrives, the availability of vehicles (both in the company's stations and in the customer's parking areas, the "sub-lease" vehicles) within acceptable walking distance from the customer's origin is verified. If confirmed, the scheduled time frame is checked. If compatible, the reservation is accepted, and the closest vehicle is assigned to the customer. Immediately upon accepting a reservation request, all the vehicle's information is updated (*e.g.*, parking location and reserved time frame) and the customer’s information is assigned to the vehicle (to clarify who has reserved the vehicle). If the vehicle is reserved from the company's stations, the vehicle will be returned to the station, and if it is reserved from the parked vehicles, it will be returned to the previous customer's parking location when the reservation time frame is over.

Assumptions considered in this study are as follows:

It is assumed that all customers are willing to sub-lease their reserved vehicles from their primary intermediate parking location. We are assuming that primary customers will not be charged the sub-leased time and/or will be compensated with some discount/credit. We recognize that this is ideal, but we are aiming to test and evaluate the best ‘upper bound’ system efficiency scenario, with maximum flexibility and availability of reservation time and vehicles;

The acceptable walking distance is set to 500 meters. A sensitivity analysis will also be performed for 750 meters (1.5*500), as suggested by (Cervero et al., 2007; Daniels & Mulley, 2013);

If the customers' distance to a station is equal to his/her distance to a parked vehicle, the parked vehicle is assigned to that customer;

When a user reserves a vehicle, it takes time to go from the pick-up location (origin) to the parking location (destination). To calculate this time period, the average speed is assumed to be 20 km/h, which is the speed obtained as the 85th percentile value (Table 1). Converting geographical coordinates to metric coordinates, the distance is calculated using Euclidean distance;

A vehicle can be leased to another user only if the vehicle's reserved time frame is more than the "critical time period" (set to one hour), which is the minimum time interval needed to guarantee the smooth performance of the system (since the vehicle speeds vary during the day due to peak and off-peak periods). Indeed, a limited critical time period could be too risky for trip chaining among different customers who could have difficulties returning the vehicle to the temporary stations on time.

Results

In the following section, we show the results of our analyses associated with experiments performed by varying four macroscopic parameters: the service model (Traditional round-trip vs. Innovative sub-lease), the data set (Casa_Lavoro vs. Playcar), the total fleet size (54 vs. 90) and the maximum acceptable walking distance (500m vs. 750m).

Table 2 shows the results for the made-up (Casa_Lavoro) and real (Playcar) dataset with a total of 54 available vehicles in stations for 500 meters acceptable walking distance. It can be seen that using the innovative carsharing type can highly increase the accepted reservation requests for the Casa_Lavoro dataset. Using the traditional type of carsharing, the acceptance rate is 14.91%; the innovative carsharing type can enhance the acceptance rate more than twice (34.96%). However, for the Playcar dataset, comparing the results shows no significant change in total accepted reservation requests. The innovative type only increases the acceptance rate by 0.03%. The reason is that the Playcar dataset is consisting of already accepted reservations of the company, not all the reservation requests.

Table 2 also indicates the results for 750 meters acceptable walking distance. Results reveal that the new acceptable walking distance does not have any meaningful impact on the reservation acceptance rate of the traditional type compared to 500 meters acceptable walking distance. This means that, in the traditional type, the trips are rejected due to time incompatibility such that increasing acceptable walking distance does not change the acceptance rate. Besides, due to the reason mentioned previously, the new walking distance does not significantly affect the Playcar dataset. However, results show that using 750 meters acceptable walking distance significantly (in comparison to 500 meters) increases the acceptance rate for the Casa_Lavoro dataset comparing to 500 meters acceptable walking distance when the innovative type is introduced.

Table 2. Summary of results for (a) made-up (Casa_Lavoro) dataset with 54 available vehicles, (b) real (Playcar) dataset with 54 available vehicles.

(a)

Acceptable Walking Distance (m)	**Type**	**Accepted reservations (1 day)**			**Rejected reservations**	**Acceptance rate (%)**	**Average walking distance (m)**	**Percent of the fleet used**
		Station trips	**Parking trips**	**Total**				
500	Traditional	58	-	58	331	14.91	259.8	98
	Innovative	58	78	136	253	34.96	253.8	98
750	Traditional	58	-	58	331	14.91	405.8	98
	Innovative	58	135	193	196	49.61	360.3	98

(b)

Acceptable Walking Distance (m)	**Type**	**Accepted reservations (1 year)**			**Rejected reservations**	**Acceptance rate (%)**	**Average walking distance (m)**	**Percent of the fleet used**
		Station trips	**Parking trips**	**Total**				

500	Traditional	6,249	-	6,249	3[1]	99.95	179.1	90.7
	Innovative	3,757	2,494	6,251	1[1]	99.98	133.5	88.9
750	Traditional	6,252	-	6,252	0	100	179.3	90.7
	Innovative	3,758	2,494	6,252	0	100	133.6	88.9

Table 2a shows that the number of accepted reservations for traditional round-trip carsharing (58 trips) is not really higher than the total number of available vehicles in the company’s stations (54 vehicles). However, for the innovative type of carsharing, results for the Casa_Lavoro dataset show that the number of accepted reservations for 500 meters acceptable walking distance is 136. This means that although 58 trips are performed from the company's stations, 78 additional trips have also been performed using reserved vehicles. The additional trips for the 750 meters walking distance are 135 trips.

The main reason for the shown increased acceptance rate in nearly all cases is associated with the larger temporal availability of sub-lease vehicles. In addition, a sizeable portion of the improved acceptance (compared to traditional type) is due to the lower walking distance and higher accessibility. These two are greatly improved in all cases by the sub-lease type service. We can measure it by comparing the average walking distance to reach the booked vehicle, which is significantly reduced (253.8m vs. 259.8m, and 360.3m vs. 405.8m).

Results from Table 2b reveal results for the Playcar dataset. For traditional carsharing type, 6,249 (6,252[2]) trips are made from the stations. On the other hand,

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[1] These customers were in fact accepted by Playcar, but their walking distance to their vehicle was barely over 500m, so our code rejected them, but without any meaningful impact on the results.

although the same number of trips have been done totally and the acceptance rate cannot significantly be improved from (nearly) 100%, in innovative carsharing type, 3,757 (3,758[2]) trips are made from the stations, and 2,494 (2,494[2]) extra trips have been performed using the vehicles already reserved. This causes a great reduction of the walking distance and improved accessibility (133.6m vs. 179.3m, and 133.5m vs. 179.1m).

To further evaluate the effect of available station vehicles on the acceptance rate of reservations in the innovative carsharing type and to compare it with traditional round-trip carsharing, another analysis has been performed considering three vehicles in each station (totally 90 vehicles for 30 stations) (Table 3).

Table 3. Summary of results for made-up (Casa_Lavoro) dataset with three available vehicles in each station (90 total), (b) real (Playcar) dataset with three available vehicles in each station (90 total).

(a)

Acceptable Walking Distance (m)	**Type**	**Accepted reservations (1 year)**			**Rejected reservations**	**Acceptance rate (%)**	**Average walking distance (m)**	**Percent of the fleet used**
		Station trips	**Parking trips**	**Total**				
500	Traditional	92	-	92	297	23.65	266.1	96.7
	Innovative	89	125	214	175	55.01	230.9	94.4
750	Traditional	92	-	92	297	23.65	386.8	96.7
	Innovative	92	193	285	104	73.26	337.4	96.7

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[2] Numbers in parentheses are for 750 meters of acceptable walking distance

(b)

Acceptable Walking Distance (m)	Type	Accepted reservations (1 year)			Rejected reservations	Acceptance rate (%)	Average walking distance (m)	Percent of the fleet used
		Station trips	**Parking trips**	**Total**				
500	Traditional	6,252	-	6,252	0	100	178.2	68.9
	Innovative	3,760	2,492	6,252	0	100	133.3	65.6
750	Traditional	6,252	-	6,252	0	100	178.2	68.9
	Innovative	3,760	2,492	6,252	0	100	133.3	65.6

It is evident that increasing the number of available vehicles would increase the number of accepted reservation requests using innovative carsharing type. For Casa_Lavoro dataset, when 54 vehicles are used, the total number of accepted reservations is 136 (193[3]). When 90 vehicles are used, the total number of accepted reservations becomes 214 (2853). For both scenarios, the total number of accepted trips is more than twice the number of the company's fleet size, a significantly more efficient way to use the available resources for the given demand. It can be inferred that to satisfy a given demand level, a lower sub-lease type fleet size is needed in comparison to the traditional carsharing type. This is also shown in Table 3b for the Playcar dataset, where all demand is served in all cases, but the percentage of used vehicles is lower for the Innovative service. Also, the same improvement in the accessibility is noted for all cases in Table 3 by looking at the average walking distance to the vehicle.

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[3] Numbers in parentheses are for 750 meters of acceptable walking distance

We would like to emphasize again that we are assuming that all customers are willing to sublease their reserved vehicles (if there is enough time to do so without any reservation slot). This is an ideal scenario coinciding with the maximum possible system efficiency. Realistically, not all customers will be willing to do so, even with a discount rate on their reservation price. However, our results are useful to identify the potential of the suggested service configuration and provide an upper-bound results and advantages. In-between scenarios (with a portion of customers willing to sub-lease) will have intermediate results and benefits.

Temporal flexibility

To further analyze the efficiency of the innovative type of carsharing, temporal flexibility has been assumed and evaluated for the rejected requests. If a trip is rejected due to the incompatible time frame, we assume that customers are willing to accept a reduction of their time frame. To do so, a reduction factor (X) is applied to the requested time frame to decrease it by X percent. Then, all the time frames (in one-minute increments) are analyzed chronologically to see if the trip can be feasible. For example, assume a customer asks for a vehicle from 10:00 to 13:00 (180 min), but there is no feasibility. Hence, the trip would be rejected. However, in the next step, a X% reduction in the reservation time frame is applied. With X=10%, the reservation time frame would be compressed by 18 minutes. So, the vehicle availability in any time frame from 10:00-12:48 to 10:18-13:00 (the step of one minute) is checked. The first available window (if any) will trigger acceptance for that customer. A sensitivity analysis is performed using the X values from 0%-20% with 1% increments. To evaluate the temporal flexibility, it is assumed that all customers accept any temporal flexibility options.

Figure 4 indicates the effects of the reduction factor (X%) on the number of rejected and accepted trip requests for the Casa_Lavoro dataset. As is mentioned previously, this reduction factor is only applied to the time frame of the rejected requests and checked if the rejected trip can be accepted considering the new compressed time frame. The acceptable walking distance is 500 meters, and total fleet size is 90 vehicles.

Results in Figure 4 show that using the X% reduction factor will decrease the rejected reservations and increase the accepted ones. Analyses indicate that using the station vehicles does not change meaningfully by increasing the X value (randomly between 87-90 trips). However, parked-vehicles assignment is mainly affected by the reduction factor. As X increases, the rejected trips become accepted due to the availability of a parked vehicle for the updated compressed time frame; consequently, the reservation acceptance rate increases. Increasing X from 0% to 20%, the number of accepted reservations would go up by 32% (282 vs. 214).

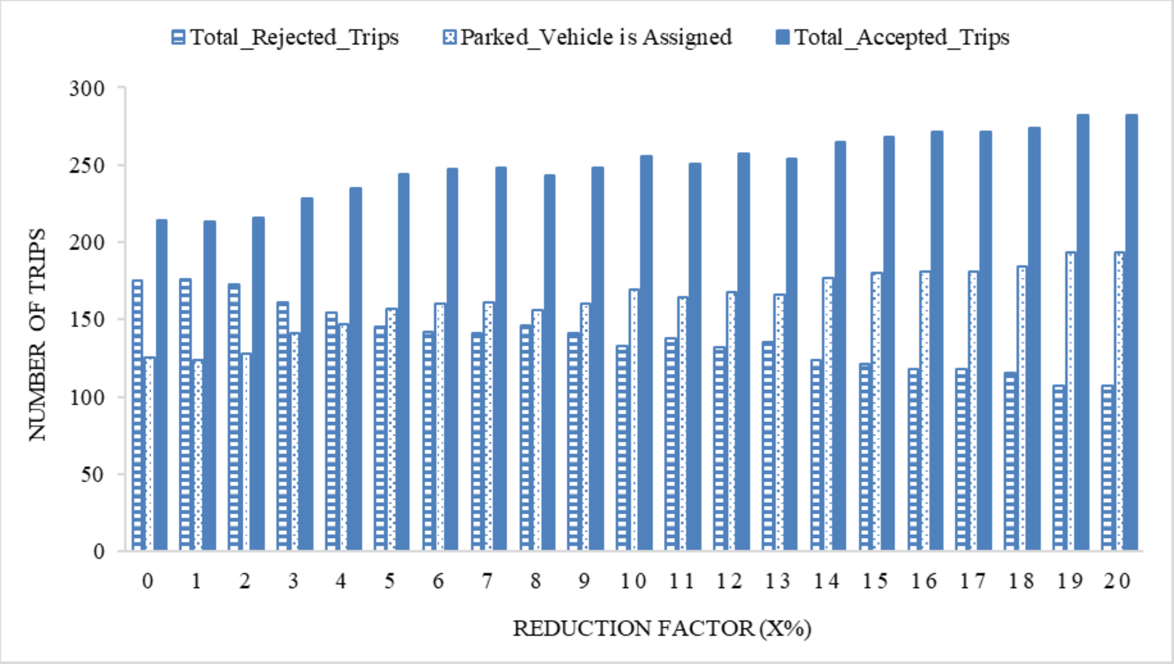

Figure 4. The effect of the reduction factor values on the number of trips for the Casa_Lavoro dataset.

Summary and conclusions

This study introduces a subleasing type of round-trip carsharing to enhance its efficiency and improve the advantages for both customers and companies. This innovative type of carsharing would add extra temporary stations (which are customers' parking locations) to increase the availability of vehicles and increase the popularity of the round-trip carsharing. Customers can both access the station vehicles and parked vehicles, which are reserved by other customers (parked and unused), and now can be considered as available vehicles for other customers. The innovative round-trip carsharing is tested with different sets of data: a real dataset from Playcar Company and a made-up dataset named Casa_Lavoro.

Results show that the new carsharing significantly improves the operational efficiency of the service by increasing the spatio-temporal availability of the vehicles. The acceptance rate (Casa_Lavoro) is improved (15% to 35%); the accessibility is increased by reducing the average walking distance in all cases; and the fleet size need is slightly reduced.

Sensitivity analysis for the acceptable walking distance reveals that it has a high effect on the Casa_Lavoro dataset in the innovative carsharing type. Using 750 meters instead of 500 meters would increase the acceptance rate from 35% to 50%.

In order to evaluate the effect of the company’s fleet size, a scenario of having three vehicles in each station (90 vehicles in total) is also evaluated. Results reveal that the acceptance rate jumped from 15% to 23% in the traditional carsharing type, and from 35% to 55% in the innovative carsharing type (Casa_Lavoro). Therefore, compared to 54 fleet size, the number of accepted reservations increases by 50% approximately. The effect of the acceptable walking distance for the 90 fleet size increases the acceptance rate from 55% to 73%.

Lastly, a sensitivity analysis to temporal flexibility has been conducted, assuming a compression of X% of the requested reservation time. Results show an expected monotonic trend and a X = 20% would increase the accepted reservations by 32% for the Casa_Lavoro dataset with 90 vehicles and 500 meters acceptable walking distance.

In terms of future developments, this innovative carsharing system will soon be introduced and tested in the city of Cagliari by the Playcar Company. The deployment will allow assessing the convenience of the sub-lease system from the company's point of view and the improvement in accessibility for customers. Customers using this service will be asked to answer a satisfaction survey to identify further the strengths and weaknesses of this new round-trip carsharing. Moreover, the test will be able to evaluate the correct functioning of the algorithm integrated into the existing Playcar application for smartphones to highlight if customers use this service correctly and respect space and time limitations imposed by the company's policy in order to guarantee the continuous spiral use of the system. Additionally, detailed regulations and policies have to be published to overcome real-world issues such as vehicle damage liability, parking cost payment, and late return vehicle. After proper testing, the proposed sub-leasing type of round-trip carsharing introduced in this study can be adopted anywhere else to improve operations efficiency.

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