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Heuristic algorithms for the operator-based relocation problem in one-way electric carsharing systems

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HIGHLIGHTS

- Economic sustainability of E-VReP in one way carsharing systems was addressed.
- Computational complexity and APX-hardness is addressed.
- Heuristics were designed to overcome the drawback of the high CPU times of the MILP.
- Variable revenues associated with requests satisfied were also considered.
- Sensitivity analysis was carried out on the number of requests and the revenue.

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ABSTRACT

This paper addresses an Electric Vehicle Relocation Problem (E-VReP), in one-way carsharing systems, based on operators who use folding bicycles to facilitate vehicle relocation. In order to calculate the economic sustainability of this relocation approach, a revenue associated with each relocation request satisfied and a cost associated with each operator used are introduced. The new optimization objective maximizes the total profit. To overcome the drawback of the high CPU time required by the Mixed Integer Linear Programming formulation of the E-VReP, two heuristic algorithms, based on the general properties of the feasible solutions, are designed. Their effectiveness is tested on two sets of realistic instances. In the first, all the requests have the same revenue, while, in the second, the revenue of each request has a variable component related to the user's rent-time and a fixed part related to customer satisfaction. Finally, a sensitivity analysis is carried out on both the number of requests and the fixed revenue component.

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1. Introduction and literature review

Carsharing consists in the shared use of cars made available by paying a charge which is based on the time of use. It differs from a car rental service since it envisages the use of the car only for a short time (usually for a fraction of an hour) in order to favor the sharing of each car by different people throughout the same day. Due to environmental sustainability issues, nowadays, several carsharing companies are providing their customers with Electric Vehicles (EVs) rather than traditional internal combustion engine cars. Examples of real electric carsharing systems are: Car2Go (http://www.car2go.com/) in Amsterdam and Vienna; Autolib (www.autolib.eu) in Paris; Autobleue (http://www.auto-bleue.org) in Nice-Côte d'Azur (France).

The planning and management of a carsharing service poses some important decision-making problems. As regards planning, two significant issues are the size of the fleet and the location of the parking stations [1–3]. On the management side, some carsharing services permit one-way trips, which allow the user to pick up the vehicle at one station, and return it to another. The flexibility offered by a one-way system makes it more attractive to users. However, it is harder to manage since it involves a possible imbalance between the demand and the availability of vehicles or, vice versa, between the number of vehicles in arrival and the availability of vacant parking lots, thereby making vehicle relocation necessary. In these cases, the service provider has to develop strategies to relocate the vehicles and restore an optimal distribution of the carsharing fleet. Such strategies also depend on the available data. Barth and Todd [4] propose the classification: *static relocation*, based on the immediate needs of a particular parking lot; *historical predictive relocation*, based on an estimation of the requests made using either the historical data of the service or travel demand estimation techniques; *exact predictive relocation*, based on a known demand (as is the case for a carsharing service which uses a system with reservations).

Vehicle relocation can be carried out by either the user or the service provider [5]. In the first case, the user is motivated to carpool or to choose another parking station or reservation time (generally through the pricing lever); in the second case, the vehicles are either transported on trucks or driven by the service provider staff.

However, in general, operating with EVs rather than traditional internal combustion engine cars further complicates the management of these systems, as shown in [6]. In particular, the authors consider several problems related to EV management (e.g. the poor battery range) from an optimization point of view. Hafez et al. [7] minimize the total travel time for relocation, using three different heuristics. Jung et al. [8] address the problem of locating infrastructures for EVs (i.e. electric taxis in their case) by proposing a new model in which the passenger demand is not known *a-priori*, thereby leading to a stochastic dynamic itinerary for each EV.

Kek et al. [9] design a system based on a three-step optimization-trend-simulation for supporting carsharing operators in relocating the vehicles. Such a system is tested considering the realistic scenario of a carsharing company in Singapore. Di Febbraro et al. [10] model the complex dynamics of the carsharing system, using a discrete event system simulation. The paper considers relocation by both users and staff, and has a twofold objective: to reduce the number of staff required and to minimize the number of carsharing vehicles needed in order to satisfy the system demand. Correia et al. [11] study the flexibility of one-way carsharing systems and propose a new mathematical formulation including the possibility for users to select the station according to its vehicle availability and not only depending on the distance from their origin/destination. A real life case study, concerning a carsharing system in Lisbon, is taken into account during the experimental campaign.

Very recent studies are reported in the work by Nourinejad and Roorda [12] in which the authors propose both an *a priori* benchmark model and a dynamic vehicle relocation optimization model. The latter is solved via a discrete-event simulator where the arrival of a user request constitutes an event. The numerical results discussed have shown that the optimization–simulation based model is suitable to determine a trade-off between the vehicle relocation time and the fleet size.