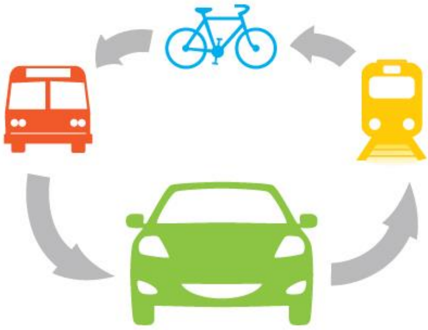

An event-based simulation for optimising one-way car-sharing systems

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Abstract

Car-sharing systems allow registered users to use cars spread throughout an urban area: vehicles are at their disposal anytime they need one against some amount of money per minute rental. The customer avoids some issues linked to the ownership of a car such as insurance fees, maintenance or parking. Such a system is beneficial for the society in terms of environmental, energetic impacts and congestion. It completes the urban transportation service by allying the efficiency of public transportation and the flexibility of owning a vehicle. Car-sharing systems can be classified in different families depending on the rental conditions. For instance, free-floating systems allow people to park the vehicles anywhere in city area whereas non-free floating impose to users to park them inside stations with limited number of allowed spots. In this last family, another differentiating feature is the "one-way/two-way" characteristic: two-way systems force the user to return the car to the location where it was picked-up whereas one-way systems allow drop-off at any station.
We focus in this research mainly on non-free-floating one-way electric systems. The system operations naturally induce imbalances in the distribution of vehicles that need to be corrected by performing relocations. Our aim is to model and simulate those operations to first analyze the way the system evolves with time and then to test different management policies for operations and especially relocations in order to both maximize customers' satisfaction and make the operation of the system sustainable for the operator.

Keywords

Car-sharing, relocation, one-way system, electric vehicles, event-based simulation, optimization

Introduction

Car-sharing systems have been implemented in various cities all over the world [1]. Their aim is to propose a new mobility alternative to people in urban areas who might need a car sometimes but do not own any due to different reasons (e.g. costs linked to ownership of a car, availability of parking space). It has social benefits such as reducing the number of vehicles in a network as well as pollution and congestion [2, 3].

Different type of systems have been implemented depending on the customers' expectations, operators' constraints and municipalities. The system explored in this paper can be described as a *non-floating one-way electric car-sharing system.* In such a system, operation conditions are the following:

i. *Non-floating*: vehicles can be picked-up and dropped-off only at specific locations called *stations.*
ii. *One-way system*: vehicles can be returned at a different station than the one from which they were picked-up. In a *two-way system*, any vehicle has to be returned to the station where it was picked-up.
iii. *Electric*: vehicles have limited trip range. Their availability to the customer is based on their charging level.

These conditions introduce constraints for the operator and impacts the availability of vehicles at different stations. Some other constraints can be added in order to improve customers' satisfaction such as the ability of booking in advance a vehicle and reserve a parking spot at the destination. This creates a need for relocation and rental policies to make the system operate in a sustainable way for the operator and in a satisfactory way for the customer. In order to design and test these policies, an event-based simulator was developed. Different optimization algorithms are embedded as different modules to improve system characteristics for the users and the operator.

Simulator framework

The simulator is composed of different components such as *Stations*, *Spots*, *Vehicles* and relocation *Personnel*. Other classes describe actions and movements of personnel and vehicles such as *Demand* (customer's demand for a vehicle), *Trip* (displacement of a vehicle due to a demand accepted by the system) and *Relocation* (movement of vehicles performed by personnel to redistribute vehicles).
The creations and modification of the states of these components are ruled by *events* happening with time. A rental request, the beginning/end of a rental/relocation, a personnel's shift end constitute such events. Other events can also be designed to retrieve information from the system and store them in other files: this is for instance the case for the calculation of statistics to evaluate how the system performs.

Evolution of time in the simulator is modeled through an *EventList* where events are sorted by their time of realization: whenever an event is realized, the first element of the list is retrieved and the simulator time actualized to the retrieved event's realization time. This *EventList* is filled before the beginning of the simulation with rental requests and any event we wish to see happen and is continuously refilled during the simulation since the happening of an event triggers generally the creation of a new one. Simulation is stopped either when the *EventList* is empty or at a predetermined time.

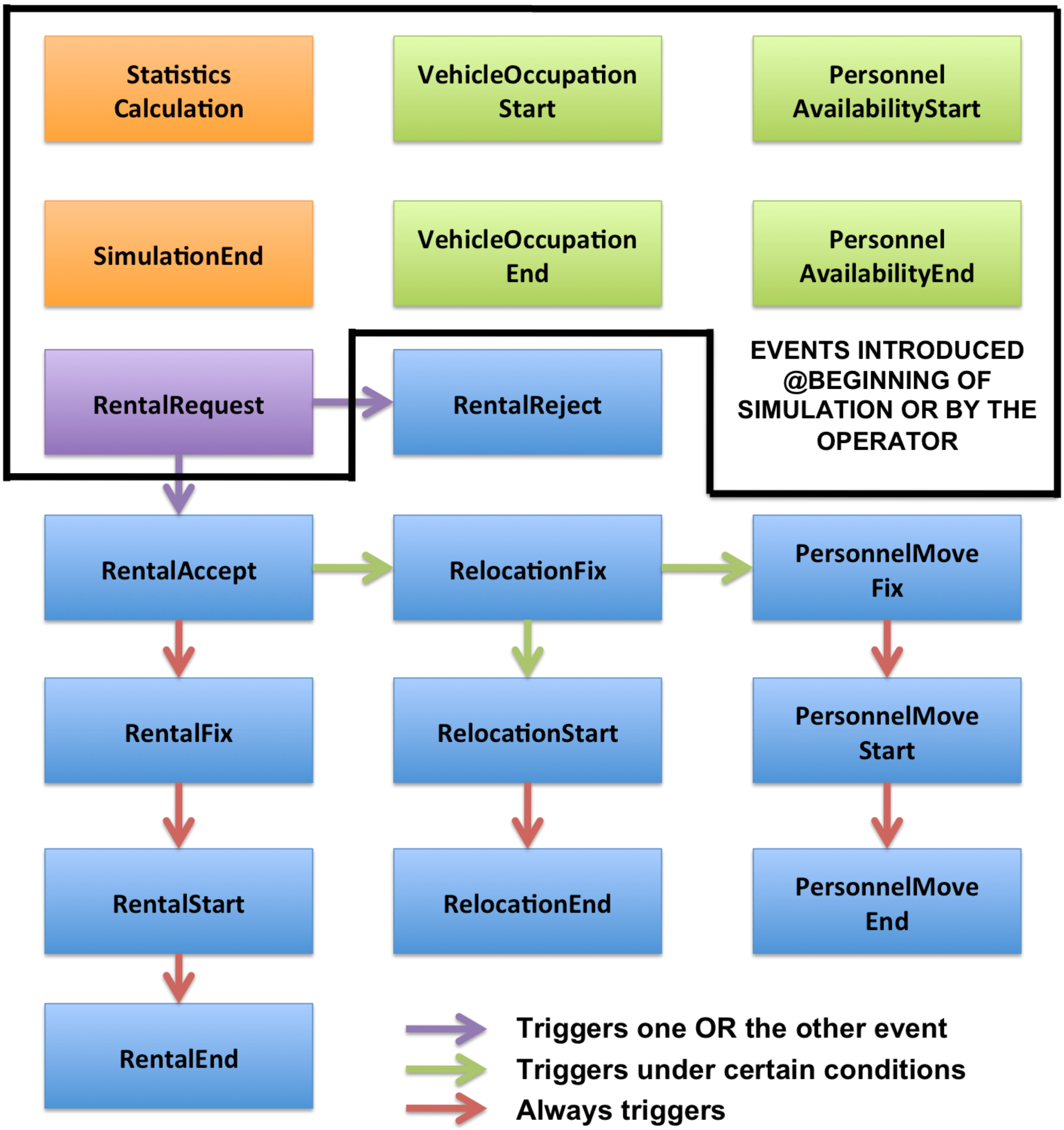


Figure 1: Simplified structure of events in the simulator and their links to one another

Simulating the operation of a one-way non-floating electric car-sharing system

The operation of the system was simulated for 10 days and for different daily demand levels: 50 / 100 / 200 demands per day. Data consist of real demand from a two-way car system currently operating in the city of Nice. A technique based on the frequency of stops was utilized to transform the two-way to one-way demand [4]. Origin-Destination demand, location of stations and travel times between stations were estimated from real data. No reservation of the vehicles was considered: a request was served only if a vehicle was immediately available in a close range. The system was also partially free-floating, namely, if no spot was available at drop-off station, the vehicle could be parked on the road nearby in a close range (it would be stored into extra spots in the simulation). For each demand level, several one-way demand seeds were generated.

The following policies were applied:

i. Battery threshold to allow picking of a vehicle: 20% / 50%
ii. Resetting vehicle distribution, i.e. perform relocations each night to return the system to its initial distribution state every morning. This mimics the effect of relocating vehicles and allows us to evaluate the effect of a relocation policy.
iii. Number and distribution of vehicles in the system

Our analysis showed that battery threshold does not have any impact at the demand levels studied on any of the observed system parameters. On the contrary, resetting or increasing the number of vehicles in the system increases the rental acceptance and reduces the spatial dispersion of vehicles among stations. A table and graphs for different settings are presented. Initial configuration 1 (IC1) refers to the initial configuration of vehicles with one vehicle per station (60 vehicles in total) and each station has three spots available for parking. Initial configuration 2 (IC2) means there is one vehicle at each station plus one vehicle more in the 10 stations with the highest demand according to the historical data. In those, four spots instead of three are available for parking. Demand is 50 rentals per day for the graphs.

Demand/day	**50**	**100**	**200**
No resetting + IC1	73%	68%	62%
No resetting + IC2	86%	83%	75%
Resetting + IC1	88%	86%	79%
Resetting + IC2	97%	96%	92%

Table 1: Rental acceptance ratio depending on demand level and management policies

To read the following graphs properly, it should be noted that each station has two states:

- an *O* state that counts the number of vehicles in the spots of the station. *O1* means there is one vehicle in a station's spots.

- an *E* state that counts the number of vehicles dropped-off at a station and parked outside (i.e in an extra-spot). *E2* means there are two vehicles at station which are not in the spots.

The larger the number of *E* states different than *E0*, the furthest from the initial state the system is. Spatial dispersion of vehicles among stations increases with the number of *E* states observed. Besides, statistics were taken each hour from 6 a.m. to 12 p.m. Each bar in the histogram corresponds to station states distribution at one of these discrete points.

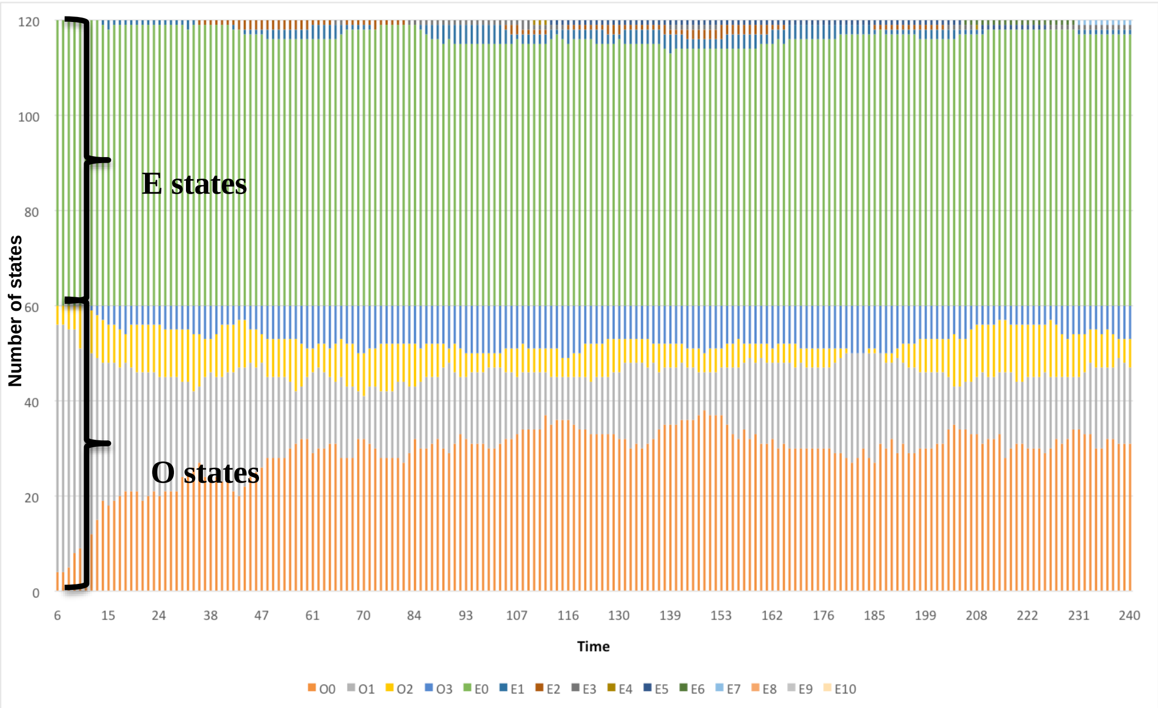


Figure 2: Evolution of station states with respect to time (No resetting and IC1)

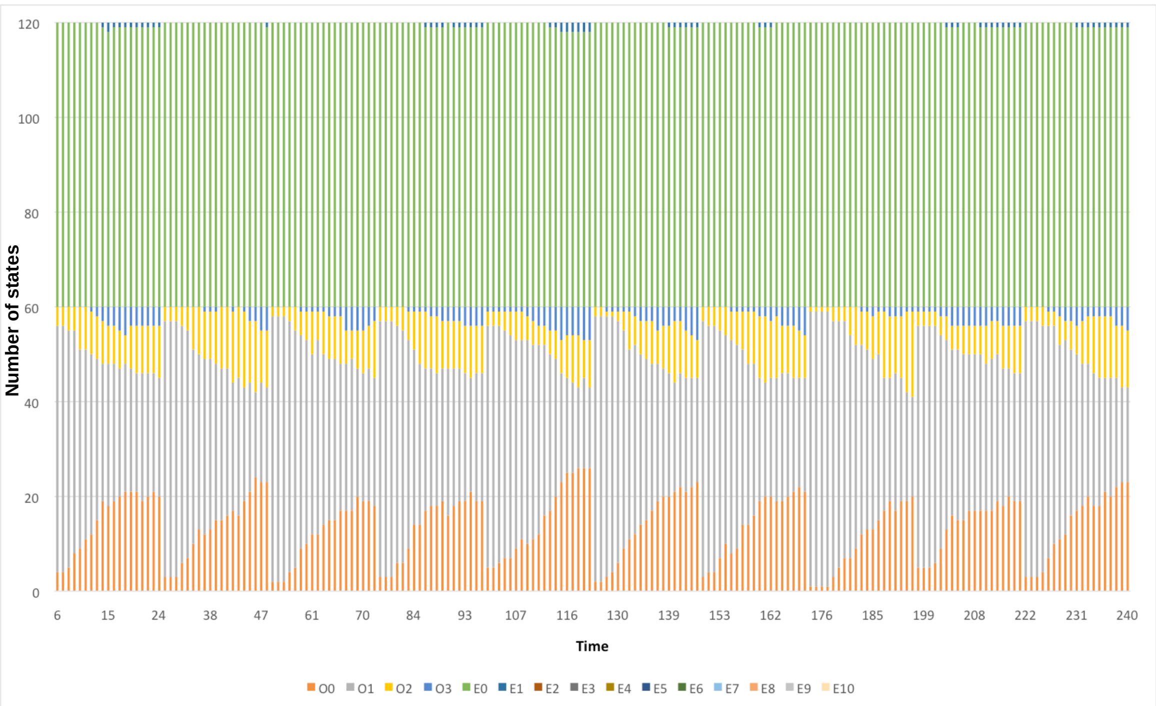


Figure 3: Evolution of station states with respect to time (With resetting and IC1)

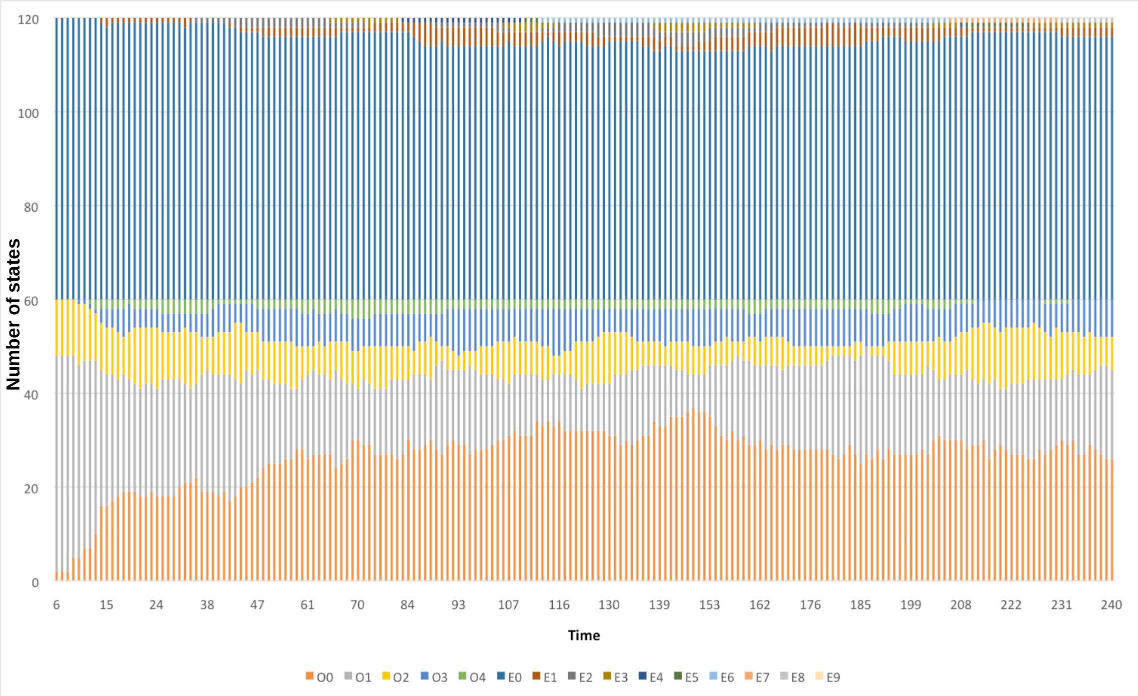


Figure 4: Evolution of station states with respect to time (No resetting and IC2)

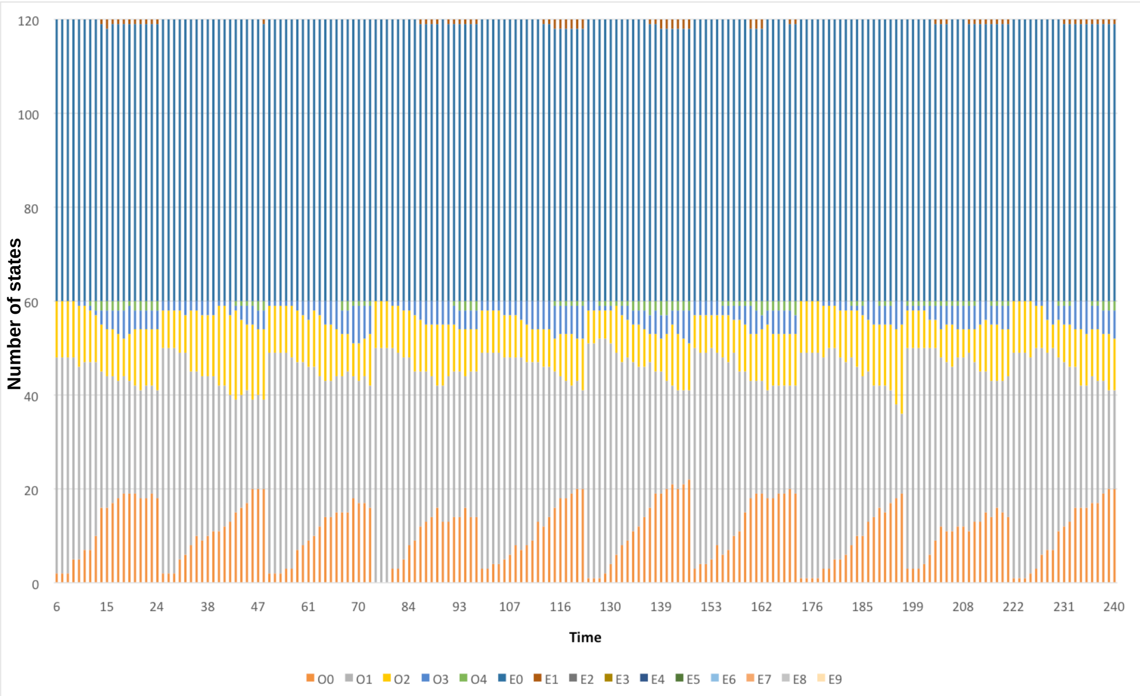
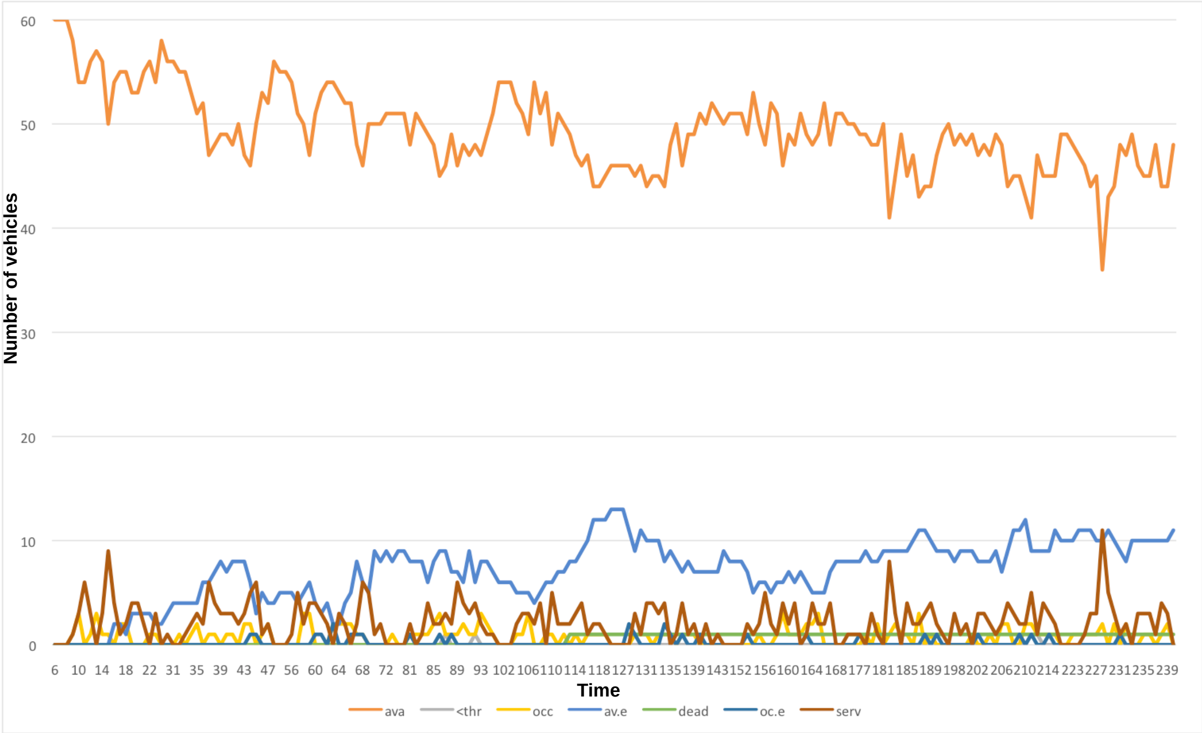


Figure 5: Evolution of station states with respect to time (Resetting and IC2)

Thanks to resetting, many less high E-states are observed. When no resetting is performed, there is an accumulation of vehicles in some specific stations over time which leads to an imbalance in vehicles distribution. In terms of stations with no vehicles available, the number is on the contrary quite constant in time after the initial first days' increase.

Vehicles activity distribution is also to be observed in order to evaluate the level of use of the system. Due to the fact that the system is partially free-floating and to charging level threshold conditions for allowing rental of a vehicle, some vehicles may be lost to the system because they would be undercharged in an extra-spot: this results in a loss of capacity for the system. The following graph presents the number of vehicles in each state at every time statistics were calculated.



ava.		Available in 1-way spot
<thr		Available in 1-way spot – charging level under minimum threshold
occ		Occupied in 1-way spot (reserved for demand to be served)
av.e.		Available in an extra-spot
dead		Available in an extra-spot – charging level under minimum threshold
oc.e		Occupied in 1-way spot (reserved for demand to be served)
serv		Vehicle is rented and not present in any station

Figure 6: Number of vehicles per state with respect to time
(100 demands per day, IC1 and no resetting)

The total number of available vehicles in extra spots increases with time. This highlights the need for relocation and/or pricing policies that either penalizes cases of vehicles parked outside a station or provide bonuses for users that pick up these vehicles at the start of the trip. Number of vehicles under service is not constant but almost always less than 10 which means there is only a smaller number of vehicles performing service.
Number of dead vehicles remains low: this small loss of capacity in the system is not problematic and can easily be corrected by relocating the specific vehicles to nearby one-way spots.
The same kind of patterns are observed for any level of demand between 50/100/200 requests and for any seed at each of these levels even though whenever a vehicle is needed, priority is given to vehicles outside the station that still have a high enough level of charge.

Other statistics are interesting in this study: they concern the number of rejections per station. Demand is not equally distributed over the stations. It is bigger in the stations located in Nice and especially in the city center where most people are travelling. The goal of the operator is to serve as much demand as possible: reasons for rejecting a demand must be analyzed and understood in order to improve the service of the customer.

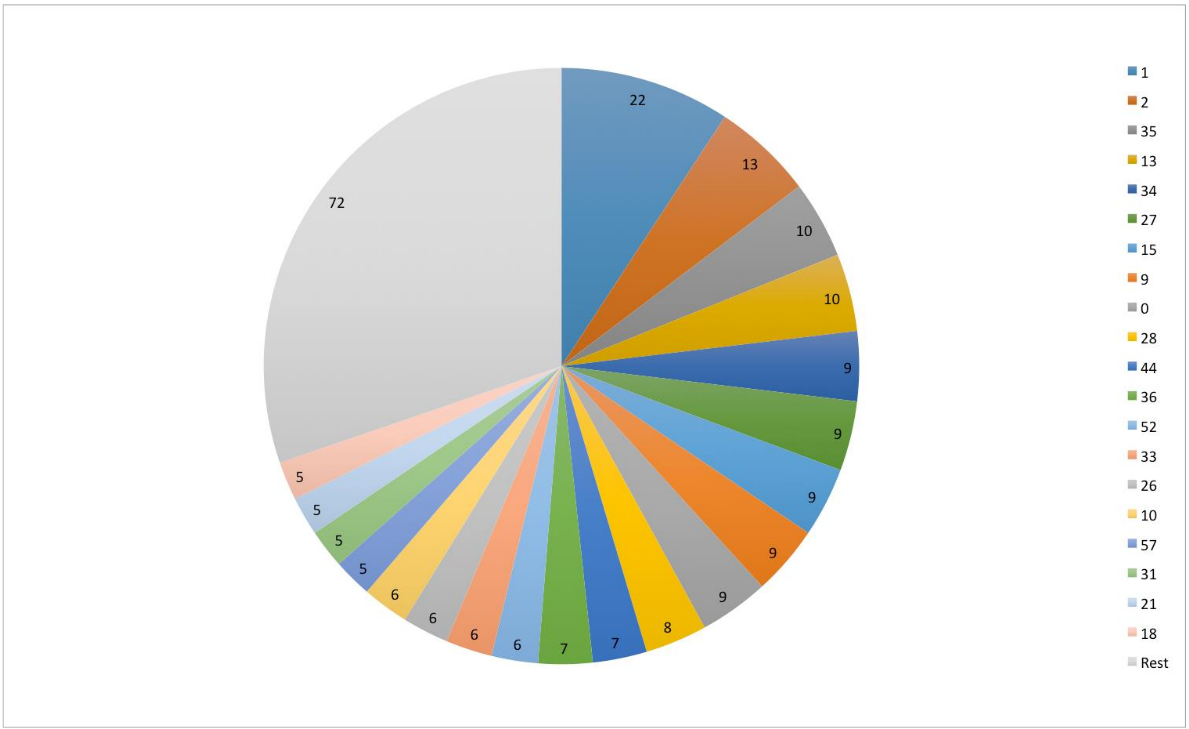


Figure 7: Demand rejections per station during 10 days simulation
(100 demands per day, IC1 and no resetting)

Figure 7 shows the 20 stations where rejections occur more frequently. Station 1 rejects by far much more demand than any other station, because of lack of available vehicles (station as origin). In the case of totally non-free-floating system, demand can also be rejected due to lack of available spot (station as a destination). Stations 2, 13 and 27 also reject much demand as they belong to the top 10 stations with the highest demand. With this analysis, we can define strategies at a local level for stations, which face the higher demand, to serve or reject a request because no vehicles are available.

On-going work: designing relocation policies

Simulations showed that relocation had a significantly good impact on demand acceptance (as shown also in [5]) and the goal of our future work is to further investigate this feature. As a matter of fact, resetting the system to initial configuration is not fully equivalent to relocating since it does not take into account the time needed to perform these relocations for the personnel available and does not define from which station to which other the relocation shall be done.

In order to address this matter, a mathematical optimization framework is under development. It solves sequentially the problem of defining relocations to perform and when (previous works in optimizing relocations have already been partially explored [6]). As a first step, it defines a wished distribution of vehicles for the system according to rental and vehicle-spreading constraints over the network: these constraints shall take into account the specificities of each station in terms of demand and rejection thanks to the analysis made with figure 7. In a second step, the problem of choosing the relocations to do is addressed given the actual vehicle distribution and the previously defined wished (ideal) vehicles distribution; stations with too many vehicles are matched with those who have too few with an objective to minimize the total distance travelled. Given the output of this second step, the optimal relocations' set is then assigned to the personnel available in a third step. It is either done by minimizing the maximum time spent by any personnel to perform the assigned relocations or by maximizing the number of relocations realized in a given amount of time depending on the way the operator of the system wants to handle relocations.

Dividing the global problem in different steps will allow us to reduce the time needed to compute the solution but will not always give us the optimal solution. These different steps can also be combined in order to obtain an overall better solution if computational time does not increase too much. Various combinations of these steps will be investigated in a mixed integer linear programming formulation that will be presented in the full paper.

This optimization framework shall be tested and solved on different datasets and under different optimality gaps and computational constraints. It will be included in the simulation framework afterwards and linked to the other simulator's modules. Different policies not yet defined will then be tested on various scenarios in order to achieve optimal operation of the system and propose an accurate description of how such a car-sharing system could work in the best way.

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A more detailed reference list will be provided in the final paper.