Social costs of metropolitan passenger transport in Barcelona

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Abstract

The paper defines the costs (in monetary terms or in other units) of metropolitan passenger transport in Barcelona, Spain, including public transport modes (buses, railway, subway and taxi) and private vehicles (cars and motorcycles). A graph for the main streets and roads allowed to estimate traffic congestion costs.

Considered costs include operation costs (fuel, lubricants, tires, and operating personnel), indirect costs (insurance, taxes, vehicle depreciation, infrastructure, etc.), travel time (access, waiting, riding and transfer time) and externalities. The application of the models to Barcelona city yield a cost of 0.51 Euro/pax-km for public transport, whereas private vehicle costs are around 0.77 Euro/pax-km.

Numerical elasticities for the unit cost to travel speed increases are -0.38 for public transport, while the same elasticity is -0.57 for speed reductions. A sensitivity analysis has been performed regarding the most relevant variables of the model, especially the value of time savings, concluding that the model is robust. Effects of unit transfers of trips from public transport to traffic and vice-versa are also analyzed. The model is also consistent with shopping basket expense distribution surveys.

In addition to its value as a means of learning about relative social benefit of transport modes, the model has also the mission of establishing common grounds for clarity in metropolitan transport data. The objective is to define future quality of life policies based upon the overall costs of transport as described in this paper.
1 Introduction

A “deontology” of the mobility for a city of the XXIst century implies internalizing the real costs (in time and money) generated by the mobility and contemplating the street space as a scarce social resource. Any exercise dealing with the quantification and objectification of the mobility costs is a step towards the pedagogy and rational usage of the transportation system.

The Metropolitan Transport Authority of Barcelona, Spain, (ATM, Autoritat del Transport Metropolità) has brought together a group of institutions dealing with the mobility in Barcelona (Chamber of Commerce of Barcelona, Catalonia Regional Government, City of Barcelona, Royal Automobile Club of Catalonia, and the Public Transportation Promotion Association, an NGO) to monitor the data and results of the study presented in this paper. Approximately sixty more institutions, companies and associations also collaborated in the study, contributing data and ideas.

The paper presents the social costs of the metropolitan transport in the metropolitan area of Barcelona. It includes direct operating costs, indirect operating costs, time costs and externalities. The data is for 1998 and the study is currently being updated for 1999 and 2000.

The metropolitan area of Barcelona covers approx. 3,200 km² and has approx. 4.2 million inhabitants. During 1996 ATM carried out a large household survey (more than 25,000 surveys) that yielded a lot of information about mobility patterns, distance travelled, mode market shares, etc. Data have been updated to 1998 when possible and otherwise, the raw data of 1996 have been used. Fig. 1 shows the traffic loads in the main streets of Barcelona city (Annual Average Daily Traffic, AADT).

![Traffic loads in Barcelona city (AADT, 1998)](image)

The European Union supports the idea of internalizing the externalities and a lot of effort is currently being put into defining homogeneous values for the
unit externalities. Fig. 2 shows the idea of congestion tax or Pigou’s tax as applied to traffic: because marginal (social) costs are higher than average (perceived) costs, the equilibrium with the social benefit (demand curve) is produced at large flows; with a flow-variable money tax the average costs are equal to the marginal costs and the economic optimum is re-established at a lower traffic flows.

Table 1 shows the current wide range of values for the externalities in the European Union: some effort is needed to narrow down such variations that in some cases are larger than an order of magnitude.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Accidents</th>
<th>Air Pollution</th>
<th>Noise</th>
<th>Climate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car – urban</td>
<td>56-204</td>
<td>7-84</td>
<td>N/A</td>
<td>2-5</td>
</tr>
<tr>
<td>Car – interurban</td>
<td>8-25</td>
<td>8-109</td>
<td>3-14</td>
<td>2-10</td>
</tr>
<tr>
<td>Trucks – interurban</td>
<td>50-60</td>
<td>40-344</td>
<td>71-278</td>
<td>22-68</td>
</tr>
<tr>
<td>Bus – diesel</td>
<td>51-870</td>
<td>152-1,575</td>
<td>210</td>
<td>8-9</td>
</tr>
<tr>
<td>Metro – tramway</td>
<td>8</td>
<td>19</td>
<td>N/A</td>
<td>33</td>
</tr>
<tr>
<td>Railway – freight</td>
<td>13-36</td>
<td>91-723</td>
<td>848-3,152</td>
<td>48-1,744</td>
</tr>
<tr>
<td>Airplane - pax</td>
<td>7-35</td>
<td>804</td>
<td>250</td>
<td>710</td>
</tr>
</tbody>
</table>

Table 1. Wide range of current values for externalities in Europe. 
Values in ECU-1995 per 1000 veh-km. Source: CAPRI-D3 1999
2 Methodology

Costs have been divided into operating direct (those that only exist when the trip is made), operating indirect (those that support the possibility of making a trip regardless of when the trip is made), time and externalities.

A graph with the main streets and roads of the metropolitan area of Barcelona has included link lengths and speeds. This tool is very useful for considering detailed contributions of the traffic costs. For public transport costs, the data have been aggregated into modes and lines. No congestion effect on bus transportation has been considered. Currency rates applied throughout the paper are 1 Euro (€) = 166 Spanish Pesetas (PTA).

2.1 Direct operating costs

These include parking costs at the destination, highway tolls, gasoline or diesel consumption, lubricants, rubber tires and maintenance costs.

Parking costs at the destination have been estimated with a decision tree distinguishing between trip purpose and accounting for the percentage of vehicles with a parking spot available at the destination (at a cost), the percentage of vehicles parking legally on the street or in a parking lot (usually underground in Barcelona) and the percentage of vehicles parking illegally (at the cost of the traffic ticket and/or tow-away times the chances that the vehicle is “caught”).

Highway tolls have been calculated from the total revenues discounting through traffic and dividing the total amount by the total vehicle-km in the metropolitan area of Barcelona.

Fuel consumption is calculated from the unit consumption of a reference vehicle traveling at 60 km/h, \( c_{60} \), a factor that increases consumption for lower speeds \( v_{ij} \), and the vehicle-km (product of the annual average daily traffic \( AADT_{ij} \) and the link length \( L_{ij} \)) that cross a link (see Eq. 1); \( P_i \) is the price without taxes of the fuel type:

\[
C_f = P_f \ AADT_{ij} \ c_{60} \left( 0.804 + \frac{12.66}{v_{ij}} \right) L_{ij} \quad \text{(Eq. 1)}
\]

Lubricant consumption is assumed to be a proportion of the consumption of fuel (0.8% for buses and 1.6% for cars); applying those proportions, the cost has identical expression as Eq. 1 but substituting the (tax-less) price of the lubricant for the price of the fuel.
Rubber tires have a cost and an average life, which depends on the road layout (flat, grades, curves), the level of service (A, B, C,....) and the speed in a similar fashion to Eq. 1.

Maintenance costs depend on the speed $v_{ij}$ and the traveled length $L_{ij}$ in a link, as expressed in Eq. 2:

$$C_m = 30 v_{ij}^{-0.44} L_{ij}$$  \hspace{1cm} (Eq. 2)

2.2 Indirect operating costs

Infrastructure costs have been considered by smoothing the total investment of the base year (1998) with the average annual investment of the previous 9 years. Static costs include vehicle value depreciation as shown in Fig. 3. Vehicle disposal has an average cost of 8,000 PTA (48.2 €).

![Fig. 3. Value of a car as a function of its age](image)

Insurance cost has been calculated from the total revenues of the sector in Spain, averaging 55,500 PTA/vehicle or 334 € per year for 1996; due to the insurance increase, the value for 1998 was considered 63,540 PTA/veh or 383 €/veh.

The Technical Vehicle Inspection (ITV) is a mandatory inspection paid by the vehicle owner; new cars have to pass their first ITV when they are four years old and they pass it every two years until they are ten years old; from then on, the inspection is passed very year. Averaging the amount spent in the inspection (cars that do not pass it on the first test are supposed to fix the
problem and to pass it again in other tests or they cannot be driven) and the life of the vehicles in Barcelona, an annual figure of 2,150 PTA/veh (13 €/veh) was obtained (for motorcycles the cost is one half of that).

The tax on vehicles of mechanical traction (IVTM) is paid annually to the municipality depending on the vehicle size and power. Traffic tickets can also be considered an indirect operating cost because, on the average, one has chances of paying an annual amount regardless of how much the vehicle is operated; the figures come from the official revenues from that concept.

Public transport has structure costs regardless of how much service is provided. Parking costs at the origin are also considered indirect costs.

### 2.3 Time related costs

Overcoming a distance requires time. Because time is a scarce good it has a value. Any trip needs different amounts of six types of time: preparation, access from origin, waiting, riding, transfer (sometimes) and access to destination.

Preparation time has been ignored in this study. Access from origin time ranges from 2.33-8 minutes on the average (the lower value if for access to the car). Waiting time is considered one half of the average headway between (frequent) public transport services and a fixed time before the scheduled departing time for less frequent services. Riding time is obtained from average speeds (including stop times). A value of 3 minutes has been taken as an average transfer time.

### 2.4 Value of time savings

Time is translated into money assuming a value of time. Although several SP and RP surveys in specific projects have allowed estimation of concrete values for trip time savings (VOT) through the ratio of time over cost parameters in a disaggregated demand model, the obtained values have been considered too high for most of the professional applications in Barcelona. Jaro-Arias and Hunt (1996), based on a logit model calibrated with several hundreds of surveys per market segment, report values of time that range from a minimum of 3,000 PTA/h (18 €/h) for elderly users of Tunel de Vallvidrera to 11,200 PTA/h (67.5 €/h) for users with an income comparable to the one of a university professor (richer and poorer people are reported to have smaller VOT; the reported values are for 1989).

Several PhD theses and graduating theses have estimated the VOT for Barcelona and even proposed new methodologies for estimating the VOT (see Oliver, Turró and Robusté, 1998). The most recent values for Barcelona range from 1,356 PTA/h (8.2 €/h) to 1,908 PTA/h (11.5 €/h). These values agree with all the international surveys of VOT in different European projects.
Regardless of the (recent) theoretical contributions by Jara-Díaz (2000) on the social value of time savings, a simple and transparent methodology was applied to the available data. The average wage in Catalonia is 1,576 PTA/h (9.5 \( \varepsilon /h \)). Assuming the maximum proportions of the average wage reported by Willeke (1984) and summarized in Table 2, an average VOT of 1,115 PTA/h (6.7 \( \varepsilon /h \)) for 1998 was estimated for the Metropolitan Area of Barcelona (Robusté, 2000).

<table>
<thead>
<tr>
<th>Trip purpose</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business</td>
<td>64%</td>
<td>82%</td>
<td>100%</td>
</tr>
<tr>
<td>To work</td>
<td>27%</td>
<td>48%</td>
<td>69%</td>
</tr>
<tr>
<td>To shopping</td>
<td>15%</td>
<td>37%</td>
<td>59%</td>
</tr>
<tr>
<td>Leisure</td>
<td>35%</td>
<td>47%</td>
<td>41%</td>
</tr>
</tbody>
</table>

Table 2. Value of Time as percentages of the average wage (Willeke, 1984)

This methodology has been recently tested and produces consistent average values of time savings that can be updated every year according to the current average hourly wage. The significance of that value lies in the consensus adopted by all the institutions that back up the study and agreed on that VOT.

2.5 Externalities

The main subject of traffic accidents has been addressed by considering the maximum official values of 30,000,000 PTA per death (180,723 \( \varepsilon \)) and 4,000,000 PTA per wounded person (24,100 \( \varepsilon \)) that are used in Spain. These values are about one third to two times higher than other values obtained from stated preference surveys in the region (Riera, 1997). It can be argued that part of these costs are already included in the insurance costs; due to the social significance of the accidents and the lack of accounting for all the family suffering, that redundancy was not considered a mistake.

Air pollution is split among emissions which contribute to global warming (CO\(_2\), CH\(_4\), N\(_2\)O, HCFC, PFC, SF\(_6\)) and the rest of pollutants (NO\(_x\), SO\(_2\), VOC, IHC); the unit costs are adapted from a study by INFRAS/IWW (1994) and summarized in Table 3, which also includes the noise costs (also taken from the same study):

<table>
<thead>
<tr>
<th>Mode</th>
<th>Air pollution</th>
<th>Climate change</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PTA</td>
<td>Euro</td>
<td>PTA</td>
</tr>
<tr>
<td>Car</td>
<td>741</td>
<td>4.46</td>
<td>842</td>
</tr>
<tr>
<td>Bus</td>
<td>472</td>
<td>2.84</td>
<td>371</td>
</tr>
<tr>
<td>Railway</td>
<td>286</td>
<td>1.72</td>
<td>505</td>
</tr>
</tbody>
</table>

Table 3. Unit costs for air and noise pollution (per 1000 person-km)
2.6 Traffic congestion effects

Traffic congestion is a common issue in any large and nonetheless efficient city: the objective is not to completely eliminate congestion but to keep it at an appropriate level; many times, congestion and pricing are the only effective tools to control car market share. Since traffic link costs continuously increase with traffic flow, it is difficult to determine the exact moment when congestion effects start to show. Practitioners have several rules of thumb though: traffic engineers in Spain assume there is no congestion in a working day in August (nation wide Summer vacation), a Sunday morning or during everyday’s lunch time (say 3 pm; regular lunch time in Spain is from 2 pm to 4 pm). Lindley (1987) used the flow/capacity ratio that changes the Level of Service from C to D in US urban freeways.

Our approach consisted in assuming that the average reference speed $v_r$ depends on the traffic light plan, $S$, the legal maximum speed (say 50 km/h in city streets), $L$, the environment (through street, parking and loading/unloading street, etc.), $E$, and the traffic flow $q$:

$$v_r = v_r(S, L, E, q)$$

(Eq. 3)

The maximum reasonable speed $v_{max}$ is reached when an optimal traffic signal plan is selected (for non-zero flows), $S^*$, and there are no cars $q=0$. Because the reference speed when congestion starts is difficult to estimate, we can approximate $v_r \approx v_{max}$ with small error since link costs are almost constant for small flows. With this approximation, there is an objective way to estimate the reference speed (through $v_{max}$): for the current traffic light plans, calculate the maximum speed without traffic flows but accounting for legal speed limits and street “environment” (which usually decreases the average speed by a percentage).

Given a network of streets and roads, the effects of traffic congestion for a variable $V_k$ (which may depend on the time $t$) can be estimated as:

$$\text{Effect on } V_k = \sum_{i} \sum_{j} \int_{\tau=0}^{t_{ij}} \left[V_k(v_{ij}) - V_k(v_{ij})\right] q_{ij}(\tau) \delta(\tau) d\tau$$

(Eq.4)

where $v_{ij}(t)$ is the real speed in link (ij) as a function of time, $v_{ij}$ is the reference speed of link (ij), $q_{ij}(t)$ is the traffic flow of link (ij) and $\delta(t)=1$ only when $v_{ij}(t)<v_{ij}$ ($\delta(t)=0$ otherwise).
3 Results analysis

3.1 Global results

The main results are summarized in Table 4. Social costs do not include taxes since they are considered transfers within the society. The inclusion of motorcycles is due to the fact that the city Barcelona has one of the highest motorcycle market shares in the world, about 17% in Barcelona city.

<table>
<thead>
<tr>
<th>SUMMARY OF UNIT SOCIAL COSTS BY GLOBAL CONCEPT (without taxes)</th>
<th>CARS AND MOTORCYCLES</th>
<th>PUBLIC TRANSPORTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PTA/km-trip</td>
<td>Cents of €/km-trip</td>
</tr>
<tr>
<td>OPERATING COSTS (DIRECT)</td>
<td>7.6</td>
<td>4.6</td>
</tr>
<tr>
<td>OPERATING COSTS (INDIRECT)</td>
<td>61.3</td>
<td>36.9</td>
</tr>
<tr>
<td>TIME</td>
<td>43.9</td>
<td>26.4</td>
</tr>
<tr>
<td>EXTERNALITIES</td>
<td>14.7</td>
<td>8.9</td>
</tr>
<tr>
<td>TOTAL UNIT COSTS</td>
<td>127.5</td>
<td>76.8</td>
</tr>
</tbody>
</table>


Table 4 shows how competitive public transportation can be in indirect operating costs and externalities, while keeping the direct operating costs only 40% higher than those of traffic vehicles. The main problem of public transportation is time. Public transportation is 34% cheaper, in social terms, than car traffic and that may grant special advantages for public transportation from the public sector.

3.2 Congestion costs

The study of social costs corroborates the order of magnitude of the results of a previous study of the traffic congestion costs in Barcelona (Robusté, 1998). With data of 1993 (many highway infrastructures were inaugurated in 1992 with the deadline of the Summer Olympic Games in Barcelona and because of the new supply and all the construction works in previous years, traffic demand decreased in the city center), the costs of traffic congestion (only the effects on the cars; there are effects on other vehicles and street users) were just 34,000 million PTA (€205 million). Barcelona was one of the large cities with fewest congestion problems then.

The new results reveal the rupture of that idyllic situation, bringing a total amount of 90,000 million PTA, a threefold increase in just five years. This tendency supports the thesis that it makes a lot of sense to assume a higher
demand elasticity to travel time for car traffic in forecasting studies in the near future.

3.3 Traffic cost components

It is interesting to note that the social cost of 127.5 PTA/km (0.77 €/km) is about one order of magnitude higher than the perceived fuel cost, but it does not include taxes (which in Spain are about two thirds of the total price for the gasoline). Figure 4 depicts a pie-chart with the percentual contribution of each concept; the numerical values are given below.

![Pie chart showing car cost components (percentage and values)](image)

**Fig. 4. Car cost components pie-chart**

Ranking of contribution to the total car cost (from more important to least important in terms of cost per km):
- Vehicle ownership and depreciation (24.4 PTA/km)
- Riding time (22.8 PTA/km)
- Insurance (11.95 PTA/km)
- Access time at origin and destination (11.7 PTA/km)
- Parking cost (9.72 PTA/km)
- Time due to congestion (9.42 PTA/km)
- Accidents (9.37 PTA/km)
- Highway tolls (7.77 PTA/km)
- Infrastructure investment (4.37 PTA/km)
- Fuel (3 PTA/km)
- Vehicle maintenance (2.96 PTA/km)
- IVTM (vehicle tax) (2.3 PTA/km)
- Noise pollution (2.12 PTA/km)
- Climate change (1.68 PTA/km)
- Other air pollution (1.48 PTA/km)
- Rubber tires (1.01 PTA/km)
- Lubricants (0.66 PTA/km)
- Tickets (0.43 PTA/km)
- Vehicle inspections (ITV) (0.39 PTA/km)

Traffic costs including taxes are 141.2 PTA/km (0.85 €/km) which means that global taxes account for 13.7 PTA/km (0.083 €/km). All the listed costs are paid by the traffic users except for the externalities (accidents, infrastructure, noise and air pollution; also a part of congestion time, which cannot be detailed in our study with the available data) that add up to 19 PTA/km (0.11 €/km). That is, in order to internalize the externalities an extra amount of 5.3 PTA/km (0.03 €/km) on the average should be included.

3.4 Sensitivity analysis

A comprehensive set of sensitivity tests was carried out concluding that the numerical model is robust. Of a particular interest is the test on the social cost of the public transportation when some changes in ridership are made. Table 5 shows that public transport costs increase when there are patronage losses, while it decreases when patronage rises.

<table>
<thead>
<tr>
<th>Changes in public transportation</th>
<th>-10% pax</th>
<th>-5% pax</th>
<th>Current Pax.</th>
<th>+5% pax</th>
<th>+10% pax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit cost (PTA/pax-km)</td>
<td>86.44</td>
<td>85.44</td>
<td>84.52</td>
<td>83.66</td>
<td>82.90</td>
</tr>
<tr>
<td></td>
<td>(0.52 €)</td>
<td>(0.51 €)</td>
<td>(0.51 €)</td>
<td>(0.50 €)</td>
<td>(0.50 €)</td>
</tr>
<tr>
<td>Patronage in millions</td>
<td>642.5</td>
<td>678.2</td>
<td>714.0</td>
<td>749.6</td>
<td>785.3</td>
</tr>
</tbody>
</table>

Table 5. Sensibility to changes in public transport patronage

3.5 Shopping basket

It was also interesting to note that the numerical model agreed with surveys regarding shopping basket expenditures in families. Table 6 shows this correspondence: left column gives the results of annual expenditures in transport from surveys in Spain, while the right column adds up the appropriate terms of the numerical model. The differences of 28% are due to higher income, higher number of vehicles per inhabitant and higher public transport supply in the metropolitan area of Barcelona than in the average of Spain.
### Annual expenditure per person in 1998

<table>
<thead>
<tr>
<th></th>
<th>Spain (surveys)</th>
<th>Barcelona (model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle acquisition and usage</td>
<td>93,027 PTA</td>
<td>119,313 PTA</td>
</tr>
<tr>
<td>Public transport expenditure</td>
<td>10,365 PTA</td>
<td>13,662 PTA</td>
</tr>
<tr>
<td>TOTAL (1998, per person)</td>
<td>103,393 PTA</td>
<td>132,975 PTA</td>
</tr>
</tbody>
</table>

Table 6. Annual expenditure per person in transportation (1998)

### Conclusions

Social costs of metropolitan transportation modes are a good tool for establishing agreed upon basic planning data and good ground for establishing transportation policies. The model developed in Barcelona is robust and shows that public transportation is one third cheaper socially than car and motorcycle transportation; it is desirable that the dissemination of these results make the social values turn into behavioral values, that is, values that may change the current transportation patterns towards a more sustainable equilibrium.

Social costs of metropolitan transportation are just one input in more global and integrated transportation management policies. In order to promote sustainable mobility, traffic restrictions in space and time as well as a fare policy that can be implemented as highway tolls and/or parking fees should be also considered.

### Acknowledgments

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### References


