An operational framework for one-way electric car-sharing systems with reservations

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Abstract

Car-sharing is a new model for car-rental which enables people to rent cars for short periods of time. These systems have several benefits including environmental, energy and societal considerations. In this work, we are proposing a framework for the operational decisions of one-way electric car-sharing systems. The system is applied on a car-sharing system in Nice, France. Preliminary results show that, relocation operations are significantly improving the quality of the service.

1 Introduction

Car-sharing has been introduced to various cities around the world. It is a cost-effective alternative for the users who prefer occasional use of a vehicle instead of owning it. It is an approach with some societal benefits as well. It creates incentive to drive less. Consequently, the pollution, congestion and demand for parking spaces in the city centers decrease.

The car-sharing systems can be categorized as *one-way* and *two-way* systems. In *two-way* systems, users drop-off the vehicle where they have picked-up. In *one-way* systems, users have flexibility to choose a different drop-off location. The former is easy to implement for the operators whereas the latter is more flexible and preferable by the users. One-way systems can also be classified into two categories namely *non-floating* and *free-floating* . *Non-floating* systems have designated parking locations whereas in *free-floating* systems, the users pick-up and drop-off vehicles in a restricted area with defined borders. Because of their nature, free-floating systems do not allow advanced reservations and they are difficult to implement with electric vehicles. Whereas with non-floating systems it is possible to design a system with one-way trips reserved in advance.

In this research we are proposing a framework to support operational decisions of *non-floating one-way electric car-sharing systems* . Operational decisions can be defined as the every-day operations to maintain the system: e.g. relocation of vehicles, assignment of relocations to personnel, accepting/rejecting/directing late reservations. Our framework contains a mathematical model for planning the system with early reservations that enables flexibility for the users pick-up and drop-off times.

2 Mathematical Model

The complete mathematical formulation will be provided in the full paper. In this abstract, we provide an overview of the model structure and its characteristics.

In the mathematical model, the physical framework is represented with nodes and arcs. Each node represents a *station* (parking spot that allows rentals), *hub* (parking spot that does not allow rentals) or *intermediary node* (an intersection of two or more arcs). Arcs represent road segments connecting any type of nodes. Each node has a capacity which is defined by the number of parking spots.

The model contains two different sets of entities moving between nodes: *vehicles* and *relocation personnel* . Both of them are modeled as discrete flows; they cannot be differentiated from each other. This approach extremely decreases the number of variables and makes the model solvable in reasonable time.

In the model, time is discretized and short (5-15 minutes) *time intervals* are utilized. Each vehicle and personnel cannot execute more than one *event* (e.g. pick-up, drop-off, relocation start/end, rental start/end) at each time interval.

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Vehicles can be *picked-up* and *dropped-off* by the users. When a vehicle is dropped-off, it is forced to be *parked* and *charged* for at least one time interval, before it is available for the next event. *Relocations* are the outcome of the model. For each relocation, a personnel needs to be present at the origin station at the start time of the relocation. Relocations can take more than one time interval, and both the vehicle and personnel becomes available at the destination station at the end of the relocation. Relocation personnel can also move between stations without relocation operations.

The number of vehicles at each parking spot, at the first time interval is an input for the model. The number of personnel is the outcome of the model. There are predetermined *shifts* with different start and end times. The model is forced to choose a number of relocation personnel from each shift. Each shift has different cost per personnel and they are added to the model to minimize total personnel cost.

In order to keep model flexible for pick-up and drop-off times of the users, a set of parameters and variables are defined and soft constraints are introduced that direct the model to have a flexible option without increasing unserved demand. These set of constraints encourage model to keep empty parking spots and vehicles at the right stations at the right time. The model seeks a solution that keeps vehicles before their pick-up and after their drop-off, and empty spots after their pick-up and before their drop-off at the related stations. This way, we end up with a mathematical model that tolerates variation between reserved and realized pick-up and drop-off times.

The objective function contains four different costs. (i) Cost of *unserved demand* is very high compared to other costs. The model is forced to serve as much demand as possible. (ii) Cost of *relocation personnel* is calculated by summing the product of the number of personnel and the cost per personnel of the same shift. (iii) There also exists a *fuel cost* in the objective function which is a function of the total distance traveled during relocations. (iv) The last cost in the objective function is related to the soft constraint defined in the previous paragraph. As the flexibility increases in the model, this cost decreases.

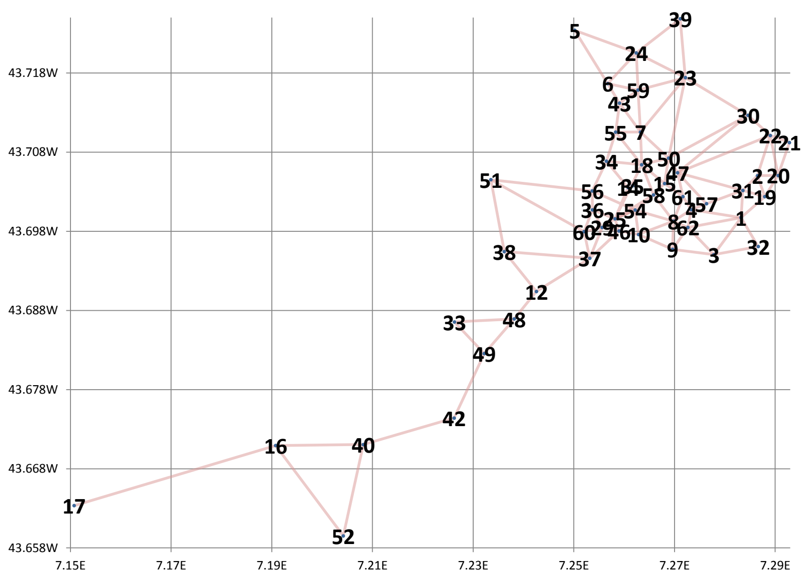

Figure 1: The car-sharing network of Nice utilized in the computational experiments

3 Computational Results

The mathematical model is applied on an existing two-way system in the city of Nice, France. In order to create one-way data from the two-way system, each two-way rental is split into more than one one-way rentals if the rental is paused for more than 30 minutes in a location which is close enough to another parking spot. The network contains 53 stations. In this network, no hubs or intermediary nodes are added to the model. The configuration of the system in the city of Nice can be seen in Figure 1.

For relocation of vehicles and movement of personnel, Euclidean distance and two different speeds are used. For relocation operations with a vehicle, average speed is set to 30km/h whereas it is assumed the the relocation personnel travels with a speed of 10km/h without a vehicle. The mathematical model is solved for a period of 16-hour with the time interval length of 15 minutes this results in 64 time intervals.

Three different shifts with a duration of 4 hours are given as a parameter to the model. It is assumed that, the cost of a relocation personnel is 72€/shift. It is assumed that a vehicle with an empty battery is fully charged within

	demand	50 trips			100 trips			200 trips		
with relocation	run time (s)	175	234	238	473	473	298	649	1099	26822
	objective (€)	8993	49082	-953	78342	78342	48186	236084	216090	176258
	personnel cost (€)	144	216	216	648	648	504	576	504	648
	# lost customer	1	5	0	8	8	5	24	22	18
	% served	98	90	100	92	92	95	88	89	91
without relocation	run time (s)	6.2	6.8	7.1	6.3	6.3	6.7	6.5	6.3	7.0
	objective (€)	108882	178909	148882	357802	357765	327755	825539	675651	725642
	personnel cost (€)	144	216	216	648	648	504	576	504	648
	# lost customer	11	18	15	36	36	33	83	68	73
	% served	78	64	70	64	64	67	58.5	66	63.5

Table 1: Comparing systems with and without relocation

8 hours and the range of the electric vehicles are 120km with a full battery. Distance traveled at each trip is set proportional to the length of the rental. Vehicle capacity in relocation operations is set to 4 persons. For each station, we set the capacity to 3 vehicles. Two fully charged vehicles are located at each station at the initial configuration. Penalty for lost demand is set to €10000. During relocation operations, we assumed that there is a fuel cost which is 0.02€/km.

In the first analysis we validate our model with the help of a Gannt chart prepared for one of the congested instances with a demand of 200. The relocation operations and the personnel movements are traced to validate the mathematical model. The whole Gannt chart of the operations can be seen in Figure 2. A Gannt chart corresponding to a smaller number of intervals can also be seen in Figure 3. Note that, in figures 2 and 3 rows are the spots belonging to each operating stations and columns are time intervals of 15 minutes. If there is a vehicle at the spot during the selected time interval, it is shown in blue. Light blue shows that, the vehicle on the spot has just returned from a trip. Darker blue states that, the vehicle on the spot needs to be charged for a new operation. Spots that are indicated with the darkest blue indicates that the vehicle on that spot is fully charged and ready for a new operation. If a vehicle is rented, the box in the Gannt chart showing the state of the spot during the time interval that the user supposed to pick-up the vehicle is painted with gray. Green and red shows the relocation operations between stations. Picked-up vehicles for relocations are shown with red. If a vehicle is dropped-off to a station after relocation, then the color of that spot at the end of relocation is green. Relocation operations can also be followed with the black arrows. Each origin and destination of relocations are connected with these arrows.

In our second analysis, we compare the same problem instances with and without relocation operations. As it can be seen in Table 1, we have observed that the percentage of served demand for the instances with relocation increase with the increase in demand. However, the effect is dramatic in the cases without relocation. Almost half of the demand (around 60%) could not be served, if relocation operations are not done for the instances with the demand of 200. This value is around 65-70% for lower demand values. Relocation slightly improves this value and serves 90% of the demand on average. Although the results are from preliminary runs, it is obvious that continuous relocation operations are needed to have a decent level of service in one-way car-sharing systems. Note that, although fuel cost is implemented in the model, since electric vehicles are used and the fuel cost is too little compared the other costs (i.e. not more than €2.8), it is not reported in Table 1.

4 Conclusions and On-Going Work

In this short abstract, we define a mathematical model that can be utilized to improve the efficiency of relocation operations in one-way electric car-sharing systems. Preliminary results show that, relocation operations are significantly improving the quality of the service.

In the final version of the paper, we plan to add some more features to the mathematical model. Firstly, since we do not differentiate vehicles, we only make them available when they are fully charged. However, this results in unserved demand during peak-hours. Our objective is to solve this problem by enabling vehicles to be rented with partial charges. However, it is preferable that the model to use mainly fully charged vehicles. Penalties on utilizing not fully charged vehicles can be introduced to achieve this objective.

In addition, we are in the process to develop a simulation platform to simulate the demand in different car-sharing systems. Work under way also includes the implementation of some simple heuristics to handle the changes in car-sharing systems. Our ultimate aim with these additional tools is to have a complete framework that will enable us to model a one-way electric car-sharing system as realistically as possible.

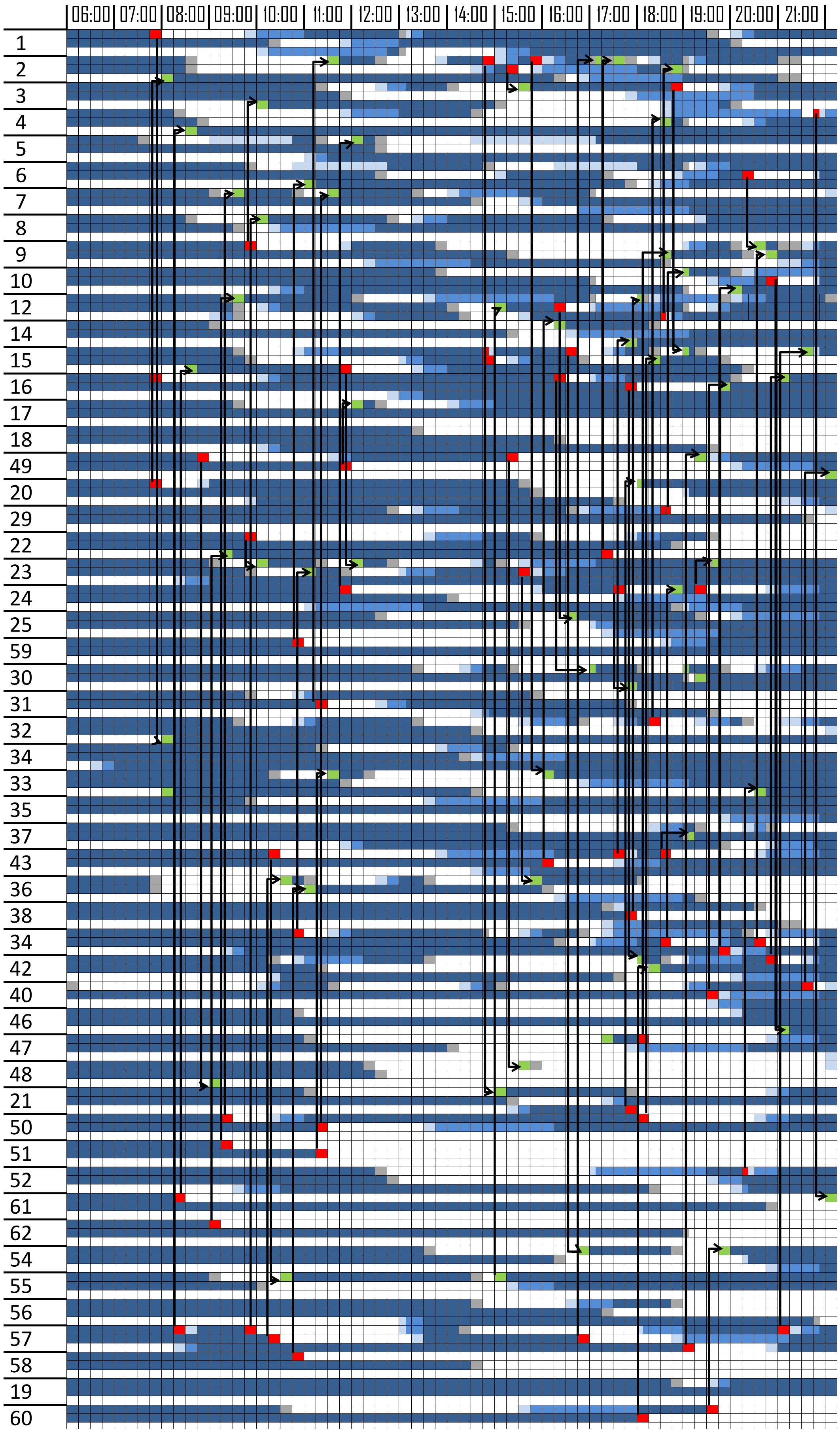

Figure 2: A Gannt chart including all time intervals and stations for an instance with 200 trip requests

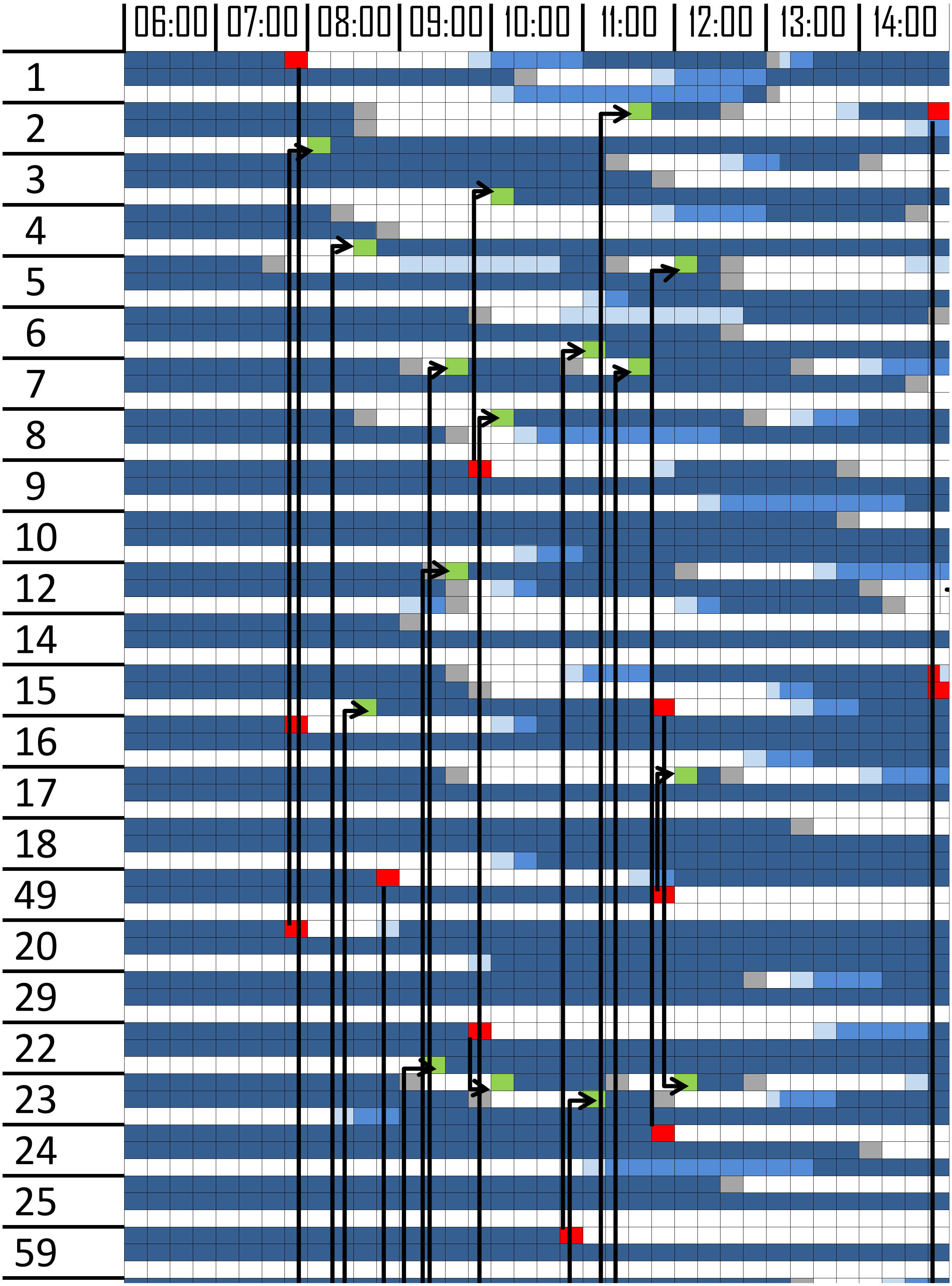

Figure 3: A smaller area of the Gannt chart given in Figure 2