MODELING AND SIMULATION OF AN ELECTRIC CAR SHARING SYSTEM

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ABSTRACT
Electric Vehicles (EVs) represent an effective response to the pressing environmental and economic problems linked to the mobility in the urban areas. However, limited drive range and high purchase costs limit strongly their popularity. The deployment of EVs in the car sharing (CS) fleets is an effective strategy to overcome these initial drawbacks. In order to make it competitive with the traditional private mobility forms an accurate planning is required. With the aim of obtaining a tool able to highlight the impact of the EVs adoption on the performances of a CS service and evaluate different operative conditions, this paper develops a discrete event simulation model of a generic electric-CS system. In order to assess the validity of the approach, a real case study is analyzed and simulated.

Keywords: Electric Vehicles, Car Sharing, Discrete-event Simulation.

1. INTRODUCTION
In the last decades, the pressing need of reducing the energy dependency of the mobility on fossil fuels and the growing environmental problems highlighted the importance of identifying concrete alternatives to the traditional Internal Combustion Engine (ICE) vehicles. In particular, Electric Vehicles (EVs) are reaching increasing interest and the Governments of many Countries all over the world have been investing huge amounts of money in the research and the development of this technology. In particular, the drawbacks that mainly affect the popularity of the EVs are high prices and limited driving range (which causes the so-called *range anxiety*): concrete answers to these concerns have to be given. In this context, an opportunity is represented by the *shared-use vehicle systems*, i.e., systems in which a company makes available to registered users a common fleet of vehicles and customers pay only for the actual utilization of the rented vehicle (Barth and Shaheen 2002). Thanks to this new form of mobility, therefore, users can share the fixed costs usually associated to the ownership of a private means of transport and, at the same time, the overall mobility behavior becomes more rational, since customers are more aware of the effective costs associated to the conformation of their trips. Moreover, among the other forms of shared-used vehicle systems, the *car sharing* (CS) seems to be the most suitable for the adoption of the EVs. In this kind of organization users can rent a car also for limited time periods and, usually, for trips within a specified urban area. Hence, the distances typically travelled in this context are compatible with the EVs driving ranges.

However, the deployment of EVs in CS fleets introduces some management complexities that have to be faced carefully in order to guarantee service efficiency and flexibility and, therefore, to overtake the undeniable competitive advantages of the traditional private mobility forms. In this context, a simulation approach can be useful to identify the best operative strategies and to highlight the critical issues of the considered service.

This paper is part of this framework and deals with the development of a simulation model useful to analyze the behavior of a generic CS service and to assess the impact of the EVs adoption on the overall system performances.

Moreover, the used approach can be outlined as follows. First, a detailed analysis of the peculiarities characterizing the management of a generic CS service and the deployment of the EVs is conducted. Second, the results of this phase are formalized through the Unified Modeling Language (UML) and, in particular, class and activity diagrams are developed. Finally, a simulation model is realized in the Arena environment, a discrete event simulation software. In order to assess the validity of the developed simulator and the effectiveness of different operative conditions, a real case study involving the electric-CS service of Pordenone, a city of the North of Italy, is taken into account, and different simulations are carried out.

The remainder of the paper is structured as follows. In section 2 the electric-CS problem is analyzed and formalized through UML class and activity diagrams. Section 3 describes a specific case study, while in Section 4 the Arena model is developed and the system behavior under different operative conditions is simulated. Finally, in Section 5 the conclusions are summarized.

2. THE ELECTRIC-CAR SHARING PROBLEM

2.1. UML Class Diagram

In order to make a generic CS service efficient and competitive, several parameters must be analyzed and calibrated properly. More in detail, the main key issues to consider are:

1. the *optimal fleet size* (George and Xia 2011, Nakayama, Yamamoto and Kitamura 2002);
2. the *location of the parking areas* (Correia and Antunes 2012);
3. the *pricing policies*;
4. the *service accessibility* (Barth, Todd, and Xue 2004);
5. the *rental rules*, intended as the possibility or not for the users to pick up the vehicle in a parking area and to return it in a different one (Wang, Cheu and Lee 2010, Ken, Chew, Meng and Fung 2009, Uesugi, Mukai and Watanabe 2007, Mukai, Watanabe 2005).

Moreover, when EVs are deployed in the service fleet, additional concerns must be taken into account (Nakayama, Yamamoto and Kitamura 2002, Xu, Miao, Zhang and Shi 2013, Chen, Kockelman and Khan 2013):

6. the *number of the charging stations*;
7. the *location of the charging stations*;
8. the *recharging policies*, that is, when and how the EVs must be recharged (every time the users return them after the rental, or when the battery SoC is below a certain threshold, and so on).

In order to formalize these aspects in a synthetic manner, the UML formalism is adopted. In particular, to represent the structure of a generic CS service whose fleet consists also of EVs, a class diagram is developed. This kind of diagram is useful to highlight the different types of objects that the considered system have and the relationships between them. More in detail, each class represents a set of objects characterized by the same attributes, operations and relationships. Every class is depicted by a rectangular box divided into compartments: the first compartment holds the class name, which must be unique and distinguishes the classes from each other; the second one holds the class attributes, which are the qualities that describe its characteristics; the last compartment holds the operations, that is, features that specify the behavior of the class. Between classes various types of relationships are possible and they are represented with different graphic connections: association (solid line), aggregation (solid line with a clear diamond at one end), composition (solid line with a filled diamond at one end), generalization (solid line with a clear triangle at one end), realization (dashed line with an arrow at one end) and dependency (dashed line with an arrow at one end). In addition, labels on the lines express the multiplicity of the considered relationship, that is, how many instances of a particular class are involved in a relationship.

In Fig. 1 the class diagram describing the CS problem is depicted. As can be seen, in a generic CS system the following structural components can be pointed out:

- *Management System*: it deals with the monitoring and the coordination of the system and with the system state information collection;
- *Reservation Management System*: system dealing with the management of the vehicles reservation operations;
- *Payment Management System*: centralized system that, once collected travel data of a specific rented vehicle, calculates how much the customer has to pay and, then, manages the payment phase;
- *Relocation Activities Management System*: if the user can pick-up and return the vehicle in different parking areas, this system monitors the distribution of vehicles among the parks and, if necessary, starts the vehicle relocation activities;
- *Pricing Policies Determination System*: system that determines which pricing policy must be chosen and if a mechanism of economic incentives to the users has to be started;
- *Emergencies Management System*: module that handles any emergency that users communicate to the system through ICT tools installed on board each vehicle;
- *Registrations Management System*: centralized system which manages the registration phase of new customers;
- *Maintenances Management System*: module that deals with the maintenance and repair of fleet vehicles;
- *Car Sharing Company*: CS company on the whole;
- *Operator*: employee of the CS organization;
- *User*: once registered into the system, he can rent a vehicle;
- *Vehicle*;

- *Traditional Vehicle*: child class of "Vehicle", represents any car with an Internal Combustion Engine (ICE);
- *Electric Vehicle*: child class of "Vehicle", represents any kind of Electric Vehicle (EV);
- *Parking Area*: station at which it is possible to rent/return a vehicle;
- *Traditional Parking Area*: child class of "Parking Area", identifies simply the place where the vehicles are available to be rented or can be returned;
- *Charging Station*: child class of "Parking Area", identifies a parking equipped with an EV charging infrastructure and, then, a parking area characterized by a greater management complexity.

Moreover, the following association classes can be stressed:

- *Rental* (between the classes *User*, *Parking Area* and *Vehicle*);
- *Relocation* (between the classes *Parking Area*, *Vehicle* and *Operator*);
- *Maintenance* (between the classes *Vehicle* and *Operator*);
- *Emergency* (between the classes *Vehicle* and *Operator*);
- *Purchase/Substitution* (between the classes *Vehicle* and *Operator*);
- *Share a Vehicle* (between different instances of class *User*).

2.2. UML Activity Diagrams

The values of the attributes of the classes described in the previous subsection represent the state of the system: the attributes update rules and the system behavior is modeled by the activity diagrams. Indeed, UML activity diagram is useful to highlight the set of events that, coming in succession, determine any process occurring in a given system.

More in detail, each activity diagram is divided in columns, the so-called *swim lanes*, in order to clearly stress which actor is responsible for which action. The main elements characterizing this kind of diagram are: the *initial activity* (depicted with a solid circle), the *final activity* (represented with a bull's eye symbol) and *generic activities*, depicted with rectangles with rounded edges. *Flows* are represented through arcs connecting activities, while *alternative flows*, and, therefore, *decisions*, are denoted with diamonds. Finally, concurrent activities respectively beginning and ending at the same time (*forks* and *joins*) are depicted with a tick horizontal line.

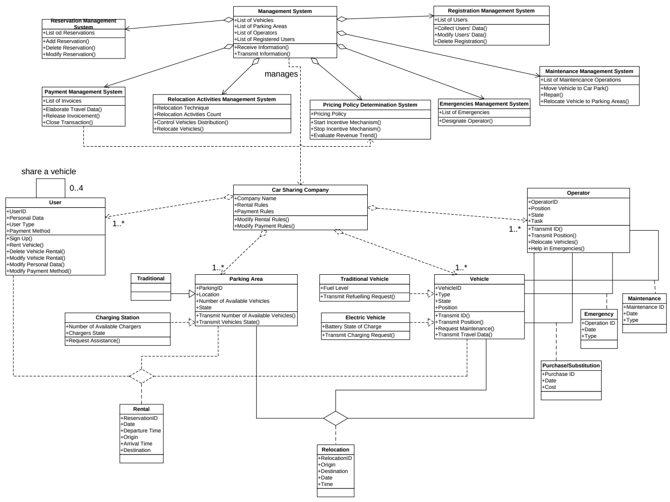

Figure 1: Electric-CS service class diagram

In this context, among the other process characterizing the evolution of an electric-CS service, we consider the car renting process and its rules, since it is the most affected by the introduction of the EVs. When EVs are deployed in the service fleet the management complexity increases, since the wait for an available charger and the charging time are additional delays that can reduce drastically the number of served users and, so, the company gain.

In Fig. 2 the activity diagram of the car renting process is reported. Such a process involves three actors: the *user*, the *vehicle*, and the *management system*. Seven main phases characterize it:

1. the *vehicle request* phase, representing the request and the user waiting for an available vehicle;
2. the *checking vehicle availability* phase, during which the management system checks if there are available vehicles at the parking area;
3. the *rental and use of the vehicle* phase: note that the *"Travel time determination*" and "*Destination parking determination*" activities are simple schematization of the users' decision process and not required declarations to the system.
4. the *vehicle restitution* phase;
5. the *charging* phase: each vehicle, once given back in a parking area, waits for an available charger and starts its recharging process. In this case it is assumed that the charging takes place after each rental period, as it is reasonable to suppose that users will be more confident if they start their travel with a fully-charged vehicle.
6. the *maintenance* phase, which involves only the vehicles that need maintenance operations after the rental period;
7. the *payment* phase, after which the user leaves the system.

3. A CASE STUDY

In order to analyze more comprehensively the effects of the introduction of EVs in a CS fleet, a particular case study is considered. From data derived from the experience of the electric-CS service of Pordenone, a town of the North of Italy, the following system is studied.

A number of 10 electric vehicles is made available to the users for rental in two parking areas, named respectively P1 and P2. Furthermore, we assume that the parking area P1 is characterized by a greater attractiveness (and, so, a greater mobility demand) than the other one. The service fleet consists of small EVs, with a driving range of about 40 km and a maximum recharge time of 1.5 hours.

The following rules, relevant for the purpose of this work, manage the service:

- it is not allowed to leave the municipality territory;
- rented vehicles must be given back by 8:15 pm;
- rented vehicles can be returned in any parking area of the system.

Moreover, the following additional assumptions are considered:

- *maximum waiting time*: we assume that users are not willing to wait more than 10 minutes to rent a vehicle and so, after this time interval, they leave the system without being served;
- *maintenance*: we consider the possibility that a vehicle, after the rental period, needs a repair service. Moreover, two different types of maintenance are taken into account: the first one is of about 8 hours, the second one takes 1 hour;
- *initial distribution of the vehicles*: we consider that initially vehicles are equally distributed between the two parking areas;
- *vehicle recharging operations*: we assume that vehicles are recharged after each rental and that the users start their travels with a fully charged vehicle;
- *number of available chargers*: initially we assume that both P1 and P2 are equipped with 2 chargers.

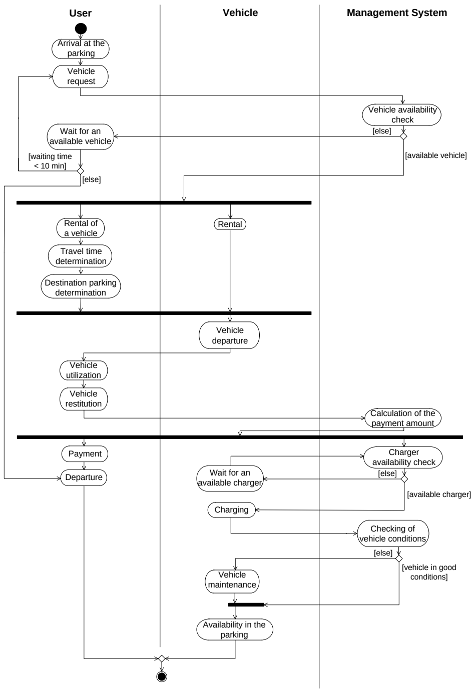

Figure 2: UML activity diagram of the car renting process

4. THE SIMULATION MODEL AND RESULTS

4.1. The Simulation Specification

In order to analyze the behavior of the considered system, a simulation model is implemented in the Arena environment, a discrete-event simulation software. More precisely, each activity of the UML diagram of Fig. 2 is modeled by a discrete event of the simulation. Users and vehicles are entities requiring and seizing resources and the management system is the actor that determines the system evolution rules.

Users' inter-arrival times (named A1 and A2 for parking area P1 and P2, respectively) are modeled by an exponential distribution of mean λ time units (t.u.), where the minute is considered as t.u. In order to express the operation time, the rental, maintenances and charging operations have triangular distribution.

Two possible travel times, denoted by T1 and T2 respectively, are considered and different modeling approaches are used: T1 is modeled by a triangular distribution, T2 is modeled by an exponential distribution.

The parameters of all the mentioned distributions are reported in Table 1: the third column reports the average values of the exponentially distributed times (EXPO) and the modal (δ), minimum (d_δ) and maximum (D_δ) values of the triangular distributions.

Table 1: Used Probability Distributions and Parameters

Delay	Distribution	Parameter [min]
A1	EXPO	λ=24
A2	EXPO	λ=30
Rental	TRIA	$(d_\delta,\delta,D_\delta)$=(2,3,4)
Return and payment	TRIA	$(d_\delta,\delta,D_\delta)$=(3,4,5)
T1	TRIA	$(d_\delta,\delta,D_\delta)$=(13,20,30)
T2	EXPO	λ=60
Move to car park	EXPO	λ=60
Maintenance (short)	TRIA	$(d_\delta,\delta,D_\delta)$=(48,60,72)
Maintenance (long)	TRIA	$(d_\delta,\delta,D_\delta)$= (384,480,576)
Charging	TRIA	$(d_\delta,\delta,D_\delta)$=(30,60,90)

The performance index defined to evaluate the system behavior is the *Level of Service* (*LOS*), defined as the fraction of served users as follows:

$$LOS = \frac{number\ of\ served\ users}{total\ number\ of\ users\ in\ the\ service}. \quad (1)$$

The metric *LOS* are evaluated by a long simulation run of 21600 t.u., with a warm-up period of 30 t.u.. The estimates are deduced by 50 independent replications with a 95 % confidence interval, whose half width is about 2.2 % in the worst case.

Note that the average CPU time for a simulation run is about 15 seconds on a PC with a 1.40 GHz processor and 6 GB RAM: the presented simulator can be therefore applied to larger and more complex systems.

4.2. The Simulation Results

In order to analyze the system behavior as the level of request changes, a 5 minutes-step variation of users' average inter-arrival times is considered. More specifically, the mean values of the exponential distributions of the users' arrival times vary in the following intervals: $\lambda\in[5, 59]$ in P1 and $\lambda\in[10, 65]$ in P2.

In Fig. 3 the comparison between system LOS of a traditional CS service (i.e., a CS with ICE vehicles) and of an electric-CS service is depicted. It is apparent that there is a general worsening of the system performances when EVs are deployed in the fleet, since vehicles are not available for rental for longer time periods (on average, 21% less users are served).

Moreover, with the aim of assessing how the number of available chargers influences the *LOS*, we consider one more available charger in P1 (which is the most attractive destination). System performances under this new operative condition are reported in Fig. 4. The results highlight that the increase of the number of available chargers leads to a growth of the *LOS*. Moreover, we point out that when the level of congestion of the system is low, this solution is not incisive and still 15% of users are not served. At the same time, even when the system is really congested, the availability of this new resource leads to a moderate increase (of about 5%) of the fraction of served users. Therefore, such a kind of action is not sufficient to overcome the system inefficiency.

Finally, we finally use the simulation to determine the number of EVs that has to be initially available in the service in order to obtain the same *LOS* of the case with ICE vehicles. In particular, for this analysis we consider in P1 and in P2 the average inter-arrival times reported in Table 1. As can be seen in Fig. 5, a value of *LOS* equal to 0.92 (which is the value of *LOS* in the corresponding scenario when ICE vehicles are considered) is reached when there are 23 available EVs, which means when the size of the service fleet has been doubled.

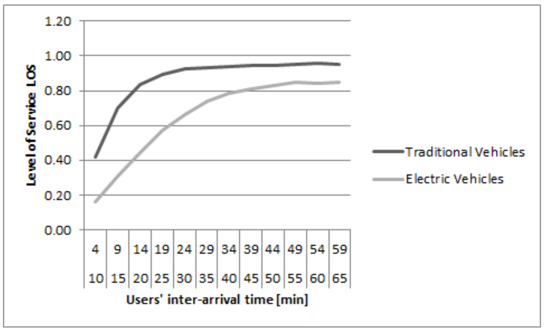

Figure 3: Level of Service comparison: ICE vs. electric vehicles.

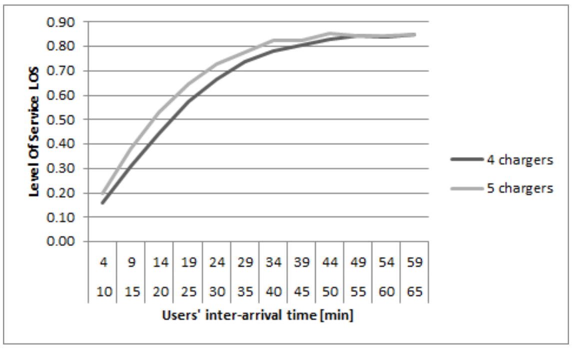

Figure 4: Level of Service comparison: 4 vs. 5 chargers.

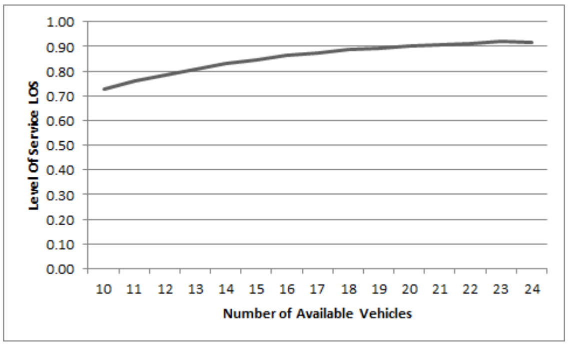

Figure 5: Level of Service in function of the number of available vehicles.

5. CONCLUSIONS

The aim of this paper is to formalize the issues characterizing the adoption of EVs in CS fleets and to develop a tool useful to assess system performances and evaluate different possible operative scenarios. In particular, a discrete event simulation in Arena environment is realized and a specific electric-CS service based on a real CS experience is analyzed.

Simulations results enhance the management complexities introduced by the EVs deployment. There is a general deterioration of the system performances and different parameters have to be re-calibrated in order to obtain the same level of service guaranteed in the traditional case. However, environmental benefits and the incentive that an electric-CS service can give to the diffusion of the EVs, encourage finding solutions able to ensure the competitiveness and the efficiency of such a kind of mobility form. The realized simulation is useful to perform this type of analysis. Moreover, considering its modular structure and the average CPU time for a simulation run, the simulation model can be easily extendable to greater and more complex systems.

Future researches will investigate about the possibility of improving system performances by influencing users' mobility behavior and applying suitable pricing strategies.

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