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Management of On-demand Transport Services in Urban Contexts. Barcelona Case Study

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Abstract

Urban mobility transport mostly focuses on collective transport based on largely exploited models such as metro, trains or buses. The basis of current public transport is a fix network of both infrastructure and services, presenting a high lack of flexibility, especially regarding geographical issues. Traditional and innovative on-demand transport services, such as taxi and carsharing respectively, can provide the level of flexibility to the public transport needed to provide both a better service while reducing the exploitation costs. In this context, the study aims to improve the efficiency of on-demand transport systems, mainly taxi and carsharing through the development of analytical models and their application to the city of Barcelona. The optimization of the fleet management and the allocation of resources aim to ensure both the level of service of public transport users and the agency's profitability. The decision variables are the fleet size (number of vehicles) as well as the number and capacity of the depots or stands. Two models are presented, one for the provision of taxi stand service and one for the provision of one way carsharing service. Both models are applied to the demand for taxi services of the city of Barcelona, presenting for each model the optimum number of vehicles and depots, the depots' capacity, the system unitary costs and the level of service. Although the results show that the performance of both systems is very similar, the taxi service is up to three times more expensive due to the extra cost from the need for having a driver.

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1. Introduction

Urban mobility transport is usually focused on collective public transport such as metro, train or bus. This is a large exploited model where users have to adapt to the public network offered. Collective public transport has many advantages but flexibility is not one of those. To respond at this drawback, we must talk about on-demand transport services which pursue improving flexibility by adapting the offer to the demand. User's flexibility lead to a complex effectiveness from operator's point of view that have to be smartly managed.

On-demand transport services are a different way to solve mobility issues. Taxis are probably one of the best examples of on-demand transport services, but nowadays sharing systems are arising and increasing its presence in urban scenarios. Sharing systems constitute a collaborative mobility system in which users don't have the ownership of the vehicle, yet they share the use of a vehicle from a fleet. This mobility system can be formed by cars, motorbikes or bikes powered either by electricity or conventional energy systems, thus presenting a wide range of options for users to cover their needs and a large variety of niches for transport operators and companies.

Nevertheless, these on-demand systems present a series of concerns and challenges that policy makers, operators and companies have to deal with to optimize the service and its productivity. On the one hand, the efficiency of the taxi service is crucial to ensure its profitability and reduce its externalities. As an example, real data used in this study shows that 47.4% of the daily mileage of the taxi in Barcelona is made in vacant, and that during the 62.1% of the service time (i.e., 37 min per hour) the taxi has no customer (CENIT 2004). On the other hand, sharing systems are usually less known by citizens, furthermore they present important challenges for operators like the sizing and the managing of the fleet and its costs, the use of public space and the energy consumption.

In this context, the aim of this paper is to propose some models that should be used as smart tools for agencies and police makers to figure out a first approach for a taxi or a carsharing fleet to ensure an optimal and smart performance of its resources. In order to better manage scarcity resources such as public space, vehicles and energy, we proposed two analytical models one performed by taxis and another, by a sharing systems to optimize the fleet offered. The results should be addressed to set optimal guidelines and regulations for taxi and sharing services. Thus the main aspect of this paper is to evaluate in a real case study the difference between performing a taxi service or a carsharing system when demands are homogeneous and affordable for both modes. It is point out how depending on the demand one of the two proposes can perform better than the other one.

The paper is structured as follows. After the introduction a brief state of the art on on-demand transport services is presented, followed by the description of the taxi and carsharing models. The paper concludes with the applications of the two models to the city of Barcelona and the conclusions section.

2. State of the art on transport on-demand models

On-demand transport is characterized by its flexibility in both the spatial route and temporal scheduling dimensions. The traditional and most popular form of on-demand transport is the taxi, with a history of more than 100 years and presenting numerous variants (khattee, jitney, shuttle service...), while new and innovative on-demand transport schemes, such as car-pooling, car-sharing, even Uber, are arising significantly in the last years, especially due to the technological advances. Various on-demand transport modes have been modeled accordingly aiming at optimizing their performance or selecting the most appropriate for each city. The taxi and carsharing models are briefly reviewed below.

2.1. Taxi modeling

Many taxi models have been developed focusing on the profitability of the sector and the Level of Service offered to their customers, the effects of regulation/deregulation on the mentioned metrics as well as the nature and relation of the taxi market most significant variables (demand, waiting time, driver earnings). The main families of models are three: econometric models using aggregated values and continuous variables; equilibrium models taking into account the spatial distribution of both the demand and the offer; simulation-based models based on discrete-events and multi-agent systems. The most important contributions to the modelling of taxi services are the ones of Douglas (1972) and Yang and Wong (1998), developing aggregated and equilibrium models respectively, while the

contributions of de Vany (1975), Beesley (1973), Beesley and Glaster (1983), Schroeter (1983), Manski and Wright (1976), Arnott (1996) and Cairns and Liston-Heyes (1996) as well as the work of professors Wong and Yang are also significant. Due to its simplicity, the aggregated models do not fully consider the geographical dimension of the taxi market, which is the main characteristic of the equilibrium models in exchange for higher complexity. The significance of the simulation models is lower due to their high complexity, data and processing requirements, but these kinds of models are in a better position for handling such a complex multi-agent system. The most relevant simulation taxi model is the one presented by Lioris et al. (2010). The econometric approach has been selected for this paper due to its simplicity and its comparability with the car-sharing model. A detailed review of the aggregated and equilibrium models of taxi services can be found in Salanova et al. (2011).

The main advantage of the aggregated models is the low data and processing requirements, since they are based on average values and apply econometric models for estimating the principal indicators of the taxi sector, while their main drawback is the incapability of taking into account the spatial distribution of both the taxi demand and offer. These models are mostly used for planning purposes and decision making rather than for operational issues. The equilibrium models are able to take into account the spatial distribution of the taxi sector components, but they require more data and processing capabilities. Finally, the simulation models are the ones with the most data and processing requirements, but at the same time are the ones able to generate the most detailed data sets and to model such a complex multi-agent system. Both models can be used for defining planning and operational issues.

2.2. Car sharing modeling

Carsharing is defined as a mobility service that can improve sustainability through a more flexible transport system (Shaheen & Cohen, 2013) at a lower cost (Duncan 2011) in comparison to the major transport service at cities. The key aspects that should be taken into account when developing a carsharing model are the fleet size and the position of the depots, which location is directly related to the provision of an optimal sharing service. Two main family models have been developed: analytical models based on continuous approaches and geometrical probabilities and simulation models. In this context, “geometrical probabilities” refers to the use of analytical formulation based on probability for the estimation of some variables, which are considered to be heterogeneous in the geographic extension, so the probabilistic formulation apply. They are supposed to be homogeneous using probabilities in order to simplify the model definition.

Analytical models are inspired on the optimization of transport logistic problems. Following this pattern Daganzo (2010) provides an analytical optimization model for a hybrid network of buses. Nourbakhsh et Ouyang (2012) develops a similar methodology but the author use a more flexible network. Both models result in a simple way to obtain the key values to perform a transport service. The details and complexity of the analytical methodologies can give a nice overview of the service required depending on the inputs used. Correia and Antunes (2012) and Boyaci et al (2015) are also worth mentioning carsharing models. Barrios et Doig (2014) and Li (2011) developed simulation models aiming at modeling such complex operative service.

3. Problem formulation

The econometric models presented in this paper are based on the system unitary cost for the provision of the transport on-demand services, taking into account the users and the agency costs. All cost functions are estimated using continuous approximations and geometric probabilities while the optimization is done both analytically and numerically. The decision variables are two: a) the number of stands or depots, and b) the fleet size. The time interval of the model is a whole day, as it will give a better estimation of the system costs instead of just taking the peak hour. Figures 1 and 2 show the different legs of the trip for a car-sharing and taxi service respectively, while figure 3 shows an indicative representation of the grid approaches in both models.

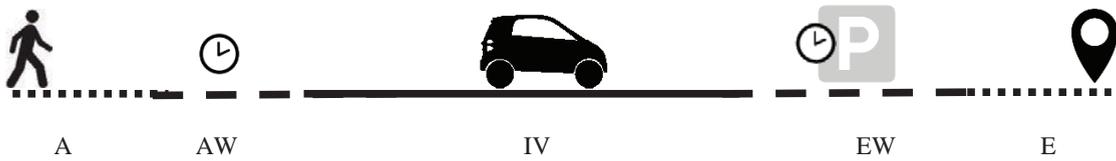


Fig. 1. Trip description for a car-sharing service.

In the car-sharing service there are five legs of user costs for any trip: access time (A), access waiting time (AW), in-vehicle travel time (IV), egress waiting time (EW) and finally, egress time (E). A part from that, there are some agency cost that have to be taken into account to find optimal results for total costs of the carsharing system.

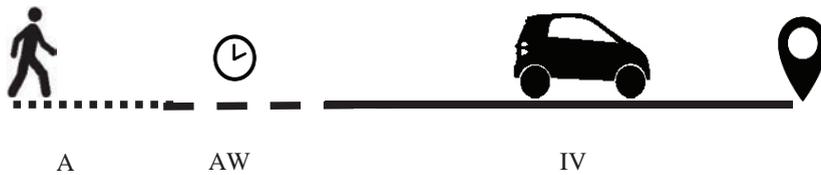


Fig. 2. Trip description for a taxi service.

In the taxi service there are three legs of user costs for any trip: access time (A), access waiting time (AW) and in-vehicle travel time (IV).

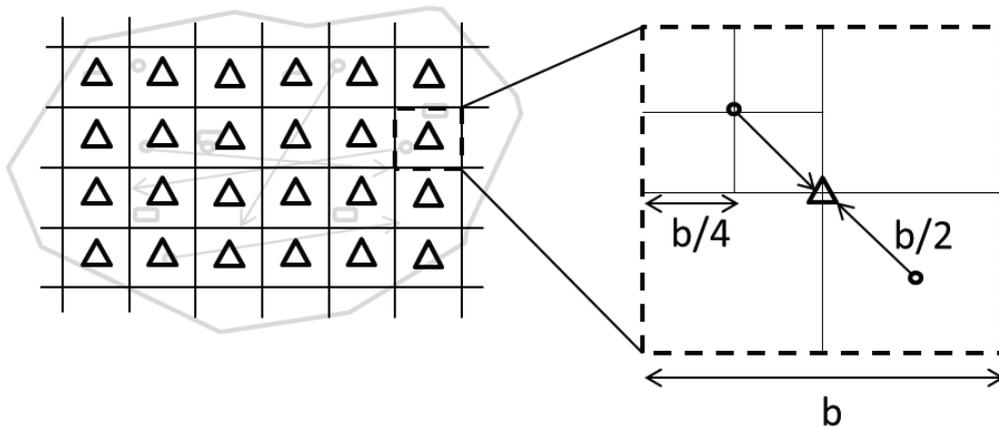


Fig. 3. Grid representation of the study zone.

3.1. Variables

Both models are expressed thanks to a common set of variables. Table 1 presents the summary of variables used, their definitions, units and values used.

Table 1. Variables used for models of carsharing and taxi stand.

		Definition	Units	Values
Model outputs	Z, Z_d, Z_u	System costs, agency costs and customer costs	€/day	-
	T_A, T_E	These are the access and egress time per user	min/day	-
	T_{AW}, T_{EW}	These are the access and egress waiting times per user	min/day	-
	N	Number of stands/depots service	stands/km ²	-
Decision variables	M	Supplied fleet	veh/(h·km ²)	?
	C	Capacity of each stand/depot	slots/stand	?
Model inputs (variables)	A	Area of the region	km ²	100
	T	Operative service timer per day	h/day	24
	λ_u	Hourly demand	trips/(h·km ²)	50 - 250
	T_{IV}	In-vehicle time per trip	min/trip	12 - 14
	\bar{d}	Average distance of the trip	km	5 - 6
	\bar{n}	Average number of taxi trips per hour and driver	trips/(driver·h)	1 - 3
	\bar{c}	Monetary cost of the trip	€	7 - 10
	\bar{v}	Average speed of the trip	km/h	30
	\bar{v}_w	Average pedestrian speed	km/h	4
	VoT	Value of time	€/h	20
	α_A, α_E	Customer perception factor of the access and egress times	-	2.2
	α_W	Customer perception factor of the waiting time	-	2.1
	α_{IV}	Customer perception factor of the in-vehicle time	-	1
	ε	extra distance factor expressed as the ratio between \bar{d} and the $\bar{d} +$ distance to the nearest taxi stand	-	1.1
	C_{deps}, C_{stand}	Daily cost of each stand or depot	€/(stand·day)	3
	C_{slot}	Daily cost of each slot	€/(slot·day)	20
C_{km}	Operational cost per unit of distance	€/km	0.35	
C_h	Operation cost per unit of time	€/day	0.33	
C_{veh}	Daily acquisition cost of each vehicle	€/(veh·day)	54	

Four weighting parameters ($\alpha_A = \alpha_E, \alpha_w$ and α_{IV}) are used in order to take into account the differences in the customers' perception of time in each step of their trip while using a unique Value of Time (Kittelson et al. 2003).

3.2. Objective function

The objective function (Equation (1)) represents the system cost, composed by the costs of the involved actors and the cost of the infrastructure. The objective function is composed by the users cost (Z_u) accounting for the in-vehicle travel time (T_{IV}), waiting times ($T_{AW}+T_{EW}$), access and egress times (T_A+T_E) and the monetary trip cost (\bar{c}); the agency cost (Z_d) is the cost of offering the transport on-demand services. The decision variables are the fleet size and the capacity of the stands/depots. Both user and agency costs are slightly different depending on the service offered (taxi or car-sharing), but the formulation below apply to both models simply by eliminating some components. The proposed objective function is the following:

$$\min_{M, C \in \mathbb{N}} \{Z = Z_d + Z_u\} \quad (1)$$

$$Z_u = VOT \cdot \lambda_u \cdot A \cdot T \cdot \left[\alpha_A \cdot T_A + \alpha_W \cdot T_{AW} + \alpha_{IV} \cdot T_{IV} + \alpha_W \cdot T_{EW} + \alpha_E \cdot T_E + \frac{\bar{c}}{VOT} \right] \quad (2)$$

$$Z_d = \lambda_d \cdot A \cdot T \cdot \bar{d} \cdot C_{km} + C_h + C_{dep} \cdot N + C_{slot} \cdot C \cdot N + C_{veh} \cdot M - \bar{c} \cdot A \cdot T \cdot \lambda_u \quad (3)$$

There are no mathematical constraints, but thresholds for various variables (access and waiting time of customers and benefit of service provider) can be defined aiming at reflecting physical or temporal restrictions of the policy decisions as well as minimum levels of service. In addition, all the demand should be served, which means there won't be any non-served demand.

3.3. Common assumptions

Taxi and carsharing are services that can be estimated based on different scenarios and conditions. In order to compare the models, two main assumption are imposed for both on-demand services.

- Common assumption 1: the demand is distributed homogeneously within the area of study, so the trip distance can be estimated as proportional to the area as presented in Equation 4.
- Common assumption 2: the access distance can be approximated by $a/2$ (using a L1 metric), where a is the length of the squares generated by an orthogonal stand/depot network, so the access time is presented in Equation 5.

$$T_{IV} = \frac{rA^{1/2}}{2\bar{v}} \quad (4)$$

$$T_a = \frac{a}{2\bar{v}_u} \quad (5)$$

4. Taxi model

4.1. Definition

The taxi model is based on an econometric model of the systems unitary cost accounting for the agency (drivers) and users' costs. All variables are estimated using continuous approximations and geometric probabilities while the optimization is done analytically. The mathematical formulations are derived in order to obtain the analytical expressions of the optimal solutions, which allows for having a good understanding on the contribution of each variable to the solution. Salanova et al (2014) review various formulations developed for the estimation of the variable of the taxi market, some of them used in the model. The model formulation is developed for the three operation modes (hailing, dispatching and stand) and is presented in detail in Salanova and Estrada (2015). The stand model is the one used for the purpose of this paper.

4.2. Additional assumptions

Additional assumption for the taxi model 1: The trip cost calculation is simplified by taking into account only the distance (in real world is estimated using both the distance and the time depending on the speed at each time). The term \bar{c} does not affect the system cost since it appears in both the customers' and the drivers' cost with opposite signs, but it is an important factor when the profitability of each particular stakeholder is analyzed, especially the profitability of the transport on-demand provider (taxi drivers).

Additional assumption for the taxi model 2: The number of stands (s) can be approximated by A/a^2 , where A is the area of the region and a is the distance between stands (each stand serves an area of a^2). Assuming that the number of stands is proportional to the number of free taxis in the way that there is always almost one taxi waiting at

every taxi stand (meaning the waiting time of taxi customers is zero), the number of vacant vehicle hours for finding the value of a can be used and the access time can be formulated as indicated in Equation 7:

$$s = \frac{A}{a^2} = \frac{A\lambda_d - A\lambda_u \frac{rA^{1/2} \varepsilon}{2\bar{v}}}{C} \quad (6)$$

$$T_a = \frac{\sqrt{C}}{2\bar{v}_u \sqrt{\lambda_d - \lambda_u \frac{rA^{1/2} \varepsilon}{2\bar{v}}}} \quad (7)$$

5. Carsharing model

5.1. Definition

For the sharing model, a similar methodology based on an analytical formulation is applied and adapted to the different operation scheme that it may present. As well as taxi systems, sharing services have three different ways to operate: round system, free-floating and one-way. In order to compare to a taxi stand service, it is suitable to base the model on a one-way system. In this case, there are cars spread around a service area. Users are able to reach a depot where vehicles are park. Then, they can take one up to the closest depot to their final destination. It might exist waiting times for both taking and parking vehicles depending on the current demand and supply of the system. A part from the user costs as defined in figure 1, there are some agency cost that have to be taken into account to find optimal results for total costs of the carsharing system. There are four different aspects regarding agency costs: depot, slot, vehicle and fuel costs. Roughly speaking there is a trade-off between user and agency cost. User costs decrease when there are more vehicles and more depots, whereas agency costs increase. When there is more supply, it means users will undergo lower access and waiting costs. That is why optimal decision variables (M and C) will result in a balanced cost system.

The analytical formulation of the access waiting time and the egress waiting time are presented in equations 8 and 9. It could be surprising why expected waiting time is inversely proportional to the demand per station, but it make sense if we interpret $\lambda_u \cdot a^2 \cdot T_{IV}$ as the rotating car uses per station.

$$T_{AW} = P_{veh} \cdot \frac{T_{IV}}{2 \cdot \lambda_u \cdot a^2 \cdot T_{IV}} = P_{veh} \cdot \frac{1}{2 \cdot \lambda_u \cdot a^2} \quad (8)$$

$$T_{EW} = P_{slot} \cdot \frac{T_{IV}}{2 \cdot \lambda_u \cdot a^2 \cdot T_{IV}} = P_{slot} \cdot \frac{1}{2 \cdot \lambda_u \cdot a^2} \quad (9)$$

Where P_{veh} and P_{slot} are the probabilities of not finding a vehicle and not finding an available free slot, respectively.

5.2. Additional assumptions

Additional assumption for the carsharing model 1: Supposing homogeneous demand along the area leads to simplify our service. By doing so, it is not necessary to take into account fleet's reallocation. Therefore, there are no extra costs to rebalance the fleet. This is a main assumption due to the impossibility to compute analytically this imbalance. Apart from that, to compute waiting times, the model is based on probabilities about finding an available vehicle or a spot at a depot. Those probabilities come from depot's occupancy regarding capacity and demand. Capacity can be divided into 2 main capacities: one regarding the vehicles that are going round so they will need a spot at the end of the service (C_f) and the second part (C_u) is a threshold to ensure the probability of finding a car

whenever you need it. As it is supposed a constant demand anywhere for a time interval, there is a stationary depot's occupancy status after an initial period of time due to $T_{IV} \ll T$. This value represents the threshold capacity (C_u). Thus, there are assumed constant probabilities for both access and egress waiting times.

Additional assumption for the carsharing model 2: Another major assumption is applied to the calculation of the vehicles going round. C_t is defined as the maximum number of vehicles going round. By doing so, it is ensured there won't be a shortage of slots and consequently it won't be any egress waiting time at any case.

6. Barcelona case study

The two models are applied to the city of Barcelona. Above at Table 1, there are presented the values of the variables used for both models. By means of a few decision variables and making some demand hypothesis, the model states the appropriate design and management for taxi and sharing fleets to operators and companies in this urban context. Furthermore, to test the models we use real data provided by executed projects and existing mobility services for the taxi model. A sample of monitored taxis provided by the IMET (Metropolitan Taxi Institute) enables us to gather data to contrast productivity and profitability values such as the average hourly number of trips (1.75) and incomes (17,78 €/h) or the time between two consecutive services (24 min). While for a sharing system, there is not any previous experience on sharing services apart from the Bicing (bike-sharing system in Barcelona). As there is no standards regarding the cost of the provision of carsharing services, results use data presented at Rickenberg et al. (2013) for the city of Hannover due to its similarities with Barcelona regarding cost of life. The rest of the variables more related to the city geometry, traffic and demand are the same as taxi inputs. This study is oriented to analyze the feasibility and the impact of the introduction of a car-sharing service in Barcelona compare to a taxi model set up through stands.

6.1. Taxi model results

The stand model has been applied to the demand for taxi of the city of Barcelona. Figure 4 below presents the users' costs and the drivers benefit for different supply levels. There are no agency costs since the cost of the taxi stands is negligible.

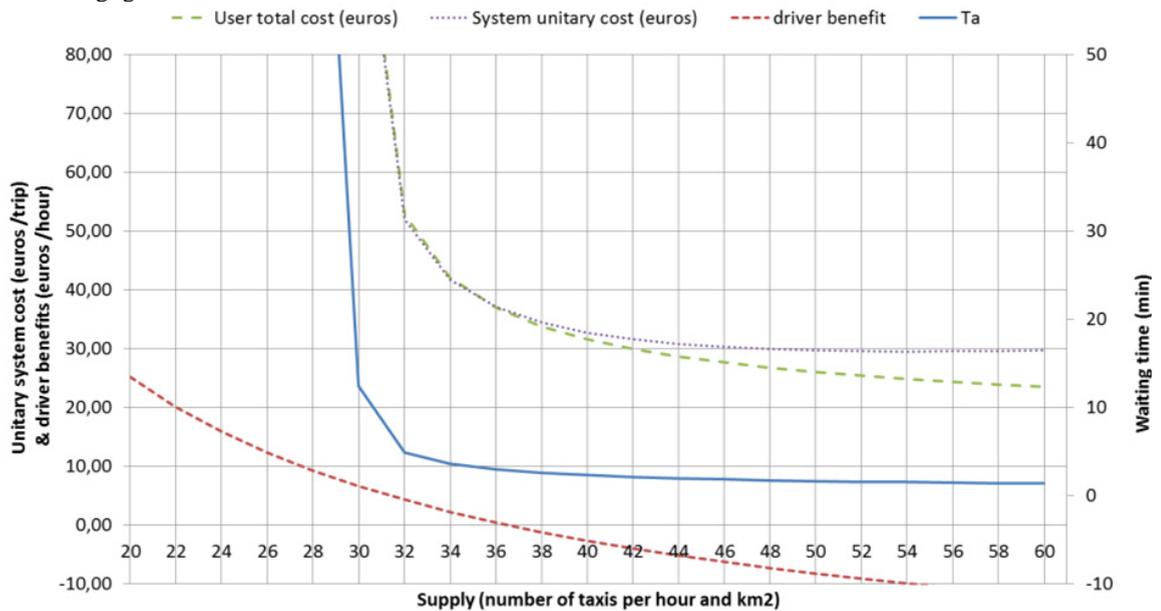


Fig. 4. Access time, driver benefits and unitary costs for each fleet size obtained by the aggregated model (stand operation mode).

The optimum capacity is equal to one, which was expected since having one taxi at each taxi stand the number of taxi stands is the maximum, thus reducing both the costs of the users and the agency. Regarding the optimum number of taxis, figure 3 shows the user total cost (the trip generalized cost in euros including access, waiting, travel time and trip monetary cost), the system unitary cost (the total cost of the system per user), the driver benefit (the difference between the trip costs with regards to fixed and variable costs and the trip monetary cost), the access time.

It can be observed that the number of taxis per hour and km² should be higher than 30 since the access time for smaller fleets is very high due to the low number of free taxis (and therefore the low number of taxi stands). The real minimum fleet size is 28 taxis/hour*km², which means that with this taxi fleet size, the number of demanded customer hours are equal to the offered vehicle hours. The optimum number of taxis taking into account the system costs is 52–54 taxis/hour*km². It can be also observed that the maximum number of taxis where the operator will have benefits is 37 taxis/hour*km² since more taxis than this value will generate losses to the drivers. These losses can be subsidized by the state in order to provide a better level of service to the taxi customers by an amount of 9.5 euros per trip.

Table 2. Results of the application of the aggregated stand taxi model in the city of Barcelona.

Minimum number of taxis	28 taxis/hour*km ²
Social optimum solution	52 – 54 taxis/hour·km ²
Subsidy	9.5 euros per trip
Maximum number of taxis without creating losses for the operator	37 taxis/hour·km ²

6.2. Carsharing model results

Similar to taxis, carsharing model is applied to the city of Barcelona under the same basic conditions.

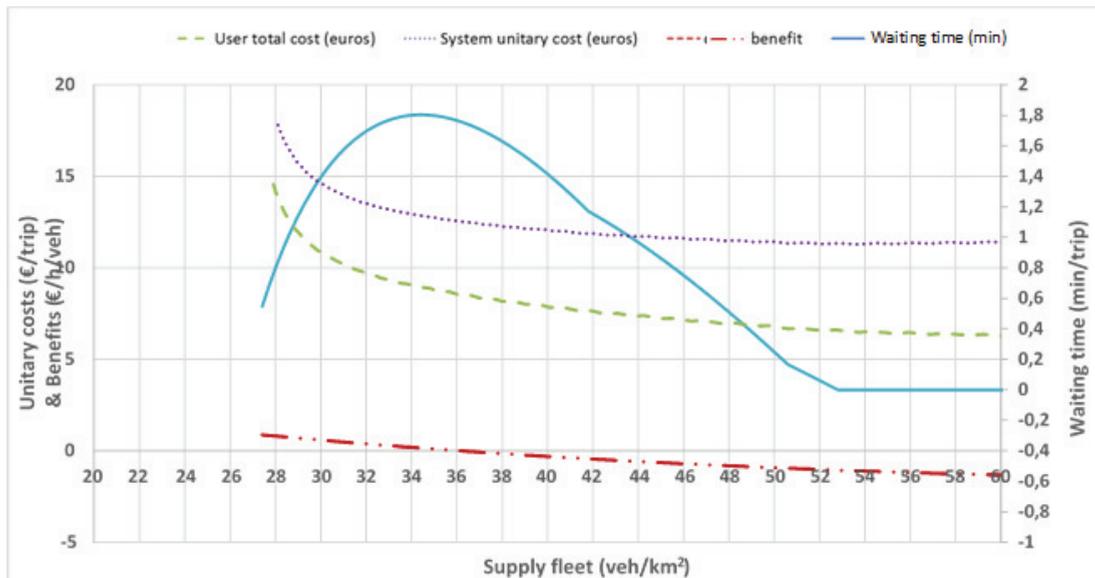


Fig. 5. Waiting time, agency benefits and unitary costs for each fleet size obtained by the carsharing model.

Figure 5 represents the cost of the system for different fleet sizes and the evolution of the waiting time. In general, costs and benefits seem to have the same trend as the ones from the taxi model. It can be observed that results start to be plotted at a minimum supply of 27 veh/km² because this is the fleet size required to provide

service at the peak hour. The optimal fleet size is set at 53 vehicles per km². At this point, total unitary costs are minimum; benefits for the agency are negative, though. This happens just because waiting costs start to become negative, therefore any user is just taken into account access and in-vehicle cost. From the agency point of view, the model needs to ensure benefits to encourage companies to run his own service. This should be the second best optimal fleet, the one willing to achieve some benefits for the agency while trying to minimize system costs. In this context it is required a supply of 35 vehicles per km². Here is where benefits are positive just at the same point, as access-waiting cost are the highest.

Table 3. Results of the application of the carsharing model in the city of Barcelona.

Minimum number of taxis	27 taxis/hour*km ²
Social optimum solution	53 taxis/hour·km ²
Subsidy	1,5 euros per trip
Maximum number of taxis without creating losses for the operator	35 taxis/hour·km ²

Looking at the waiting time it seems unexpected the shape it forms. The expected waiting time is defined at Equation 10. The evolution of this variable can be explained through the fleet size. It is easy to see that when the fleet increases the shortage vehicle probability decreases. Furthermore, the distance between depots decreases when the fleet size increases. The key point here to understand this evolution is to observe the cover area of each depot and the routing vehicles that are about to arrive at it. When areas are huge the in-out flow is very big so there are many arrivals and departures, even that the probability of finding a vehicle is low. Depot cover areas decrease according to the fleet size so there are fewer movements but more chances to get an available car. There is a point where these two effects are balanced so waiting times are the highest and from that point on, they start to decrease up to zero.

$$EWT(P_{veh}, s) = P_{veh} \cdot t_w(s) = P_{veh} \cdot \frac{T_{IV}}{2 \cdot \lambda_u \cdot T_{IV} \cdot s^2} = \beta \cdot P_{veh} \cdot \frac{1}{s^2} \quad (10)$$

7. Conclusions

Two models have been developed for supporting decision makers regarding the design and operation of taxi and car-sharing services. The models will allow practitioners comparing the performance of both schemes and selecting the most suitable or for supporting the implementation of one of them with regard to the number and location of the stops/charging stations. Although both models are aimed at minimizing total social cost (first best solution), they alternatively provide an economic feasible solution when the profitability of taxi drivers or sharing system is not guaranteed by the former one (second best). Both models have been applied to the city of Barcelona in order to illustrate their use and provide indicative values about the performance of on-demand transport modes.

The results have been analyzed from an econometric point of view, concluding that the first best option (the social optimum) is the same for both taxi and carsharing services, with a supply of 53 veh/km², but with a three times higher unitary cost for the taxi service. The second best option (benefits are positive for all actors), provides different fleet sizes for each service: taxis stands will require a maximum fleet of 37 veh/km², whereas a carsharing system could provide up to 35 veh/km². The minimum number of vehicles is also very similar in both models. Finally, the subsidy needed for providing the level of service of the first optimum while respecting the positive benefits of all actors is significantly larger for the taxi model since it should cover the driver salary, which does not exist in the carsharing model.

Regarding the cost structure, user cost has some different components: access and egress costs depend on the total number of depots as taxi does not have egress costs; access waiting cost for a carsharing depends on both the number of depots and the distance between them while for the taxi service there is no access waiting time; for the in-vehicle cost both models present same results; finally, taxi and carsharing systems does not present any egress waiting cost, and in the case of taxis, users does not expect any egress cost. This supports previous results, which

suggested that a service provided by taxis will be more expensive than a similar service provided by a carsharing fleet spread at depots. That is the result of having to pay a taxi driver and the acquisition of a taxi license. Both expenses increase significantly the unitary cost of a taxi stand service.

Finally, both models require a significant investment of money; different agents could finance taxis whereas a carsharing service should be funded by a unique agency. This can compromise the feasibility of starting up a sharing system and may be taken into account by decision makers and practitioners.

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References

- Arnott R., (1996) Taxi Travel Should Be Subsidized. *Journal of Urban Economics* 40, 316 – 333.
- Barrios, J.A., Doig, J.C., 2014. Fleet sizing for flexible carsharing systems: a simulation-based approach. In: Proc. Transportation Research Board 93rd Annual Meeting.
- Beesley M. E. and Glaister S. (1983) Information for regulating: the case of taxis. *Royal economic society. The economic journal* 93 (371), 594 – 615.
- Beesley M. E. (1973) Regulation of taxis. *Royal economic society. The economic journal* 83 (329), 150 - 172.
- Boyaci, B., Konstantinos, G. Zografos, Geroliminis, N., 2015. An optimization framework for the development of efficient one-way car-sharing systems. *European Journal of operation Research*. p718-733.
- Cairns R. D., Liston-Heyes C. (1996) Competition and regulation in the taxi industry. *Journal of Public Economics* 59, 1 – 15.
- CENIT. Metodologia per a l'establiment de les tarifes del taxi a l'AMB i la seva revisió, 2004. Informe final per a l'Institut Metropolità del Taxi.
- Correia, G. H. A., Antunes, A. P., 2012. Optimization approach to depot location and trip selection in one-way carsharing systems. *Transportation Research Part E: Logistics and Transportation Review*, 48(1), 233–247.
- Daganzo, C.F., 2010. Structure of competitive transit networks. *Transportation Research 9 Part B*, 44(4), pp. 434–446.
- De Vany A. (1975) Capacity Utilization under Alternative Regulatory Restraints: An Analysis of Taxi Markets. *Chicago Journals. The journal of Political Economy* 83 (1), 83 – 94.
- Douglas, G., 1972. Price Regulation and optimal service standards. *The taxicab Industry*.
- Duncan, M., 2011. The cost saving potential of carsharing in a US context. *Transportation*, 38(2), 363–382.
- Kittelson, and Associates, 2003. Transit Capacity and Quality of Service Manual. Transit cooperative research program report 100, 2nd edition.
- Li, L., 2011. Design and Analysis of a Carsharing System Offering One-way Journeys. Master Thesis. University of Wisconsin-Milwaukee.
- Lioris, J. E., Cohen, G., La Fortelle, A., 2010. “Evaluation of Collective Taxi Systems by Discrete-Event Simulation”, *Proceedings of the ITE Western District, San Francisco*.
- Manski C. F. and Wright J. D. (1976) Nature of equilibrium in the market for taxi services. *Transportation Research Record: Journal of the Transportation Research Board* 619, 296 – 306.
- Nourbakhsh, S.M., Ouyang, Y., 2012. A structured flexible transit system for low demand areas. *Transp. Res. Part B* 46, 204–216.
- Rickenberg, T. A. A.; Gebhardt, A., Breitner, M. H., 2013. A Decision Support System For The Optimization Of Carsharing Stations. *ECIS 2013 Completed Research. Paper 207*.
- Salanova, J. M., Estrada M., Aifadopoulou, G. and Mitsakis, E., 2011. A review of the modeling of taxi services. *Procedia and Social Behavioral Sciences* 20: 150-161.
- Salanova, J. M., Estrada, M., Amat, C., 2014. Aggregated modeling of urban taxi services. *Procedia - Social and Behavioral Sciences (ISSN: 18770428)*, 20: 352-361.
- Salanova, J. M., Estrada, M., 2015. Comparison of taxi operational modes. Under review at the *Transport Research Part B*.
- Schroeter J. R. (1983) A model of taxi service under fare structure and fleet size regulation. *The Bell Journal of Economics* 14 (1), 81 – 96.
- Shaheen, S. A., Cohen, A. P., 2013. Carsharing and personal vehicle services: Worldwide market developments and emerging trends. *International Journal of Sustainable Transportation*, 7(1), 5–34.
- Wong K. I., Wong S. C. and Yang H. (2001) Modeling urban taxi services in congested road networks with elastic demand. *Transportation Research Part B* 35, 819 – 842.
- Wong S. C. and Yang H. (1998) Network Model of Urban Taxi Services. Improved Algorithm. *Transportation Research Record: Journal of the Transportation Research Board* 1623, 27 – 30.
- Yang, H., Wong, S. C., 1998. A network model of urban taxi services. *Transport Research B*, 32(4): 235 – 246.
- Yang H., Yan Wing Lau, Wong S.C. and Hong K.L. (2000) A macroscopic taxi model for passenger demand, taxi utilization and level of services. *Transportation* 27, 317-340.
- Yang H., Wong S. C. and Wong K. I. (2002) Demand-supply equilibrium of taxi services in a network under competition and regulation. *Transportation Research Part B* 36, 799 – 819.
- Yang H., Cowina W. Y. L., Wong S. C. And Michael G. H. Bell (2010a) Equilibria of bilateral taxi-customer searching and meeting on networks. *Transportation Research Part B* 44, 1067 – 1083.