Car sharing relocation strategies: a state of the art

E. M. Cepolina, A. Farina, A. Pratelli
Department of Civil and Industrial Engineering, University of Pisa, Italy

Abstract
Traditional car sharing systems are round-trip and require advance reservations. The advances of ICT and vehicle automation allow to improve car sharing systems and to provide users with greater flexibility. As it concerns reservation, new car sharing systems offer users open-ended reservation and/or instant access. As it concerns the trip typology, new car sharing systems are multiple station shared vehicle systems (MSSVS). Roundtrips still occur in this type of system, however there is a large number of one-way trips made between the multiple stations. Operating an MSSVS is much more difficult than operating a round-trip shared vehicle systems. The problem is that the system can quickly become imbalanced with respect to the number of vehicles at the multiple stations. These systems are called new (or second) generation car sharing systems. Third generation systems are the last being developed; in these systems vehicles can be accessed at any point of the area. An overview of all these car sharing systems is provided in this paper.

Keywords: relocation procedures, operator-based relocation, user-based relocation, vehicles automation, vehicles localization techniques, capillarity

1 Introduction

The earliest origin of shared use vehicle systems is in 1948, in Zurich, which has been performed by a cooperative called “Sefage”. Afterwards, another shared vehicle system, Procotip, has been settled in 1971 in Montpellier, and Witkar in Amsterdam in 1973. All these experiences have been unsuccessful. However, in the 1980s several other initiatives have been launched, such as “Mobility Car sharing” in Switzerland, and “Stattauto” in Berlin. All these car sharing systems belong to the first generation: members need to book cars beforehand and the time the car will be dropped off should be specified (fixed-period reservation);

besides, generally cars must be returned to the same location where they were picked up (two-way trips). In 1990s, the car sharing concept has become popular also in the U.S., where several pilot projects have been performed.

After, to overcome the barriers of first generation car sharing systems, a new generation of car sharing has been developed which provides the following specific services: instant access; open-ended reservation and one-way trips. Among these new systems, we should mention: UCR IntelliShare at the University of California at Riverside [1], CarLinkI and CarLink II in Dublin-Pleasanton [2]; Autolib' in Paris; and Honda ICVS in Singapore. The features provided by the new generation systems on one hand provide great flexibility to users, but on the other hand they create a serious problem, which is the unbalancement of vehicles available at the various stations, therefore in some stations there is an excess of vehicles, while in others there is lack of vehicles. Therefore, relocation is necessary. The target of a relocation strategy is twofold: firstly to reduce management costs and secondly to provide users high flexibility and low waiting times.

Recently, some "third generation" car sharing systems, such as Car2Go [3] and DriveNow, have been developed. In these systems, vehicles can be accessed also along the roads and be returned to the system at any point of the intervention area. They have been specifically designed for those residential areas where the population is low and sparse and therefore users may have a quite long walking distance to reach the closest station.

The performance of a relocation strategy is generally assessed as a function of users waiting times and of the number of relocations. Several authors, such as Shaheen *et al* [4], assesses the performance in terms of the capability of car sharing systems to attract users from private transport modes.

The paper is structured in the following way. In section 2 first generation car sharing systems are described. In section 3 second generation car sharing systems are described. Section 3.2 concerns the operator based strategies. Section 3.3 concerns instead the fully user based strategies. Sections 3.4 and 3.5 concern two recent specific car sharing systems: Autolib' in Paris, a system where relocation is not needed because of the high number of vehicles and stations, and because vehicles can be accessed only through reservation, performed in short advance; and the PICAV car sharing system, where vehicles relocate automatically without the need of a driver. Section 4 analyses the transport system's capillarity issue and therefore focuses on the third generation of car sharing systems. Conclusions follow.

2 First generation car sharing systems

First generation car sharing systems show the following characteristics:

1. one way trips are impossible: it is always necessary to return the vehicle at the same station or bay from which it has been taken;
2. it is necessary to book the shared vehicle before accessing it;
3. fixed ended reservation: the user must return the vehicle at the end of the period booked. This may constitute a problem if some impedances in the trips occur, such as traffic jams.

2.1 Some examples of first generation car sharing systems

Today car sharing systems of the first generation are widely spread worldwide, with over a thousand cities where car sharing services are available. Existing services include:

1. Zipcar [5], developed in Spain, Canada, UK and U.S. As of November 2012, Zipcar has 767,000 members and offers 11,000 vehicles throughout North America and Europe.
2. City Car Club [6], developed in the UK.
3. Ibilek [7], developed in Spain, in Bilbao, Donostia, Vitoria.
4. Stadtmobil [8], developed in Germany.
5. CityCarShare.org [9], in San Francisco area, U.S.
6. NTUC Incarne Car Ca-op, CitySpeed and WhizzCar in Singapore [10].
7. In Japan: ITS Mobility system in Osaka, Tourist Electric Vehicle System in Kobe, Ebina Eco-Park & Ride, Inagi EV-Car Sharing for residential areas, Minato–Mirai 21 in Yokohama [10].

Some of these companies, such as Zipcar, allow users to book the car shortly in advance, and prolong the booking period if some impedances, such as queues or traffic jams, occur during the trip. But in all cases vehicles must be returned to the same pick-up stations.

In Italy, several cities have a car sharing system. The Italian Ministry of Environment has launched a circuit called Car sharing Initiative (ICS), where members registered to a city taking part in the initiative can make use of the car sharing in all the other cities. Currently more than 23 Italian cities take part in this initiative [11]. All cities of ICS have a web site in which the location of the stations is reported. However, the state of each station, i.e. the availability of vehicles or of free spaces, is never shown. With the initiative called "IoGuido", there are promotions like high discount in prices of car sharing systems, aimed to encourage people to visit cities by train + car sharing instead of private car.

3 Second (new) generation car sharing systems.

New generation car sharing systems have been developed to overcome the barriers of traditional car sharing systems.

New generation systems provide the following services to users:

- *Instant access*: The system can be accessed by users without any need of a booking. Only the registration or some identification of the users is needed.
- *Open ended reservation*: The user does not have to specify a return time when he accesses the vehicles. Therefore, he can return the vehicle at any time, when he has finished all his trips. This feature is extremely useful as it is usually impossible to forecast the time required to perform a given trip or trip chain. For example, if the vehicle is used to go shopping in the city centre, the duration of the trip depends on: the traffic, the time spent at each shop, etc.
- *One way trips*: The user can return the vehicle in a station different from the pick-up one.

Relocation strategies could be classified in two main categories: operator-based and user-based. *Operator-based* strategies resolve the balancement problem by operators that manually relocate a vehicle or a platoon of vehicles from stations having vehicles in excess to stations having lack of vehicles. In *user based* strategies, instead, relocations are performed by the trips of the transport system users.

The activities performed by the operators are: vehicle maintenance: such as refuelling, cleaning, etc.; movement of the operator: from the station in which he is currently present to the station in which the relocation must start; and relocation: the vehicle movement. The great majority of shared vehicle systems involve operator-based strategies. This category includes also some strategies which could be partially user-based: some users may be available in performing few of the required relocations if motivated by a reduction in the transport price. Only a few partially user-based strategies have been developed. In IntelliShare the integration of operator-based strategies and partially user-based strategies has been considered [1].

3.1.1 Some examples of new generation car sharing systems

Several pilot projects have been developed at the end of 1990s and beginning of 2000s in the U.S. In particular, it is worth to mention:

- the Coachella Valley system [12], settled in a Californian holiday resort;
- UCR IntelliShare [1], settled at the University of California at Riverside;
- CarLink I, settled in the Dublin Pleasanton Bay Area, and its continuation CarLink II, settled in Palo Alto, California [2];
- Honda ICVS, established in Singapore. However, it has been recently removed due to high staff costs;
- Autolib' [13], operating in Paris and Ile de France, and in Lyon.

3.2 Operator-based strategies

3.2.1 Where and when a relocation is required?

A relocation is required when a critical situation occurs. A critical situation occurs when the actual number of vehicles idle at a station equals one of the station's critical thresholds. Two thresholds could be defined for each station:

- the *high critical threshold*. If the number of vehicles in a given station at a given time instant goes above the high critical threshold, the station has reached its capacity. This situation is referred as FPT, *i.e.* full port time [14]. When this condition takes place, users who want to return the vehicles to the congested station need to be redirected to other stations.
- the *low critical threshold*. If the number of vehicles in a given station at a given time instant goes below the low critical threshold, the station is in shortage of vehicles and some users may be in queue at the current time instant. This situation is referred as ZVT, *i.e.* zero vehicle time [14]. When this condition takes place, a request for a vehicle is generated.

The high critical threshold is upper limited by the space available in the station. Some authors (Kek *et al* [15]) calibrate the high critical threshold in such a way to minimize the space occupancy. The low critical threshold could be assumed constant in time or a function of time.

3.2.2 Which is the supporting station?

If a ZVT situation takes place, a vehicle needs to be allocated to the station in short supply. The point is: which station provides it? Kek *et al* [14] introduce a new threshold: the *low buffer threshold* which is the minimum number of vehicles that a station needs to have in order to be able to send vehicles. According to these authors, the vehicle request could be addressed only to stations where the number of vehicles is above the low buffer threshold. Among these stations, the providing station could be selected according to several criteria: the nearest station, the closest station (*shortest time* criterion), the station having the highest number of vehicles (*inventory balancing*). Actually, inventory balancing means to fill a station with shortage of vehicles with vehicles coming from another station, not necessarily a neighbor one, having vehicles in excess.

If a FPT situation takes place, vehicles in excess at the station need to be moved to another station. The point is: which station is able to accept them? Kek *et al* [14] introduce a new threshold: the *high buffer threshold* which is the maximum number of vehicles that a station can have in order to be able to accept new vehicles. According to these authors, vehicles could be sent only to stations where the number of vehicles is below the high buffer threshold. Among these stations, the accepting station could be selected according several criteria: the nearest one, the closer one (*shortest time* criterion), or the station having the lowest number of vehicles (*inventory balancing*).

Performance of the criteria used for selecting the supporting station

The shortest time criterion relates mainly to service levels, while the inventory balancing mainly focuses on system efficiency. Therefore, an appropriate choice of relocation technique should be made according to the current system situation. In periods of low usage, the most appropriate relocation technique is by inventory balancing. In periods of high usage, then the shortest time technique performs best. In reality, the results of these techniques depend also on several set-ups, such as the number of stations, that should be kept as little as possible in order to reduce the number of relocations.

The concepts of shortest time and inventory balancing have been implemented in Honda ICVS in Singapore, which is an operator-based car sharing system. For this system, through simulation, the inventory balancing and shortest time criteria have been studied under various operating parameters, *e.g.* staff strength, number of car park lots in each station and threshold values. The interesting outcome is that a reduction of resources usually is expected to worsen the service levels, *i.e.* the number of occurrences of ZVT and FPT. But in reality when this reduction is balanced with the right combination of relocation techniques and operating parameters, performance indicators can even be improved. In particular, the use of inventory balancing technique in situations of low resources is able to keep low the number of relocations while maintaining satisfactory levels of ZVT and FTP. The use of the shortest time technique instead brings to an increase of the number of relocations, but also on the other hand some improvements in ZVT, while FTP levels are maintained.

All authors agree that to exceed in the number of parking spaces at each station is not good because of the amount of space consumed, therefore the ratio between the maximum number of idle vehicles at a station and the number of parking spaces should be kept close to 1. But on the other hand to reduce in an excessive way the number of parking spaces makes the two critical thresholds nearer to each other, therefore the number of relocations increases relevantly.

3.2.3 How is the relocation performed?

Usually relocation is performed by an *operator* who manually relocates a vehicle. But this results in unaffordable staff costs. Therefore two relocation techniques have been proposed in the IntelliShare [1]: towing and ridesharing. In the towing technique, vehicles are towed from a location to another using a dedicated towing vehicle or simply another vehicle which is part of the system. Towing can be both mechanical, through tow bars, or electronic, through some sensors. This is an operator-based technique but, thanks to improvements in "vehicle intelligence" and vehicle's sensors, in a short time vehicles will be able to tow on their own, without the need of an operator [16]. Ridesharing is when separate drivers take separate vehicles in some ride, and the same vehicle in some other ride. Drivers could be operators or eventually users. Therefore this technique could be operator-based or partially user-based. In the first case, some system operators relocate vehicles through sharing the ride or splitting into different vehicles. If the system operator needs to get to another station without moving a vehicle, a small scooter is available to travel between stations. This scooter can be mounted on the towing hitch. Ridesharing can be performed also via a regular user trip. Therefore, if two or more users travel from a station with a shortage of vehicles to a station having an excess of vehicles, they are encouraged, through high price reduction, to joint together in the same vehicle (trip joining), while in the opposite case they are encouraged to split into different vehicles (trip splitting). Also in the reservation process, users are encouraged in telling in advance if they accept to joint their trip or to split their trip.

The effectiveness of the two techniques *of trip splitting and trip joining* on the number of relocations has been analyzed in Barth *et al* [17]. The evaluation procedure by Barth *et al* [17] refers to the Campus of the University of California at Riverside. The relocation strategy is base on constant critical thresholds. The number of vehicles has been varied between 22 and 30. The overall travel demand volume is about 200 trips / day. The percentage of users who accept to rideshare has been assumed equal to 100% because users, being university students, have no problem in ridesharing, even less if this leads to a discount on the transport cost. In this evaluation, the main interest was to assess the number of relocations necessary during the day to keep the system balanced. The simulation results show that trip joining reduces the number of relocations by 11%, trip splitting by 26%, and the two techniques implemented together by 42%. The analyzed transport system performed very well. However, if the willingness to rideshare is less, the performance drops. In the case of Honda ICVS in Singapore, the willingness to rideshare has been assessed nearly 0%, because Asiatics evaluate much more privacy than monetary cost [15].

The huge development in the degree of intelligence of vehicles allows relocation to be performed automatically by vehicles, which relocate among stations without the need of a driver. A fully *vehicle based relocation strategy* is proposed in Cepolina and Farina [18]. This research has been proposed within the PICAV project funded by the European commission (SST-2008-RTD-1).

When a ZVT condition occurs, a request for a vehicle is generated. The vehicle request is addressed only to stations where the number of vehicles is above the low buffer threshold. When a FPT situation occurs, a station has reached its capacity and therefore arriving vehicles must be redirected to other stations, because there is no free space for parking. In this case, vehicles are redirected to the nearest station, in order to reduce the downtime to users.

The parameters that describe this transport system are defined through two vectors. Their dimension equals the number of stations in the area. The value of each vector component is the station's low critical threshold for the first vector and the station's low buffer threshold for the second vector. The transport system's performance is considerably affected by these two vectors, therefore their values should be carefully selected.

An optimization procedure of the PICAV transport system has been developed for assessing the threshold values that minimize the total system cost [18]. The cost function takes into account the operator cost and the users cost. The operator cost takes into account also the relocation cost, which depends on the overall duration of relocation trips. The user cost is a function of waiting times.

3.3 User-based strategies

3.3.1 The PICAV fully user-based strategy

In all management strategies exposed above, a relocation is required when in a station a critical situation occurs. In Cepolina *et al* [19] and in Cepolina and Farina [20], a relocation strategy fully based on users was proposed.

The PICAV transport system is a new multimodal shared use vehicle system for urban pedestrian environments.

The proposed transport system admits the existence of a system supervisor who is in charge of addressing at least part of the PICAV users (*flexible users*) to specific stations. A flexible user is a PICAV user who has a choice set including all the stations that are equally suitable for returning the PICAV unit. This set includes all the stations close to intermodal exchange points where public transport services, suitable to reach the user's home, stop. When a flexible user finishes his mission in the pedestrian area, he calls the system supervisor and asks him where he has to return his PICAV unit. The supervisor according to: the choice set of the flexible user; the current waiting times at the stations within the user's set; the travel times between the user's current position and the stations within his choice set; assigns a station to the user that results good from the point of view of the flexible user (since it belongs to the user's set) and good from the point of view of the transport system management. This schema should help in keeping a internal balance between the number of the PICAV units at the stations, without a need to have any staff to relocate vehicles.

This scheme can work in contexts where the public transport is mainly used for reaching the pedestrian area. In fact in this case the user can exit the pedestrian area close to any stop where suitable public transport lines pass. In this case the number of flexible PICAV users is supposed to be consistent.

The PICAV transport system has been simulated for the historical city centre of Genoa, Italy. The performances of this relocation technique have been described in detail in Cepolina and Farina [20], pp. 237-242.

The disadvantage of the proposed user based relocation is that its field of application is limited. In some scenarios users may not have a choice set or their choice set may be too small. Therefore in these cases the system is not capable to cope with unbalanced demand. This results in a very high unbalancement among stations and therefore in the failure of the relocation procedure.

3.3.2 An user based strategy which requires booking in advance

Another user-based system has been proposed in Di Febbraro *et al* [21].

Relocations are performed by travelers who wish to return their vehicles: travelers who wish to relocate vehicles receive a high discount in the ticket price. The system manager tells them where to return the vehicles and in which time interval. However, the reservation, though shortly in advance, is necessary. Travelers pick up vehicles not at specified locations but in a restricted subarea. Parking areas within either zone are not specified. There is a given probability that any reservation could be canceled or modified by the user.

The system has been represented through a discrete-event simulator. The events taken into account are: vehicle booking, booking modification, booking cancelation, vehicle pickup and vehicle drop-off. An optimization algorithm has been proposed, which optimizes the position and the time interval vehicles must be returned, and the amount of discount. The proposed relocation procedure has been applied to a test area which corresponds to a portion of Turin city centre.

3.4 A car sharing system where relocation is not required: Autolib'

Autolib' [13] does not have a relocation system: the user is provided with an application, where the location and the state of each station is shown. This application helps the user for accessing and returning the vehicle:

- Regarding accessing the vehicle, the user is informed about the state of each station, in terms of number of vehicles available, therefore he reserves the desired vehicle and reaches the station on his own.
- Regarding returning the vehicle, the user is informed about the free space available. If at the destination station there is no longer space available, he returns the vehicle at another station.

This management scheme avoids the relocations. However, it creates a disutility to users, which is the necessity to cover major distances on their own, and it results more expensive for installation costs, because the stations are quite close, with a distance of about 600 – 800 metres, and the number of vehicles is huge. Furthermore, as reservation and booking is performed through this application, the access to the Autolib' system may result quite difficult for an aged person.

4 Third generation car sharing systems

In the third generation of car sharing systems, vehicles are available not only at stations but also along the roads. Stations are only meant to vehicles maintenance, *e.g.* refuelling. The key point of third generation systems is the capillarity. Capillarity has been defined by Ciari *et al* [22] and Schwieger [23], as the degree of diffusion of vehicles within the application area of the transport system.

Several newer car sharing systems have been developed according to this concept. In such systems vehicles can be accessed and returned at any point of the area.

Several third generation car sharing systems have been applied on the field. In all these systems vehicles are accessed with a reservation performed just a couple of minutes before accessing the vehicle; moreover the vehicle can be returned at any point of the area. Vehicles can also exit the intervention area, in Car2Go they can also be used abroad. However, they must be returned in the intervention area. No relocation is necessary. Users have real time information on the position of the vehicles, through an application for computers and i-phones: they reserve the vehicle they prefer and reach the vehicle's position on their own.

In such systems, as stated above, relocation is not necessary. However, balancement is achieved because:

1. the user must reach the vehicle's position on his own; however this may constitute a high discomfort if the nearest vehicle is quite far;
2. the fleet dimension is kept very high to satisfy the users' demand, and the utilization rate of each vehicle is low.

The most important third generation car sharing systems diffused nowadays are Car2Go, DriveNow and Greenwheels. In all these systems, an application is available to users (for computers and mobile phones) in which the position of vehicles, fuel stations, registration kiosks, etc., is shown on the map.

Car2go [24] has been initially settled in Ulm, Germany, and now is diffused in other cities in Germany, The Netherlands, England, U.S. and Canada. DriveNow [25] is also diffused in Germany, and in San Francisco. Greenwheels [26] instead is diffused all over The Netherlands.

4.1 The PICAV third generation vehicle based system

A trip by PICAV may have, as origin or destination, either a station or any position along the roads within the intervention area. When the origin of the user's trip is not a station, a PICAV reaches the user in a fully automatic way. A fully vehicle based relocation strategy is proposed. Relocations are required:

1. when the number of vehicles available at stations is below the low critical thresholds (ZVT situation). In this case, the request for a vehicle could be addressed:

   a. firstly to the stations where the number of vehicles is above the low buffer threshold; among these stations, the providing one is selected according to the shortest time or the inventory balancing criteria.
   b. otherwise, to the vehicles parked along the road. In this last case, the nearest vehicle automatically relocates towards the station in shortage.
2. when the origin of the user's trip is not a station. In this case, the system supervisor assigns to the user the vehicle nearest to the user's position. If the nearest vehicle is in a station, it can be provided only if the number of vehicles available in the station is greater than the low critical threshold of the station. Results from simulation experiments show that if we refer to the low buffer threshold instead of the low critical threshold situations where all the parked vehicles are at stations occur very often as stations are never capable to provide vehicles.

At the end of their trips, the user can leave the vehicle at any position along the roads within the intervention area. When a vehicle is returned, if the level of battery charge is below the minimum charge level, the vehicle automatically reaches the nearest station to recharge the battery. As soon as it reaches the minimum charge level, it becomes available and if not required, continues the charging process. Further details on this system are provided in Cepolina *et al* [27].

5 Discussion and conclusions

In this paper, an overview about existing shared vehicle systems, with a particular focus on vehicles relocation techniques, has been performed. Three generations of car sharing systems are operated: first generation, where vehicles must be reserved in advance, and returned at a fixed time lag and in the same station from which they were picked up; new generation, where these three constraints were in great part removed (usually just the need for a reservation in short advance was kept); and third generation, where vehicles could be accessed and returned at any point of the intervention area.

The main problem which arises, and which is the focus of this paper, is the unbalancement of vehicles among stations. Several relocation schemes have been proposed, which resolve the balancement problem but have several other disadvantages.

The current trends are the following.

Traditional operator based strategies will evolve into vehicle based relocation schemes: vehicles automatically driven relocate among stations, thanks to the high improvement in the technology of control systems and sensors in the last years. Indeed, cyber mobility is one of the key topics of the European and international research.

User based strategies will be more and more diffused in the future thanks to the availability of real time information about the car sharing system. The user will therefore be asked to modify his trip, according to the current relocation needs. The trip planner tools on smartphones or computers could provide help in replanning the trips, minimising the impacts of relocation tasks. This request will involve either the beginning or the end of the user's trip, or only the end of his trip.

Finally, third generation systems are being successfully implemented: vehicles will be no longer available only at stations but at any point of the area. Stations will be only refuelling and maintenance points for vehicles.

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