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An optimization model for renting public parking slots to carsharing services

Stefano Carrese[a], Fabio D'Andreagiovanni[b,c,]*, Tommaso Giacchetti[a], Antonella Nardin[a] Leonardo Zamberlan[a]

[a]*Dipartimento di Ingegneria, Università degli Studi Roma Tre, Via Vito Volterra 62, 00146 Roma, Italy*
[b]*National Center for Scientific Research (CNRS), France*
[c]*Sorbonne Universitès, Universitè de Technologie de Compiégne, CNRS, Heudiasyc UMR 7253, CS 60319, 60203 Compiégne, France*

Abstract

Smart mobility systems represent a new generation of transport systems that are strongly supported by information and communications technologies, allowing a continuous connection between the system administrators, the customers/users, the transport infrastructures and the vehicles. A major example of these systems is represented by carsharing. Carsharing can relieve people from the costly and non-sustainable burden of owning a car, especially when residing in a city. Furthermore, it can reduce pollution and traffic congestion and has been worldwide recognized as a fundamental component of smart cities by policy-makers In this study, we provide an overview of relevant regulations for carsharing, highlighting in particular 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. We test the model on realistic data of the city of Rome, showing that we can obtain a fair territorial distribution of the parking slots that satisfies population needs. The data were defined on the basis of our collaboration with professionals of the electric utility company Enel within E-Go Car Sharing, an electrical vehicle carsharing service established at the University Roma Tre.

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

* Corresponding author. Tel.: +33 344-234-234.
E-mail address: d.andreagiovanni@hds.utc.fr

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1. Introduction

In recent times, smart mobility systems have attracted a lot of attention, since they are considered a fundamental component of modern smart cities, as recognized by national and international establishments and by major companies active in the landscape of digital economy (e.g., Benevolo et al. (2016); EU-INEA (2017)). A Smart Mobility (SMOB) system can be defined as a strongly Information and Communications Technology (ICT)-supported Transport System (e.g., GeSi-ACN (2015), Kenny (2013)). ICT is a crucial component of SMOB systems: it enables a continuous connection between the system administrators, the customers/users and the mobile and fixed infrastructures and represents a key building block for offering innovative trustable and sustainable ways to move in urban and extra-urban scenarios. A major example of SMOB is represented by carsharing services. Nowadays, carsharing is intended as a mobility service that allows a user to rent a car for very short period of times (e.g., a few minutes) using a smartphone application and paying a per-minute fee (see e.g., Weikl and Bogenberger, (2013)). Such services have contributed to revolutionize urban mobility in the last decade, basing their success also on the strong diffusion of smartphones.

It is now widely recognized that carsharing and other SMOB systems can have a (very) positive impact on the quality of life in urban and extra-urban scenarios, sensibly reducing the negative sides of transport systems (e.g., pollution caused by traffic, road congestion). For an overview of the benefits of SMOB, we refer the reader to Benevolo et al. (2016), Carrese et al. (1996), Bencardino and Greco (2014), GeSi-CAN (2015). Some studies have tried to precisely assess this positive impact. For example, Martin and Shaheen (2011) showed that the introduction of carsharing in North America led to a decrease in the average number of vehicles per family from 0.47 to 0.24 and that, on average, each shared car substituted from 9 to 12 private cars. Besides the positive impact on environment and economy, carsharing and other SMOB systems have a positive social impact too. Indeed, a considerable part of the costs that road transportation entails does not appear as internal costs borne by the drivers, but is taken into account as external costs (e.g., environmental impact) and thus is borne by the collectivity. Such external costs represent a third of the total transport costs and about 90% is due to private car owners, as highlighted by Lombard et al. (2005). Within this context, carsharing and other SMOB systems present features that can ease the internalization of costs, since they support the passage from privately-owned cars to mobility as a service, based on the concept of pay-as-you-go.

Though their benefits are pretty evident and clear, SMOB systems have found difficulties in being implemented. This is due to various reasons, such as: 1) the presence of regulatory frameworks that are often confused and not up-to-date for welcoming new innovative SMOB digital platforms and services; 2) the inertness of policy makers, which may ineffectively support the expansion of SMOB services, thus dooming them to remain just at an experimental and very low-scale level.

In the present work, we review some major carsharing regulations, highlighting the importance of adopting reserved parking slots for carsharing vehicles. Also, we propose a mathematical optimization method for establishing where to put reserved slots at disposal of the users. Specifically, our major contributions are the following:

1) we provide an overview of the regulations and policies of a set of major cities where carsharing has been introduced, particularly highlighting the importance of parking policies in making carsharing a success and discussing the Italian case in more detail;

2) given the crucial role of parking policies in carsharing, we introduce a mathematical optimization model to represent the decision problem of a Local Government (for example, the council of a municipality) 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. To the best of our knowledge, such decision problem has never been addressed through optimization techniques as we do in the present paper. The objective of this model, is to provide an easy-to-use mathematical tool for Local Governments, which can be easily adopted and tuned.

3) 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 with E-Go, a carsharing service launched at

the University Roma Tre with the support of the electric utility company Enel - see Carrese et al. (2017). They also take into account the current regulations of the City of Rome for carsharing (see City of Rome - DGC136 (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. Finally, in Section 4, we derive conclusions and discuss possible directions for future work.

2. A review of local regulatory situations for carsharing

As a major expression of SMOB, carsharing has widely spread especially in the USA and Europe, becoming one of the new important modes of urban transport, as highlighted by Pinna et al. (2017). Several studies pointed out that the use of privately owned cars, though still very common, has experienced a significant decline in many countries since several years (see e.g., Millard-Ball and Schipper (2011), Newman and Kenworthy (2011)). Furthermore, carsharing has gained a lot of popularity as a more sustainable way to reduce emissions of CO2, as indicated by Martin and Shaheen (2011).

A good parking policy is indicated in literature as one of the most effective strategies that a local government can implement to stimulate carsharing, see e.g. Rivasplata et al. (2013). A detailed study made by Shaheen et al. (2010) highlights that in North America over 70 local governments and municipalities, such as San Francisco and Vancouver, have adopted specific policies to favour the parking of carsharing, also including the reservation of parking slots for shared cars. This study also reports that a survey among the San Francisco residents revealed that just 20% of the people were against the reservation of slots for carsharing. Very recently, also the New York City Council has passed legislation that will require the Department of Transportation to start a two-year pilot study for evaluating the reservation of parking slots to carsharing companies, see New York City Council (2017).

Another very interesting study that has investigated how local governments can support and stimulate carsharing, in particular by reserving parking slots, was published by Dowling and Kent (2015). The authors focused on the case of Sydney, where in 2013 there were 1000 shared cars managed by various companies, leading to an estimated benefit for carsharing users of more than 300 millions of dollars. The study highlights that the carsharing was not taken into consideration in the transport plans defined by the regional government including the city of Sydney, but was instead considered at a local level, in the regulations of Sidney city and in that of 6 out of 8 the districts where carsharing operated.

In 2016, the City of Sydney has approved new regulations for managing on-street carsharing parking slots with the aim of exploiting them more efficiently - see City of Sydney (2016). A first objective of these regulations is to define the requirements and obligations of companies that apply for reserved carsharing parking slots: for example, they require to deploy vehicles that emit less than 175 g/km of CO2 and to produce a report about the use of each vehicle each month. A second objective is to clearly state the rules by which a company may get parking slots: the rent must obtain a preventive approval from the residents and retailers of the area and from local committees for bicycle and pedestrian mobility. The number and position of the parking slots are defined on the basis of an evaluation of the potential demand for carsharing and on the basis of the 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 order to favour competition, a company without rented slots can rent without restrictions at most 3 slots in a district with up to 900 total slots or at most 6 in a district with more than 900 slots. Always in the metropolitan area of Sydney, specifically in the Municipality of Ashfield, the local government has approved regulations specific for carsharing – see City of Ashfield (2010) - which were aimed at deeply involving the citizens in the process of assignment of parking slots. Assigning slots to carsharing in an area required the approval of 75% of the residents. Furthermore, the rules favoured the location of slots close to parks and retailers. Last but not least, they provided for making pay the cost of realization of the reserved slots to the carsharing companies, which every year must submit a report on the usage of the slots.

In 2011, the Canadian city of Calgary approved regulations aimed at favouring carsharing specifically impacting on parking policy, see City of Calgary (2011). In particular, the carsharing companies are obliged to relocate their vehicles so that the reserved slots have a car available for a minimum number of hours everyday. Also, each company may receive at most 3% of the total number of slots available in any area identified as commercial.

Finally, it is interesting to cite the case of the city of Vancouver, where the price for renting parking slots differs depending upon the district, see City of Vancouver (2016): more attractive districts in terms of business activities are associated with higher prices.

Concerning Italy, urban carsharing is currently active in 29 cities and, according to a 2016 survey, was counting 5764 vehicles. Concentrating the attention on three of the largest cities (Milan, Rome and Turin), the first very interesting observation to be made is that, though carsharing was introduced in these cities 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. The city of Milan offers the most advanced urban carsharing system in Italy, with several companies operating in the city. In 2013, new regulations were introduced to allow the shared cars to access and park for free in central 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 in the city and access the benefits stated above. The more recent regulations, provided by 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, similar to those of Milan: 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, such as 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 Turin, the regulations expressed by City of Turin (2015) not only allow the free access and parking in central restricted traffic zones, but also grant the right to drive on fast lanes reserved to bus and taxi services. A distinctive feature of these regulations is that they have been especially aimed at containing the air pollution, by imposing that the fleet of each carsharing company must contain at least 30% of low-emission natural-powered vehicles (e.g., bi-fuel methane-gasoline) and at least 10 electric vehicles. Furthermore, the regulations provide for that recharge stations of the company must be open also to private electric vehicles and that each company must cover with service an area of at least 40 square kilometers.

On the basis of the overview provided in this section, it is possible to see that parking policies constitute an important element of regulations adopted to encourage the development and penetration of carsharing in cities. We can distinguish 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 (i.e., no slot is reserved to a specific company). 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. This price could be differentiated depending on the attractiveness of the area: commercial and business districts could be more attractive than residential districts and thus be associated with higher prices; also, larger groups of contiguous parking slots should be associated with higher prices, given the higher chances of attracting carsharing vehicles and thus increasing availability for the users.

In order to guarantee a full application of the policy, the local governments must keep watch on the rented slots, timely sanctioning abuses and adopting ad-hoc fines for sanctioning people parking their private cars in reserved slots. We note that this aspect is not so trivial: the first experiments of carsharing directly managed by the City of Rome also failed because the reserved slots were often occupied by private cars, which counted on the very low chance of being fined by the local police. As found in several policies, it is also important that the local governments provides for obtaining regular reports about the conditions of each carsharing company, in particular defining some key performance indicators that allow to clearly evaluate the impact of carsharing and of parking slot reservation on the administered territory. Last but not least, the reservation of parking slots to carsharing should be subordinated to a positive advice of the local residents, as provided in the policies of several cities.

As it is evident, the problem that the local governments face when deciding how to put parking slots at disposal of carsharing companies presents a lot of factors to be taken into account. This lead to a complex decision problem that typically pursues the maximization of a measure expressing the benefit for the city and the population to adopt carsharing and specific parking policy. This is actually an optimization problem where the local government wants to take the best decision on the basis of its interest. In the next section, we investigate the possibility of modelling and solving such optimization problem through a mathematical approach.

3. An optimization model for parking slot renting

In this section, we introduce a mathematical optimization model for representing the problem of the Local Government (LG) of a city that wants to decide which parking slots to rent to carsharing companies in order to favour the penetration of sharing mobility and improve traffic conditions in its territory. The mathematical optimization model has the task of translating into mathematical terms the decision problem faced by the LG and its solution leads to the identification of an optimal solution to the problem, namely a solution that grants the best performance according to an objective function that includes key performance indicators.

In general, a mathematical optimization model representing an optimization problem includes three main components: 1) a set of decision variables representing the decisions that can be taken by the decision maker (e.g., referring to the parking slot rent problem that we consider, a decision variable represents the decision of renting or not a slot); 2) a set of constraints that express limitations on fixing the value of decision variables (e.g., we cannot rent more than a fixed number of parking slots); 3) an objective function, namely a function that evaluates how good is a full valorization of all the decision variables. For an exhaustive introduction to fundamentals of Linear Optimization, we refer the reader to the well-known book by Bertsimas and Tsitsiklis (1997). Here we recall that each valorization of all the decision variables included in the problem constitutes a solution. A solution can be either feasible, if it satisfies all the constraints, or infeasible, if it violates at least one of the constraints. A solution is said optimal if it is feasible and has the best objective value among all the feasible solutions.

System elements. 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 by City of Rome - DGC136 (2016). We denote such profit by π_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 η_s^{min} and η_s^{max}, respectively. Furthermore, we assume that the LG also wants to include a lower and upper limit γ_s^{min} and γ_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, namely E-Go Car Sharing for the University of Roma Tre in Rome, 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 D 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 τ_{dt}^{min} and τ_{dt}^{max} the minimum and maximum number of clusters of type t allowed in district d.

Modelling the optimization problem. 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: $x_{dsc} = 1$ if cluster c in sub-district s of district d is rented; $x_{dsc} = 0$ otherwise.

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:

$$\eta_s^{min} \leq \sum_{c \in C(s,d)} n_c \cdot x_{dsc} \leq \eta_s^{max} \qquad \forall\, d \in D, s \in S(d) \qquad (1)$$

We remark that here the decision variable is multiplied by the number n_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:

$$\gamma_s^{min} \leq \sum_{c \in C(s,d)} x_{dsc} \leq \gamma_s^{max} \qquad \forall\, d \in D, s \in S(d) \qquad (2)$$

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

$$\tau_{dt}^{min} \leq \sum_{s \in S(d)} \sum_{c \in C(s,d):\, t(c)=t} x_{dsc} \leq \tau_{dt}^{max} \qquad \forall\, d \in D, t \in T \qquad (3)$$

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 clusters 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:

$$max \sum_{d \in D} \sum_{s \in S(d)} \sum_{c \in C(s,d)} \pi_c \cdot x_{dsc} \qquad (4)$$

The overall Binary Linear Programming problem is then obtained by joining (1-4) and the decision variables variable $x_{dsc} \in \{0,1\}$, which we use in the next section to solve the problem of renting parking clusters in the Italian city of Rome.

3.1. Application to the City of Rome

We employed the optimization model introduced in the previous section to solve the cluster renting problem for a set of realistic data related to the Italian city of Rome. These data were defined on the basis of the regulations of the city (City of Rome - DGC136, 2016) and of our experience in the collaboration with professionals of the electric utility company Enel within E-Go Car Sharing, an electrical vehicle carsharing service established at the University Roma Tre - see Carrese et al. (2017). The defined set of data refers to the metropolitan area of Rome and considers those districts where parking requires to pay a fee (hosting so-called “blue-lines”). Specifically, we consider 5 districts including 27 sub-districts in total. For each sub-district, depending on its size, road features and importance in the Roman urban mobility system, 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 identifies 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 considering 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 model (1–4). 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 Figure 1. The optimal solution specifies the clusters that must be rented in each sub-districts to maximize the total profit while respecting renting constraints.

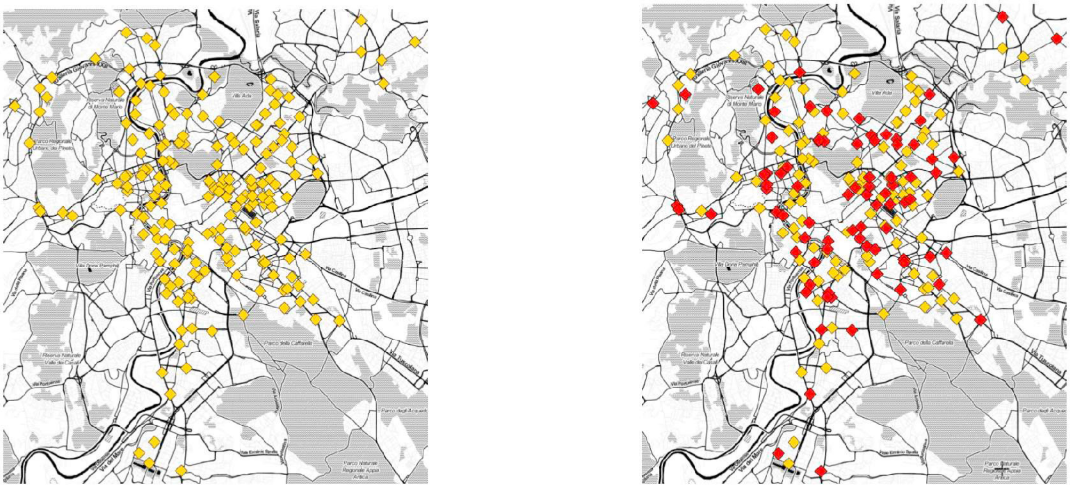

Fig. 1. Parking clusters for the city of Rome, Italy - left: candidate clusters (in yellow); right: optimally selected clusters (in red)

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 (1–3) that limit the number of slots, the number of clusters and the number of types of clusters are needed. 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 η_s^{min} in less profitable sub-districts. In contrast, more attractive districts and sub-districts, which offer clusters with a higher number of slots, present a number of activated clusters that tend to be closer to the allowed maximum η_s^{max}. 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.

4. Conclusions and future work

We have proposed 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. To show its potentialities, we applied it to data from the city of Rome. As future work, we intend to define a multiperiod version of the model, similarly to that proposed by D'Andreagiovanni et al. (2015), to consider parking slot renting over long-term periods and include variations of demand for carsharing over time according to the Multiband Robust Optimization paradigm proposed by Büsing and D'Andreagiovanni (2012), also extending the computational tests to other major cities.

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