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# A Binary Linear Programming model for optimal parking slot management of urban carsharing services

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**Abstract:** In this study, we provide an overview of relevant national and local regulations and policies for smart mobility, focusing on carsharing services. In particular, we highlight the importance of parking policies. Given this importance, we propose a mathematical optimization model that can be used by a local government to analytically choose the best subset of parking slots to rent to carsharing companies, in order to improve urban mobility. Government that must choose which parking slots to rent to carsharing companies in a city, while finding an optimal balance between the interest of the population and those of the profit-oriented companies. Specifically, we propose to formulate this decision problem as a *Binary Linear Programming* problem, which includes boolean variables to represent the possibility of renting or not a cluster of parking slots. We present the results of testing the model using realistic data related to the City of Rome. Such data are defined on the basis of the experience gained within the collaboration with our industrial partners in E-Go, a carsharing service launched at the University Roma Tre with the support of the electric utility company Enel. The application of the model to a set of realistic data of city of Rome shows that the model can return a fair territorial distribution of the parking slots, satisfying various families of constraints limiting the distribution.

**Keywords:** Smart Mobility; Carsharing; Parking Slot Renting; Mathematical Optimization

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## 1. Introduction

Over the last decade, Smart Mobility (S-Mob) has become a major topic of interest for academy, industry and governmental organizations, given its major role in smart cities (see, e.g., Benevolo et al. 2016 and EU-INEA 2017). Following the definition of works like (GeSi-ACN 2015) and (Kenny 2013), an S-Mob system can be defined as a transport system that heavily relies on ICT (Information and Communications Technology) to ensure a stable and continuous connection between the infrastructures, the users and the system administrators. A major example of S-Mob is nowadays represented by carsharing, which constitutes a mobility service that allows a user to rent a car even for a few tens of minutes using a smartphone application and paying a per-minute fee (Weikl and Bogenberger, 2013). Carsharing has rapidly spread among many cities in the world, providing a more sustainable way to move by cars and actually deeply changing the way people conceive of the personal property of private vehicles.

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It is now widely recognized that carsharing and other S-Mob systems can have a positive impact on the quality of urban life. For an overview of the benefits of S-Mob, we refer the reader to (Carrese et al., 2014; Bencardino and Greco, 2014). Martin and Shaheen (2011) showed that the effect of carsharing in North America led to a decrease in the average number of cars per family from 0.47 to 0.24. S-Mob systems have a positive social impact too. However, S-Mob have found difficulties in being implemented. This is due to various reasons, such as the presence of regulatory frameworks that are often confused, or inertness of policy makers, which may ineffectively support the expansion of beneficial S-Mob services. In this work, we provide an overview of relevant national and local regulations and policies for smart mobility, focusing on carsharing services. In particular, we highlight the importance of parking policies. Given this importance, we propose a mathematical optimization model that can be used by a local government to analytically choose the best subset of parking slots to rent to carsharing companies, in order to improve urban mobility. Also, we propose a mathematical optimization method for establishing where to put reserved slots at disposal of the users. Finally, we present the results of testing the model using realistic data related to the City of Rome. Such data are defined on the basis of the experience gained within our collaboration within E-Go, a carsharing service launched at the University Roma Tre with the support of the electric utility company Enel (E-Go Car Sharing, 2016). The remainder of the paper is organized as follows. In Sections 2, we review local regulations, whereas in Section 3, we define the model for optimal parking slot renting and present the results of the application to data of the city of Rome.

## 2. A review of urban policies for carsharing systems

Nowadays, carsharing has widely spread in USA and Europe, becoming an innovative and alternative urban transport mode (Pinna et al., 2017). In the study of (Millard-Ball and Schipper 2011), underlines a significative decline on the cars's ownership. Furthermore, carsharing has generated a lot of attention as a more sustainable way to reduce emissions of CO<sub>2</sub> (Martin and Shaheen, 2011). A parking policy is indicated as one of the most effective strategies that the urban government can implement to stimulate carsharing (e.g., Rivasplata et al. 2013). Shaheen et al., 2013 highlight that in North America, over 70 local governments have adopted specific carsharing parking policies, including reservation. The study reported in (Dowling and Kent, 2015) has investigated how local governments can support carsharing, in particular by reserving parking slots. In 2016, the City of Sydney has approved new regulations for managing on-street carsharing parking slots- see City of Sydney 2016. A first objective is to define the obligations of companies for reserved carsharing parking slots. Another objective is to have a preventive approval from the residents. The parking slots location are defined on the basis of an evaluation of the potential demand for carsharing and on district features: if in a district less than 3.5% of all the slots are reserved to carsharing, then a company *already renting slots* may request at most 4 slots, if it can prove that the 3 slots that are closest to those requested have been used at least 18 times in a month; for districts exceeding the threshold of 3.5%, the conditions are more stringent. In Italy, carsharing services are currently active in 29 cities. Carsharing was introduced in Milan, Turin and Rome many years ago, it has been interested by a limited regulation and emission of policies, particularly those on parking, aimed at improving its effectiveness and efficiency. In 2013, new Italian regulations were introduced to allow the shared cars to access and park for free in restricted traffic zones and to park in slots restricted to residents. The regulations also state that a carsharing company must pay a yearly fixed price of 1100.00 euros for operating a vehicle. The more recent regulations (City of Milan, 2016) have introduced the obligation for the carsharing company to regularly update their fleet, imposing that a vehicle must be replaced once reached 4 years of

service or 100,000 km. The city of Rome has also been interested by regulations. The first regulations from 2004 allowed free access and parking in central restricted traffic zones; then, in 2010, it has been imposed that shared vehicles must be at most 3 years old. Finally, in 2016, further regulations - e.g., City of Rome - DGC136 2016 - have been aimed at strengthening the penetration of electric vehicles, establishing the realization of additional charging stations in central zones of the city. In this study we underline how parking policies are a fundamental component to stimulate the development of carsharing in cities. We can aggregate two major parking solutions: 1) assigning specific parking slots on the basis of a request made by a carsharing company; 2) renting a set of slots to all companies without distinction. The chosen solution must be then accompanied by other decisions, such as: 1) the total number of slots made available in the city and in each zone; 2) the maximum number of slot reserved to each company; 3) the location of the slots. Furthermore, a parking policy should also fix the price that a company must pay to gain the right of using a slot. The management of the parking stalls to be allocated to the car sharing services is a central aspect for the diffusion and the penetration of the S-Mob systems. Given this importance, we propose a mathematical optimization model that can be used by a local government to analytically choose the best subset of parking slots to rent to carsharing companies, in order to improve urban mobility

### 3. An optimization model for car slot assignment

We developed a mathematical optimization model in order to resolve the problem of the Local Government (LG) of a city that wants to decide which parking slots to rent to carsharing companies to improve sharing mobility. The optimization problem faced by the LG can be described as follows. The LG administers a city made up of a *set of districts* denoted by  $D$ . Each district  $d \in D$  includes a set of sub-districts, denoted by  $S(d)$ . In each district  $s \in S(d)$  with  $d \in D$ , the LG has identified a number of *parking slot clusters* available for renting to carsharing companies: a parking slot cluster (or briefly, *cluster*) is a set of parking slots that is reserved for parking carsharing cars. Formally, for each district  $d \in D$  and sub-district  $s \in S(d)$ , we denote by  $C(s, d)$  the set of clusters available in  $s$ . For each cluster  $c \in C(s, d)$ , we denote by  $n_c$  the number of parking slots composing the cluster. A cluster must be rented as a whole, i.e. it is not possible to just rent a part of its slots. As in real-world studies, we assume that the LG has identified a profit measure that quantifies the benefits of renting each cluster  $c$  on the basis of preliminary studies (see, for example, the regulation of the City of Rome - DGC136 2016). We denote such profit by  $\pi_c$ . Such measure may take into account several distinct factors, such as the revenue obtained renting the cluster, the cost associated with maintaining the cluster, the economical benefits of having carsharing services in an area (e.g., financial, environmental and social).

In line with policies presented in the previous section, we strongly believe that the renting of parking slots should be coordinated with the local residents. To this end, we consider very important to include a limit on the total number of parking slots that can be rented in each district. This is done to not “upset” the population, which typically wants to have a fraction of the parking slots in a district to be (freely) available to car owners. For example, the number of rented slots could be required to not exceed a fraction of the total number of parking slots available in the district. Furthermore, it is also important to include a minimum number of slots that must be rented, to favour the diffusion of carsharing; this could reflect the dimension of the fleet maintained by the companies. For each sub-district  $s \in S(d)$  with  $d \in D$ , we denote such lower and upper limits on the number of rented parking slots by  $\eta_s^{\min}$  and  $\eta_s^{\max}$ , respectively. Furthermore, we assume that the LG also wants to include a lower and upper limit  $\gamma_s^{\min}, \gamma_s^{\max}$  on the number of

clusters that may be rented in each sub-district. Another important aspect that we want to model is that the LG classifies the clusters per types and wants to include a minimum and maximum number of clusters for each type in each district. For example, clusters could be distinguished per type by the number of parking slots that they include. On the basis of our direct experience with the creation of a carsharing service for the University of Roma Tre in Rome (Carrese et al., 2014, E-Go Car Sharing, 2016), we expect that an LG wants to have a good balance between clusters of bigger and smaller dimensions. Another example of type distinction is that between shopping, business and residential clusters, depending in which zone of a district they are located. From a modelling point of view, we thus introduce a set  $T$  to denote the cluster types and we denote by  $t(c) \in T$  the type of a cluster  $c$ . For each district  $d \in D$ , we denote by  $\tau_{dt}^{\min}$  and  $\tau_{dt}^{\max}$  the minimum and maximum number of clusters of type  $t$  allowed in district  $d$ . After having introduced all these elements, the optimal decision problem that the LG faces can be stated as follows: choosing which parking slot clusters to rent in each sub-district, without exceeding the minimum and maximum limits on the number of clusters and parking slots that can be activated and those on the type of clusters. We model such optimization problem as a *Binary Linear Programming* problem. In order to model the decision of renting or not a parking slot cluster, we introduce a binary decision variable  $x_{dsc} \in \{0,1\}$  for each district  $d \in D$ , sub-district  $s \in S(d)$  and cluster  $c \in C(s,d)$ , defined as follows:

$$x = \begin{cases} 1 & \text{if cluster } c \text{ in subdistrict } s \text{ of district } d \text{ is rented} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

These decision variables are employed in the following constraints defining the set of feasible solutions of the optimization problem. First, we need a set of constraints to express that, for each sub-district, the limits on the number of rented parking slots cannot be exceeded:

$$\eta_s^{\min} \leq \sum_{c \in C} \eta_c \cdot x_{dsc} \leq \eta_s^{\max} \quad (2)$$

We remark that here the decision variable is multiplied by the number  $\eta_c$  of slots in a cluster. Then, we must express the limits on the number of clusters that can be rented in each sub-district:

$$\gamma_s^{\min} \leq \sum_{c \in C(s,d)} x_{dsc} \leq \gamma_s^{\max} \quad (3)$$

Finally, we need constraints to express the limits on the number of cluster types that can be rented in each district:

$$\tau_s^{\min} \leq \sum_{s \in S(d)} \sum_{c \in C(s,d): t(c)=t} x_{dsc} \leq \tau_s^{\max} \quad (4)$$

We note that in these constraints the two summations involve the decision variables of all the clusters located in sub-districts of the district  $d$  that are of cluster type  $t$ . The objective is to maximize the total profit, expressed as the summation of the decision variables over all districts, sub-districts and clusters:

$$\max \sum_{d \in D} \sum_{s \in S} \sum_{c \in C} \pi_c x_{dsc} \quad (5)$$

The overall Binary Linear Programming problem is then obtained by joining (1 - 5), which we use it in the next section to solve the problem of renting parking clusters in the Italian city of Rome.

#### 4. A case study from the city of Rome

We applied the optimization model developed to resolve the cluster renting problem for a dataset of realistic data related to the Italian city of Rome. These data were defined through the collaboration with professionals of the electric company Enel within E-Go Car Sharing (2016), an electrical vehicle carsharing service developed at the University Roma Tre. The dataset considers those districts where parking requires to pay a fee (hosting so-called “blue-lines”). Specifically, we identify 5 districts including 27 sub-districts in total. Depending on its size, road features and importance of the sub-district in the Roman urban mobility system, for each sub-district, we identified a number of clusters: this number ranges from 1, in the case of the smallest sub-district, to 22, in the case of the biggest and more important sub-district. We identify 9 types of cluster on the basis of the number of parking slots included in a cluster. Each cluster has a number of slots ranging from 2 to 10, with bigger clusters located close to important landmarks, such as train stations. The minimum and maximum limits on the number of slots rentable in each sub-district, those on the number of clusters rentable in each district and those on the number of types rentable for each type in each district are defined on the basis of the features of the resident population, business activities, available public transportation and urban fabric.

The resulting problem was solved on a 2.70 GHz Windows machine with 8 GB of RAM and using IBM ILOG CPLEX 12.5 as software for solving the optimization problem. The code for implementing the model was written in C/C++ and is interfaced with CPLEX through Concert Technology. The results associated with the obtained optimal solution of the optimization problem are visualized in Figures 1a and 1b. As a comment to the results, we can first note that, if the problem contained just one single constraint imposing a maximum number of slots over all the districts, then we could adopt a simple and fast heuristic solution approach consisting of: 1) computing the profit per parking slot of each cluster; 2) sorting the clusters from the highest to the lowest in terms of such profit; 3) select one by one the clusters, following the sorting order, until the maximum number of rentable slots is exceeded. However, this simple solution approach would possibly lead to a sub-optimal solution (i.e., of low quality) also presenting an unfair distribution of the clusters. To avoid this, the additional constraints that limit the number of slots, the number of clusters and the number of types of clusters are needed.

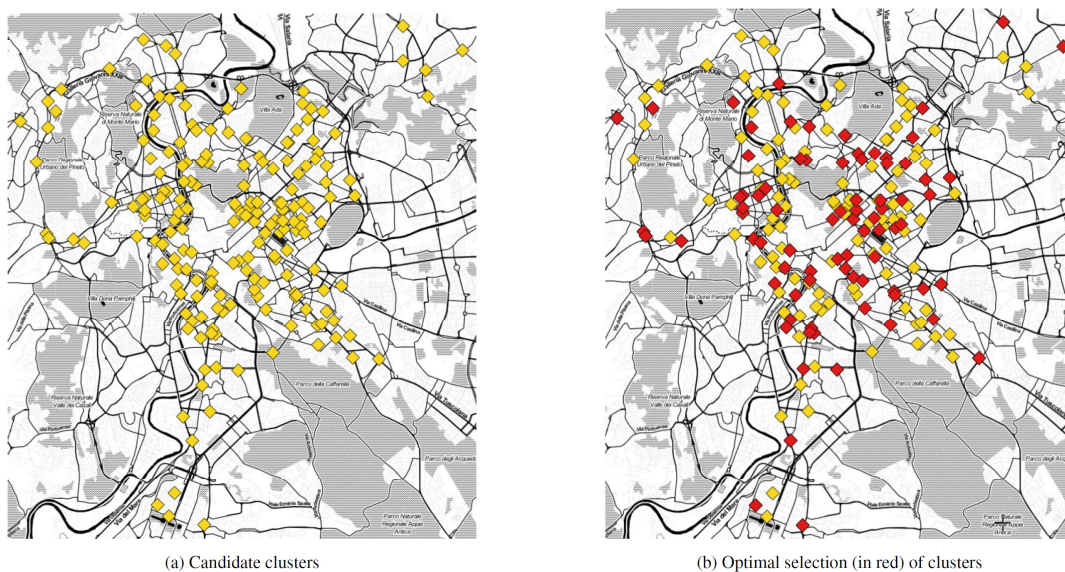


Fig. 1: Parking clusters for the City of Rome

This results into a more complex structure of the problem, where the connections between districts, sub-districts and cluster types discourage the application of the previously cited simple heuristic solution and requires instead the application of an optimization solver to get an optimal solution. Analyzing the optimal solution, which constitutes the output of the optimization process, and putting it into relation with the input of the optimization process, we can note a tendency to push the number of rented cluster to its imposed minimum  $\eta^{\min}_s$  in less profitable sub-districts. In contrast, more attractive districts and sub-districts which offers clusters with a higher number of slots present a number of activated clusters that tend to be closer to the allowed maximum  $\eta^{\max}_s$ . For example, in one of the largest central sub-district, which hosts important business and administrative activities and is close to important public transportation nodes, it is activated one of the largest clusters plus a combination of well-spaced clusters with 5 and 7 slots. As it possible to observe in the figure, the presence of the constraints expressing limitations on the rentable clusters allow to have a fair distribution of the rented clusters over all the districts, thus contributing to pursue a fundamental objective of the LG.

On the basis of the obtained encouraging results, as future work, we intend to define appropriate multiperiod versions of the optimization model, which would allow to consider the parking slot renting problem over a long-term period taking into account the variations of demand for carsharing over time.

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