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## Spatial issues revisited: A note on the role of shared transportation modes

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# Spatial issues revisited: A note on the role of shared transportation modes

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May 10, 2016

## Abstract

This paper investigates the mechanisms through which shared modes help reduce major spatial issues related to mobility in urban areas, namely road congestion and rivalry of use for parking spaces. In this article, I use gross space consumption estimations for different transportation modes as a basis and integrate the service provided by the modes. Results indicate that in terms of time-space consumption and service provided shared modes are intermediate modes between private modes and mass transit. Therefore, shared modes constitute key components of a comprehensive and efficient transportation system in urban areas. The present analysis provides guidance for local transportation authorities.

**Keywords:** mobility, shared modes, spatial issues, time-space consumption

**JEL:** R11, Q01, Q40

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# 1 Introduction

“Transport is characterized by certain specific features. The first of these specific characteristics is the role of space.”(Mc Fadden, 2011). Spatial issues related to mobility refer to the space consumed by transportation modes. According to estimations provided by mapping softwares such as BDCarto and Corine Land Cover, space allocated to mobility amounts to 5 to 25% of French city centers (CERTU, 2007) and represents 1.2% of the territory, among which 92% is allocated to private road transportation (CERTU, 1998).

In France, as in most developed and developing countries, space allocated to mobility is rapidly increasing over time. This evolution is closely associated with the development of settlement areas, which are urbanized spaces. Figure shows the share of artificial space for each NUTS 3 area<sup>1</sup> in France in 2006 and the upward trend towards urbanization. Several factors have been contributing to land artificialization. First, population increase has forced existing settlement areas to be extended. Second, the per capita housing floor area has been extended (from 31 m<sup>2</sup> in 1984 to 40 m<sup>2</sup> in 2006 in France) (INSEE, 2006). Third, and probably most importantly as regards the research question of this article, the growth in space results from the development of road facilities and car use. The latter requires more per capita space than alternative transportation modes. As such, it facilitates the change from compact development to urban sprawl. In addition, factors contributing to the increase in car use (income growth, car ownership, demographics effects) also contribute to urban sprawl (Bonnell and Pochet, 2002). Mangin (2004) reveals that in the last 40 years in France, settlement space has been multiplied by a factor 4 to 5, while density has been halved.

Conversely, the urban structure (functional mix, density, transportation system) influences the total settlement space consumption, and thus the space consumed by traffic facilities. Large floor area and low densities generate additional land artificialization, but also more car-dependent commuting patterns, which in turn requires large space consumptions. In Figure, Apel (2000) draws a correlation between transportation modes and the per person space consumed for mobility. Compared with cities where people

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<sup>1</sup>NUTS stands for Nomenclature of Territorial Units for Statistics.

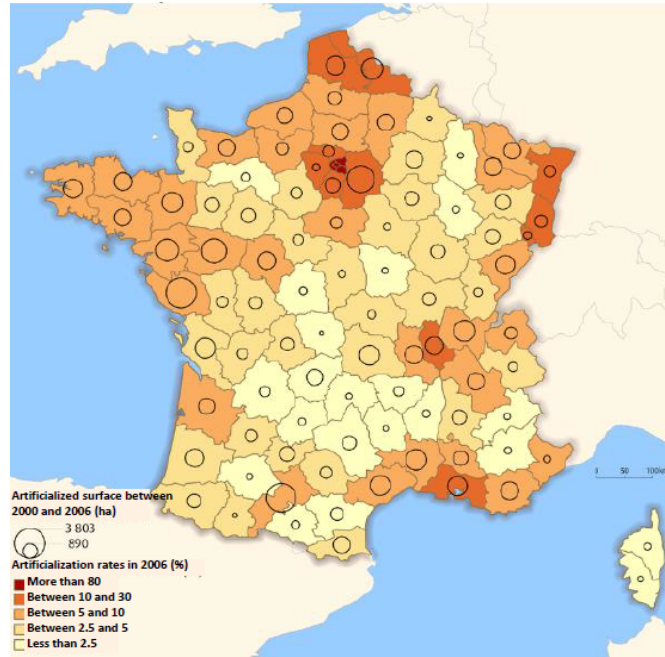


Figure 1: Land artificialization in France, an upward trend  
*Source: UE-SOeS, CORINE Land Cover, 2006*

mainly use bicycles or public transportation, car-dependent cities allocate a larger share of urbanized space to mobility, and the per person space consumed is more than six times larger.

The creation of artificial land has a cost for society. First, the joint increase in both car use and artificial surfaces rises environmental externalities, in particular air pollution due to car use, and loss of biodiversity, ecosystem fragmentation and lower resilience due to irreversibility of land use changes. Second, the opportunity cost of the space dedicated to mobility is particularly relevant when a change in land use occurs (Anas et al., 1997). The opportunity cost corresponds to the value of the forgone best alternative, i.e., the value of a unit of surface allocated to another use. According to the authors, taking into account the opportunity cost of space dedicated to mobility would increase by half the cost of infrastructures. Overlooking these costs results in an excess supply of space-consuming transportation infrastructures at the expense of space-saving ones or of management strategies of existing infrastructures (Woudsma et al., 2006). This is especially true in urban areas since the opportunity cost of space is high and the land value is affected by the accessibility of its localization (Lee, 1992; Vickrey, 1997).

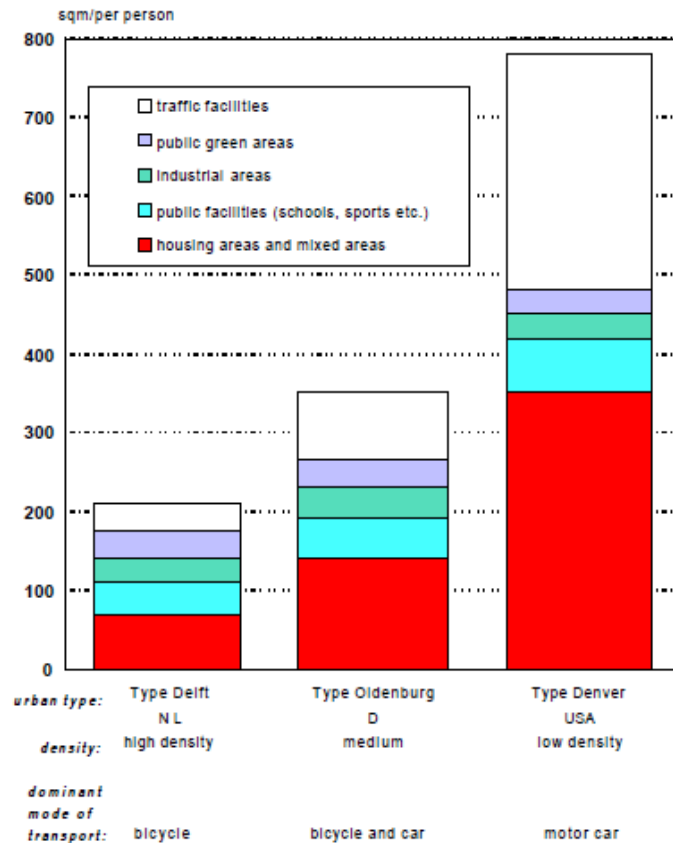


Figure 2: Relation between settlement space and transportation modes  
*Source: Apel, 2000.*

Spatial issues related to mobility are exacerbated in urban areas. Road congestion and rivalry of use for parking spaces are major issues regularly at the heart of local transportation policies. They have been dealt with through various approaches. Alternative modes, such as mass transit, bicycles and walking, have been fostered as a solution against road congestion and rivalry of use. However, private cars remain the leading transportation mode in most developed countries<sup>2</sup>. For instance, in France, 65% of trips and 83% of total distances are made by car. Walking trips account for 22% of all trips, and public transportation for 8% - these two modes are on a decreasing trend.

This article explores one possible reason for the relatively limited success of modal shift policies, namely the fact that transportation modes are assumed to offer similar services,

<sup>2</sup>There exist some exceptions: in Paris and its suburbs, France, private cars and mass transit are each used for around 44% of trips (XXX source!!XXX).

origin-to-destination trips. More precisely, I propose to overcome this limit investigating the services provided to the user by transportation modes. Spatial issues are then analyzed in the light of the space consumed by modes per unit of service provided. I question the modes to be fostered when spatial issues are taken into account, and when the size of the city (or its structure, in particular through population density) is considered. Shared modes, namely vehicle-sharing and self-service vehicles, are considered and their role in a complex transportation system is highlighted. The contribution of this paper is twofold. First, I explore the mechanisms through which shared modes help reduce road congestion and rivalry of use for parking spaces, compared to private modes. Second, I highlight the fact that services provided to users vary depending on the transportation mode. Therefore, gross comparisons in terms of time-space consumptions between modes (Marchand, 1993) are oversimplifying. I suggest to put these gross estimations into perspective accounting for additional services provided by transportation modes. Refined measures of time-space consumptions are presented. When the service provided is accounted for, the gap between mass transit and private cars is reduced. More importantly, the results show that car-sharing and self-service cars constitute relevant alternatives to private cars in terms of time-space consumption per unit of service provided.

The analysis provides guidelines for decision-makers since it clearly indicates orders of magnitude for time-space consumptions from various transportation modes. The occupancy rate of vehicles, and thus tacitly population density, is also considered in the analysis. It allows suggesting different policies for high-density and lower-density areas. The study reveals that shared modes help reduce spatial issues related to mobility in urban areas and as such constitute key components of a comprehensive and efficient transportation system. Furthermore, I mention the limits of the present organization for shared modes. More precisely, the need for institutionalizing is highlighted for car-sharing, and network expansion required for self-service vehicles. Finally, spatial issues are discussed jointly with environmental issues, namely air pollution, since they have common origins and similar remedies. Therefore, considering the space allocated to different transportation modes will reinforce local policies supporting low-carbon modes.

The article is organized as follows. Section 2 provides a brief theoretical background on

road congestion and parking issues, and investigates the role of shared modes as regards the aforementioned issues. Then, in Section 3, the concept of time-space consumption from transportation modes is explored and gross estimations of time-space consumption are refined accounting for the service provided. Section 4 provides guidance for transportation policy-makers. Section 5 concludes.

## 2 Theoretical background

The present section first provides a brief review of the spatial issues and of the measures generally implemented to address them. Then, the role of shared modes as regards these spatial issues is analyzed.

### 2.1 Spatial issues related to mobility

Road congestion occurs when demand for mobility (e.g., the number of vehicles in traffic) is higher than supply (e.g., road capacity). In city centers, congestion is often recurring, especially during peak hours, due to the increasing number of vehicles on roads. The congestion caused by an additional trip generates various external costs, “including opportunities forgone due to travel delay, the discomfort of crowding, and the impact of travel-time uncertainty on the reliability of arrival times” (Delucchi and McCubbin, 2011). Road congestion represents the largest external cost from transportation (De Palma et al., 2011): it is estimated to range from 1 to 2% of Gross Domestic Product (GDP) in Europe (European Commission, 1995, 2007). In order to address this major issue, local authorities can influence users’ modal choice through the generalized cost of travel, notably with pull and push measures. Pull measures are those “improving the attractiveness of a mode by reducing its generalized cost”, while push measures are those “making competitive modes more expensive” (Rietveld and Daniel, 2004). The former generally refer to measures encouraging alternative modes, such as public transportation, cycling and walking, while the latter aim at refraining the use of private cars. First measures addressing road congestion have aimed to expand road space, such as widening existing roads or building new road infrastructures. However, increased traffic flow leads to induced demand that generates road congestion. Then, local authorities have fostered

modal shift to mass transit, bicycles or walking, in particular through increased supply of alternative modes (bicycle lanes, pedestrian zones, frequency of public transportation services), or with lower fares, even sometimes free access (De Witte et al., 2006) to public transportation. Finally, measures combine various strategies from low-carbon transportation incentives to restricting demand for private cars (road pricing, parking restrictions), and include city planning and urban design. Bertolini et al. (2005) highlight the importance of integrating transportation and land use planning in supporting sustainable mobility.

Similarly, many distortions are associated with parking, among which are the underpricing of both auto travel and on-street parking, the subsidization of parking by employers and shop owners, and minimum parking requirements<sup>3</sup> (Arnott, 2011). The demand for parking is derived from the demand for private car travel, which is generally underpriced (Arnott, 2011). This distortion leads to an overuse of cars and parking spaces (Arnott, 2011), which worsens rivalry of use. In densely built-up urban areas, road users compete to park their cars. Conflicts are especially intense for on-street parking, considered as more convenient than off-street parking. Land devoted to mobility in general, and to public parking in particular, can be considered as common resources available to road users on free access (Anderson and De Palma, 2004). Parking spaces are non-excludable but rivalrous: any agent can park her car on public roads, but this prevents another agent to park her car at the same place. Anderson and De Palma (2004) show that equilibrium entails overuse of parking close to the city center, therefore leading to conflicts. In addition, rivalry of use for parking spaces increases road traffic, therefore contributing to road congestion. Spatial issues overlap and are mutually reinforcing.

The different transportation modes along with the users and the territory form a complex system. Crucial interactions occur between commuters. Every commuter impacts the accessibility of a territory through congestion effects and rivalry of use for parking spaces. Therefore, accessibility must be addressed taking into account each user and the

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<sup>3</sup>“Minimum parking requirements are local regulations, based on planning practice, that specify the minimum amount of parking that must be provided by a land user. They vary by land use, and may be based on the number of employees, number of apartments or hotel rooms, square footage, etc.” (Arnott, 2011).



transportation system as a whole. An efficient transportation system requires to consider collective needs, not only individual ones (Drut, 2015). On one hand, private vehicles may best respond to individual needs (comfort, flexibility, availability), but may overlook collective needs such as the global accessibility of a territory. Due to their relatively high space consumption and given the limited road space available and the competition for alternatives uses in urban areas, private vehicles may generate road congestion and rivalry of use for parking spaces. On the other hand, mass transit may best respond to collective needs related to accessibility, but may leave out of consideration individual needs. While mass transit helps reduce road congestion and rivalry of use for parking spaces, it usually provides much less services than private vehicles and may not meet all individual needs. As such, shared vehicles have a significant role to play within an efficient transportation system. They constitute an intermediate transportation mode, both in terms of reduction in spatial issues and services provided.

## 2.2 The role of shared modes

Goods in general and vehicles in particular require space, in a strictly physical sense. Space scarcity may be felt in densely built-up city centers. Shared use of goods is realistic and attractive when goods are barely used by a single agent and when they are bulky. In urban areas, private passenger vehicles are generally sub-optimally used for mobility<sup>4</sup> and could then be pooled. Two different systems of shared vehicles can be distinguished. First, vehicle-sharing systems, such as car-sharing, generally refer to a single vehicle shared simultaneously by several users. Second, self-service systems, such as self-service cars and bike-sharing schemes in urban areas, refer to a fleet of vehicles shared sequentially.

What is highly interesting with shared vehicles is the potential for reduced congestion and rivalry of use for parking spaces. Shared use allows reducing the total number of vehicles in the economy, and thus in a particular area. More precisely, car-sharing mostly helps reduce traffic congestion through higher vehicle occupancy rates. Fewer vehicles are needed to move the same number of users. Moreover, fewer vehicles would then be parked, reducing rivalry of use for parking spaces. Rens Meijkamp (2000) reports a 44%

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<sup>4</sup>Household travel surveys carried out in France (CERTU, 2004) reveal that cars are parked on average 96% of the time, i.e., unused for mobility.

reduction in the number of cars used by car-sharing members. On the other hand, self-service schemes primarily help reduce rivalry of use for parking spaces. Due to their higher use rates, pooled vehicles are parked for a shorter time. Cabanne (2009) estimates that a self-service bicycle in Lyon, France, performs on average five trips a day. Therefore, shared bicycles show far higher use rates than private bicycles. However, their occupancy rate is similar or even lower than that of private vehicles, which has consequently no impact on road congestion. Studies about car-sharing systems in German-speaking countries indicate that the vehicle mileage can decrease by up to 50% (Muheim and Inderbitzin, 1992; Baum and Pesch, 1994; Petersen, 1995; Steininger and Novy, 1997), therefore leading to reduced space occupation. This car use reduction can be explained by the change in the relation the user has with the car after it has been servicized.

Both types of shared modes allow reducing the per-person space consumption required for a trip. Vehicle-sharing systems mostly help reduce space consumption for traffic and therefore road congestion, while self-service schemes predominantly help reduce space consumption for parking and therefore rivalry of use for parking spaces. Yet, road congestion and conflicts for parking spaces are strongly correlated to each other. The more cars on road, the more cars need to park at the end of their trip. Similarly, the more cars trying to park, the more congestion on roads. Therefore, addressing spatial issues related to mobility requires both vehicle sharing structures.

Road congestion and rivalry of use are issues related to the space required by transportation modes. The above section emphasizes that shared modes reduce the per person space consumption required for a trip. The next section gives measures of the space required per trip per person for various transportation modes. Gross time-space consumptions are indicated, before I account for the service provided by the different transportation modes to refine time-space consumption estimates.

### 3 Modeling and refining estimations of space consumption

In this section, I first present the existing methodology to estimate the space allocated to mobility. Then, I discuss the underlying hypothesis and propose a refined version of the model.

#### 3.1 Gross time-space consumption estimations

Generally, a trip generates two types of space consumption: a consumption associated with the movement of individuals or vehicles (traffic), and a consumption related to the parking of vehicles. Let's call the former a dynamic consumption and the latter a static consumption (after Marchand, 1977). The two types of space consumption can be aggregated when expressed in a common unit, namely "time-space consumption" ( $\text{m}^2 \cdot \text{h}$ ) which combines surfaces ( $\text{m}^2$ ) and duration of the consumption (h) (Marchand, 1993).

On the one hand, there is a consensus on the calculation method used to assess static space consumption. Both the vehicle's dimensions and the type of parking infrastructure (off-street or on-street parking) are considered. On the other hand, several methods have been used to measure dynamic space consumption (CERTU, 2007). Road capacity measures give estimates of the necessary road width required for a given flow of vehicles, according to transportation modes. This oversimplified measure of space consumption ignores the speed of vehicles and the duration of road occupancy. The speed of vehicles impacts the flow of transportation infrastructures, the distance between vehicles<sup>5</sup>, the road occupancy time and the width of rights-of-ways<sup>6</sup>. The underlying idea is that higher speeds enable to cover a given distance in a shorter period of time, therefore consuming less time-space than slower vehicles. Time-space consumption depends therefore highly on the speed of vehicles. Moreover, higher speeds increase the road capacity. However, as the distance between vehicles increases more than proportionately with the speed,

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<sup>5</sup>Distance between vehicles corresponds to the stopping distance, i.e., both the reaction distance and the braking distance.

<sup>6</sup>Right-of-ways are lateral safety distances on both sides of vehicles and roads, sometimes combined with median strips or emergency lanes.

dynamic space consumption rises with the speed. In addition, higher speeds require larger right-of-ways, in particular for unguided modes such as cars. According to the capacity-speed curves by Cohen (2006), a speed of around 60 to 90 kmph allows for maximal road capacity. The length of vehicles is also accounted for in dynamic space consumption, despite its negligible impact.

The method developed by Marchand (1993) entails both static (parking) and dynamic (traffic) space consumptions, and accounts for the speed of vehicles. Both time-space consumptions are expressed in  $\text{m}^2 \cdot \text{h}$  and given by, respectively (Marchand, 1993):

$$TSC_i^{parking} = \frac{1}{n_i} (S_i * h_i)$$

and

$$TSC_i^{traffic} = \frac{1}{n_i} \left( l_i * d_i(V_i) * \frac{L}{V_i} \right)$$

or

$$TSC_i^{traffic} = \frac{1}{n_i} \left( \frac{l_i * L}{Q_i(V_i)} \right) * 1000$$

with  $TSC_i$  the time-space consumption of transportation mode  $i$ ,  $n_i$  the occupancy rate of transportation mode  $i$ ,  $S_i$  the surface in square meters required to park transportation mode  $i$ ,  $h_i$  the length of stay (parking) in hours for the transportation mode  $i$ ,  $l_i$  the road width where transportation mode  $i$  moves,  $d_i$  the distance between vehicles of transportation mode  $i$  which depends on their speed  $V_i$  and can be summarized by  $Q_i(V_i)$  the road capacity where transportation mode  $i$  moves,  $L$  the length of the trip in kilometers, and 1000 to obtain  $\text{m}^2$  instead of  $\text{km}^2$ .

Marchand (1993) gives estimates of time-space consumptions for several transportation modes (car, two-wheeler, bus, subway and walking) and several trip purposes (work, shopping and leisure). Parking length varies strongly according to trip purposes, from 9 hours for work trips to 1.5 hours for shopping trips. Table 3 in appendix summarizes the results from Marchand. For a 10 kilometer return commuting trip, time-space consumptions per person range from 90  $\text{m}^2 \cdot \text{h}$  for cars to 1  $\text{m}^2 \cdot \text{h}$  for subway and include 2  $\text{m}^2 \cdot \text{h}$  for walking, 21  $\text{m}^2 \cdot \text{h}$  for two-wheelers and 3 to 12  $\text{m}^2 \cdot \text{h}$  for buses. These estimations reveal

that car commuters consume up to 90 times more time-space than subway commuters. Results are striking and claim for increasing use of mass transit to reduce congestion issues in cities.

Nevertheless, these results can be considered as gross estimations. First, the underlying assumptions are strong and sometimes unclear (see Table 4 and Table 5 in Appendix). Second, transportation modes are compared without accounting for their generalized costs and the utility they provide to users. Transportation modes cannot be compared so simply since they do not provide similar services to commuters and have different generalized cost. Commuters make the final decision about transportation modes, and for this reason the determinants of mode choice should be explored. The service provided by the transportation mode, as well as its generalized cost, are leading determinants of mode choice. In the next section, I refine time-space consumptions accounting for the service provided by the mode and including other transportation modes, namely shared modes.

### 3.2 Accounting for the service provided

Gross estimations from Marchand (1993) rely on the oversimplified assumption that the only service provided by transportation modes is the origin-to-destination trip. In this paper, I assume that transportation modes do not provide similar services to commuters and neither have similar generalized costs. Accounting only for gross time-space consumption of transportation modes allows to meet collective needs, while ignoring individual needs. For this reason, time-space saving modes may remain empty despite regular incentives from local authorities. Users choose the cheapest transportation mode from which they derive a given level of utility (Hicksian utility function). Therefore, their choice depends on the services provided by the mode and on its generalized cost. The optimization program of a representative user according to transportation mode  $j$  can be written as follows:

$$\begin{aligned} \min_{t_j, x} R(t, x) &= p_t t_j + p_x x & (1) \\ s.t. & \left\{ U_j \geq U_0 \right. \end{aligned}$$

with

$$U_j \geq \alpha \ln \left( T + \sum_{i=1}^n t_j \right) + \ln x$$

and

$$p_t t_j = GC(j) = v^h \cdot h_j + v_j$$

Let's  $R$  be the revenue the user wants to minimize. With this revenue, she buys two goods: transportation with mode  $j$ ,  $t_j$ , at price  $p_t$ , and a composite good  $x$  at price  $p_x$ . The representative user wants to reach a level of utility, noted  $U_j$ , equal to or greater than  $U_0$ . The utility function is the sum of the utility derived from transportation and from composite good. The user has a preference  $\alpha$  for transportation compared to composite good. Transportation with mode  $j$  provides the core service  $T$  or origin-to-destination trip, and additional services  $t_1, \dots, t_n$  provided by the mode  $j$ . The cost of transportation mode  $j$  can be approached by its generalized cost,  $GC(j)$ , which is a combination of the time value and monetary value entailed by the mode. The time value is the length of the trip in hours,  $h_j$ , multiplied by the hourly average value,  $v^h$ . The monetary cost, noted  $v_j$ , is usually made up of the fuel cost for cars, the cost of tickets for mass transit, etc. Measures of generalized cost may also encompass measures of comfort.

The aim is not only to find which transportation mode is the more likely to reduce spatial issues theoretically, but also to assess which modes would be practically operated by users. To give an illustration of the impact of the service provided and generalized cost on the final choice of users, let us take a simple but concrete example that considers the service provided by transportation modes only - not the generalized cost.

The utility derived by commuters results from several services, not only from the origin-to-destination trip. Prettenthaler and Steininger (1999) explore additional services provided by private cars, compared with shared ones, and mention the comfort, the immediate availability, and the prestige (symbolic function). Bouladon (1974) highlights the private space provided by private cars: "The automobile fulfills a basic need, that of being alone, in a private space". In this study, I include additional services such as carrying heavy loads, driving people with reduced mobility (children, the elderly or those without a driving licence), avoiding road congestion, making physical efforts or

not, providing symbolic functions, offering private space for discussion, covering more than 5 kilometers, being available immediately, etc. Other services could be added to the list. I attribute weights to these services and aggregate them to the core service, namely the origin-to-destination trip. Let us arbitrarily set 1 for the core service and 0.2 for each additional service provided by a given transportation mode<sup>7</sup>. Note that physical efforts can be viewed either as a positive or as a negative attribute. In the latter case, the weight -0.2 is applied. A list of services and weights is provided in Table 1. The weights for each service associated with a given transportation mode are then aggregated and the time-space consumption of the mode is weighted by this value. This allows us to get time-space consumptions per person and *per unit of service provided*. Therefore, previous gross estimations are put into perspective. Furthermore, I add transportation modes not previously considered by Marchand, in particular private bicycles and shared modes (car-sharing, self-service schemes for cars and bicycles, taxi).

Table 1: Services provided by transportation modes

Service provided	Weight
Origin-to-destination trip	1
Carrying heavy loads	0.2
Driving people	0.2
Avoiding road congestion	0.2
Physical efforts (positive)	0.2
Physical efforts (negative)	-0.2
Symbolic functions	0.2
Private space for discussion	0.2
Covering distances > 5 km	0.2
Immediate availability	0.2

Table 2 summarizes the various transportation modes and the aggregated weights derived from the services they provide. Time-space consumption per unit of service provided extends and refines the work from Marchand (1993).

Private cars are defined as cars owned and used by a private user. Car occupancy

<sup>7</sup>Different weights could be set according to the importance of the service considered. However, we prefer to limit the arbitrary nature of the weight setting and set similar weights for all services.

Table 2: Time-space consumption (TSC) per person for a 10 km return commuting trip

Transportation modes		Use rate	W	TSC			WTSC
				Dyn.	Stat.	Total	Total
Private modes	Cars	1.1	2.2	20.5	81.8	102.3	46.5
	Motorized two-wheelers	1	1.6	7.5	13.5	21	13.1
	Bicycles	1	1.2	3.8	6.8	10.6	8.8
Shared modes	Car-sharing	2.5	1.2	9	36	45	37.5
	Self-service cars	1 (5/day)	2	22.5	16.4	38.9	19.5
	Taxis	1.1 (5/day)	1.8	20.5	14.9	35.4	19.7
	Self service bicycles	1 (5/day)	1.2	3.8	1.4	5.2	4.3
			1.6	3.8	1.4	5.2	3.3
Mass transit	Bus with dedicated lanes	1,500/h/day	1.4	12	0	12	8.6
	Bus without dedicated lanes	1,500/h/day	1.2	3	0	3	2.5
	Subway	10,000/h/day	1.4	3	0	3	2.1
Other	Walking	1	1.2	2	0	2	1.7
			1.6	2	0	2	1.3

Note: W: Aggregated Weight; WTSC: Weighted Time-Space Consumption; Dyn.: Dynamic; Stat.: Static

rate for commuting trips is about 1.1<sup>8</sup>. Therefore, both static and dynamic space consumptions are first weighted by the occupancy rate, and then by the aggregated weights associated with this transportation mode. Private cars rank highest in terms of service provided. In addition to the origin-to-destination trip, private cars can be used to carry heavy loads, to drive people and to cover long distances, they provide symbolic functions (mainly social status through the type of vehicle, and self-expression through customization) and private space for discussion. Moreover, private cars are available immediately, since they are owned by a single agent and generally parked close to residences.

Two different systems of shared cars can be distinguished: car-sharing and self-service cars. Car-sharing occupancy rate is logically much higher than that of private cars. In a high-hypothesis case, let us assume that shared cars move on average 2.5 people. Therefore, both static and dynamic space consumptions are weighted by 2.5 and thus reduced compared to private cars. In addition to the origin-to-destination trip, car-sharing allows to cover distances greater than 5 kilometers. Self-service cars allow not

<sup>8</sup>Occupancy rates for all transportation modes are given for France.



only to cover long distances, but also to carry heavy loads, to drive people, and they provide private space for discussion and possibly symbolic functions. Their occupancy rate is assumed to be lower than that of private cars: 1 people per trip. However, while cars shared simultaneously stay parked between outward and return trips, cars shared sequentially can perform up to 5 trips a day (high-hypothesis case). Therefore, while dynamic space consumption of self-service cars is divided by 1, their static space consumption is divided by 5.

Taxis provide functions similar to those offered by self-service cars. The difference is that they do not provide private space for discussion, but they allow to avoid road congestion through dedicated lanes. Commuting trips generally occur during peak hours and avoiding congestion leads to precious time saving. Taxi occupancy rate is assumed to be similar to that of private vehicles when the driver is not accounted for.

Private motorized two-wheelers allow to cover distances greater than 5 kilometers, and are immediately available to the user. Moreover, they may help avoid congestion in urban areas. Symbolic functions are usually not associated with motorized two-wheelers. Their occupancy rate is estimated to 1.

Private bicycles allow to avoid congestion through dedicated lanes and are available immediately. Symbolic functions are usually not associated with private bicycles. Furthermore, they require physical efforts to move from origin to destination, which can be viewed either as a positive (health benefits) or a negative (tiredness, perspiration, weather-sensitivity, need for suitable clothes) feature. Bicycle occupancy rate is 1.

Shared bicycles are usually part of a self-service scheme. They have the same characteristics as private bicycles, except the fact that they are not immediately available to the user. In addition, they may provide symbolic functions, in particular expressing environmental awareness of users. Their occupancy rate is 1, but they can perform up to 5 trips a day.

Buses are of 2 types: buses on non-exclusive lanes and buses on exclusive lanes (30 vehicles per hour). They all allow covering more than 5 kilometers. In addition, dedicated

lanes help avoid congestion. Bus occupancy rate amounts to 50 (high-hypothesis case rather suitable to large urban areas). Moreover, it is assumed that mass transit vehicles are constantly moving, especially during peak hours. When they park, they park outside city centers, where rivalry of use does not occur. Static time-space consumption for buses is therefore zero.

A subway has characteristics similar to buses, except its occupancy rate which is estimated to be much higher: 10,000 commuters per hour (hypothesis for large cities).

Walking allows to avoid congestion during peak hours, and is immediately available. Walking requires physical efforts, considered either positively or negatively.

Although the estimations from Marchand are subject to many criticisms, I use them as a basis to introduce the notion of service provided by transportation modes. Figures should be treated cautiously; the order of magnitude is far more informative in this analysis.

The underlying idea is that mass transit occupies far less time-space than private vehicles and notably than cars. Gross estimations reveal that private cars used for commuting trips require up to 90 times more space than the subway. However, I emphasize that mass transit provides far less services to users than private cars. For instance, the weight associated with the service provided by the subway is 1.4, against 2.2 for private cars. Weighted time-space consumptions remain in favor of mass transit, but the relation decreases from 1 to 90 to 1 to 22 when assumptions are modified and the service provided by the mode accounted for. This order of magnitude shows that the additional time-space consumption of private cars is not fully offset by the additional services they provide. Therefore, they remain time-space consuming modes.

Due to their intermediate position between mass transit and private modes, one may expect better results from shared modes. Indeed, self-service cars provide almost as many services as private cars, while they strongly reduce per person time-space consumption. However, effects from car-sharing are not so significant. Time-space consumption from self-service cars is divided by more than 2 compared with private cars, while that of

car-sharing is divided only by 1.2. This is due to the fact that cars require high static time-space consumption for parking which can be reduced only when increasing the use rate of vehicles.

Let us also note that private bicycles perform worse than most mass transit, even when bicycles provide more services. Shared bicycles allow to reduce the time-space consumed, but still perform worse than most mass transit. Only buses with dedicated lanes have an advantage over bicycles, either shared or private (when physical effort is viewed negatively). Furthermore, it is worth noting that private bicycles perform better than self-service cars. Shared cars' use rate should increase exponentially so that self-service cars rank higher than bicycles - which is practically impossible. The first results allow us to make policy recommendations to help local transportation authorities address spatial and environmental issues.

## 4 Policy implications

Spatial issues related to transportation can be approached by the time-space consumption required by transportation modes. In this sense, policy makers should favor transportation modes that are less time-space consuming. Mass transit has long been considered as the only solution to road congestion and rivalry of use for parking spaces. Gross estimations reveal the very low time-space consumption of mass transit compared to other modes. Moreover, mass transit is generally far less expensive than private cars. Hence, one can wonder why private cars remain dominating, even for commuting trips. In this article, I show that other needs and functions are overlooked. For instance, mass transit does not allow to carry heavy load, to drive a relative, to enjoy private space for discussion or to be available immediately. The need for these additional functions may explain the mitigated success of mass transit.

For this reason, shared vehicles constitute a credible alternative to private vehicles. They provide additional functions to mass transit and allow to save time-space compared to private vehicles. Car-sharing and self-service cars are relatively new transportation infrastructures and they have many caveats. First, the institutional framework governing

car-sharing remains confused. Car-sharing is most often based on private initiatives from neighbors or offered to non-neighbors for occasional trips, mainly inter-urban trips. It entails costly coordination costs that may discourage users to join car-sharing groups. Coordination platforms are set up on the Internet to bring car drivers and car passengers together. Lack of institutionalization contributes to confine car-sharing to sporadic uses. Car-sharing should be better regulated, with the help of a legal framework giving guarantees to both drivers and passengers. Coordination platforms should be encouraged to be comprehensive and flexible. Second, self-service cars have been introduced in some large cities. They remain however too sparse to constitute flexible alternatives to users. Moreover, the outskirts and many places in the countryside have potential to host self-service car stations. The network should be enlarged and incentives given to private car users to quit their cars and use shared cars. Third, using shared modes would discourage some users to buy private cars if their needs can be fully met with shared cars. Hence, complementary offers should be developed, such as family car rentals for several days or weeks at attractive prices. The car rental market is generally disconnected from the transportation providers within a city. In addition, the relatively high prices discourage from regular uses, since then buying a car remains cost saving. Therefore, regular car rental for long period is currently not competitive with private cars. Incentives to integrate car rental with other transportation services should be done to build a comprehensive and efficient transportation system in which shared modes are a key component.

Transportation policies fostering the use of taxis is uncommon but should be reconsidered in light of the time-space consumed per service provided. Taxis are shared modes rather similar to self-service cars, in terms of service provided and time-space consumed. However in countries with high labor costs, the monetary cost of taxis remains higher than that of other shared modes, due to the need of a driver.

Furthermore, the size of the city and its transportation infrastructure are major elements to account for when discussing the local transportation policy. Results from Table 2 indicate that subway commuters need less time-space than either private or self-service bicycles. Nevertheless, subways and similar light-rail mass transit are implemented in large cities only. Medium-sized cities would rather have buses with dedicated lanes. In

this case, results show that private bicycles (when physical effort is viewed positively) and to a larger extent shared bicycles perform better than mass transit in terms of time-space consumption. This is especially true because buses occupancy rate will fall in medium-sized cities, leading buses to perform worse than in larger cities. Consequently, shared bicycles seem to represent a rational compromise to address spatial issues in medium-sized cities.

Environmental issues related to transportation can also be approached by time-space consumption. Traditionally, policy makers encourage low-carbon modes such as mass transit, as well as active modes (walking and cycling) in order to reduce air pollution resulting from transportation. Mass transit releases far less air pollutants than private cars (for instance, rail transport releases 0.0026 kg of CO<sub>2</sub> equivalent per kilometer against 0.07 for a private gasoline vehicle (ADEME, 2006)). Walking and cycling do not release any air pollutant during their use phase. Nevertheless, mass transit has been criticized for its lack of flexibility and limited functions provided to users. Walking and cycling require physical efforts which can be considered negatively by users. In addition, mass transit vehicles and bicycles necessitate materials during the manufacturing phase. Producing vehicles contribute to pollution and resource depletion. On the contrary, shared modes help reduce the number of vehicles in the economy and therefore the number of vehicles manufactured. This is particularly interesting for bicycles whose environmental impact can be fully attributed to the manufacturing phase. In addition, time-space saving transportation modes such as mass transit, shared modes and walking are also low polluting modes. For these reason, shared bicycles should be favored by local transportation authorities rather than private bicycles, especially as the service they provide is similar.

## 5 Concluding remarks

Shared modes such as taxis, car-sharing and self-service cars or bicycles are often overlooked in transportation policies. The analyses conducted in this article helps service providers or local authorities consider the impact of shared modes on time-space consumption and related spatial issues. The analysis clearly indicates that shared cars help reduce road congestion, rivalry of use and air pollution compared to private cars, while

providing additional functions to users compared to mass transit. Indeed, shared modes are intermediate modes between time-space consuming modes such as private cars and time-saving modes such as mass transit. Moreover, shared low-carbon modes, such as self-service bicycles, have the potential to reduce simultaneously both spatial (congestion and rivalry of use) and environmental (air pollution) issues in medium-sized city. Both vehicle-sharing and self-service vehicles constitute credible alternatives to private cars when investigating time-space consumptions per service provided. Shared modes contribute to address spatial and environmental issues related to transportation and should be favored as a leading component of a comprehensive transportation system. As such, this study provides guidance for policy-makers.

Similarly, cars are the most polluting mode and transportation policies fostering bicycles have thrived in order to reduce air pollution, in particular carbon dioxide (CO<sub>2</sub>) and nitrogen oxide (NO<sub>x</sub>) emissions, as well as particulates (PM).

However, these issues are strongly correlated with each other and require a comprehensive approach of the transportation system.

Both road congestion and parking issues exacerbate air pollution by extending the engine running time. Moreover, very low speeds of vehicles trapped in road congestion result in higher levels of emissions. Air pollution is another major issue related to mobility in urban areas. Transportation, and in particular road traffic, generates various air pollutants. Vehicle exhausts release large quantities of CO<sub>2</sub>, a greenhouse gas which is a leading contributor to climate change. In OECD countries, transportation accounts for 27.5% of total CO<sub>2</sub> emissions, with road transport accounting for the larger share of emissions (89%) (IEA, 2011). Local air pollutants such as carbon monoxide (CO), NO<sub>x</sub> and particulates (PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1.0</sub>) also arise from transportation. They have significant effects on the environment (acide rain, contribution to ozone pollution and to climate change) and the health (asthma, lung cancer, heart diseases and strokes). In France, 19% of CO emissions can be attributed to the transportation sector (CITEPA, 2013). NO<sub>x</sub> emissions result mainly from transportation due to the exhaust of diesel vehicles. In France, 61% of NO<sub>x</sub> emissions are released by transportation<sup>9</sup>, among which 93% from road transportation (CITEPA, 2013). Moreover, the transportation sector re-

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<sup>9</sup>In France, more than half of the fleet (61.3%) is made up of diesel vehicles in 2013 (CCFA, 2012).

leases around 15 to 20% of the total particulates in France (CITEPA, 2013), mainly from vehicle exhausts and the wear of roads, tires and brakes. Local authorities regularly warn against pollution peaks in large cities and against their effects on health. Measures to reduce air pollution have long been technical responses (catalytic converters, reduced oil consumption), and are now increasingly directed to road demand management. Transportation policies mainly aim to foster low-carbon or no-carbon modes (mass transit, bicycles, walking). Shared modes, such as car-sharing and self-service cars or bicycles, are usually overlooked by policies as a credible alternative to address spatial and environmental issues related to mobility.

Indeed, spatial issues overlap each others and they also overlap environmental issues.

From an environmental perspective, pooling is especially interesting when products have high material or energy content. Reduced environmental impacts arise primarily from a decrease in the number of units manufactured. This is made possible not only by maintenance and re-use, but also mainly by shared use. Both higher use rates and recycling slow down resource flows in the economy (Scott, 2009), as well as emissions generated by raw material extraction and manufacturing. Moreover, as explained above, shared vehicles help reduce spatial issues which in turn contributes to curtail vehicle polluting emissions. In addition, vehicles offered in self-service schemes are generally less polluting than private vehicles. Self-service cars are most often electric cars which do not release CO<sub>2</sub> or NO<sub>x</sub> and which cut down PM emissions.

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# Appendix

Table 3 presents the gross estimations from Marchand (1993) related to the time-space consumptions per person in  $\text{m}^2 \cdot \text{h}$  for a 10 km return commuting trip with different transportation modes. Table 4 and Table 5 present the underlying assumptions for Marchand’s dynamic and static time-space consumption estimations, respectively. Finally, Table 6 presents the services provided by each transportation modes.

Table 3: Time-space consumption per person for a 10 km return commuting trip

Transportation modes	Time-space consumption		
	Dynamic	Static	Total
Cars (1.25 people/vehicle)	18	72	90
Two-wheelers	7.5	13.5	21
Bus with dedicated lanes	12	0	12
Bus without dedicated lanes	3	0	3
Subway	1	0	1
Walking	2	0	2

Source: Marchand (1993)

Table 4: Assumptions for Marchand’s dynamic TSC estimations

Transportation modes	Distance $d_i$ (m)	Width $l_i$ (m)	Speed $V_i$ (kmph)	Occupancy rate $n_i$ (people/veh)	Road capacity $Q_i$ (veh/h)	Trip length $L$ (km)	Dynamic TSC ( $\text{m}^2 \cdot \text{h}$ )
Cars	15	2.7	18	1.25	1200	10	18
Two-wheelers	6	1.5	12	1	2000	10	7.5
Bus with dedicated lanes	500	3	25	50	30	10	12
Bus without dedicated lanes	50	3	15	50	200	10	3
Subway	500	3	25	600	50	10	1
Walking	1.4	0.7	5	1	3571	10	2

Source: Derived from Héran (2008)

Table 5: Assumptions for Marchand’s static TSC estimations

Transportation modes	Surface $S_i$ (m <sup>2</sup> )	Stay duration $h_i$ (h)	Occupancy rate $n_i$ (people/veh)	Static TSC (m <sup>2</sup> .h)
Cars	10	9	1.25	72
Two-wheelers	1.5	9	1	13.5
Bus with dedicated lanes	N.A.	0	50	0
Bus without dedicated lanes	N.A.	0	50	0
Subway	N.A.	0	600	0
Walking	N.A.	0	1	0

Note: N.A. = Not Applicable

Source: Derived from Marchand (1993) and H eran (2008)

Table 6: Services provided by transportation modes

	Origin-to-destination trip	Comfort	Carrying loads/driving people	Avoiding road congestion	Physical efforts	Symbolic functions	Private space for discussion	Covering distances > 5 km	Immediate availability
Private cars	✓	✓	✓			✓	✓	✓	✓
Private motorized two-wheelers	✓			✓				✓	✓
Private bicycles	✓			✓	✓				✓
Car-sharing	✓							✓	
Self-service cars	✓		✓			✓	✓	✓	
Taxis	✓		✓	✓				✓	
Self-service bicycles	✓			✓	✓	✓			
Bus with dedicated lanes	✓			✓				✓	
Bus without dedicated lanes	✓							✓	
Subway	✓			✓				✓	
Walking	✓			✓	✓				✓