Automobile has been a key element to foster economic, social and cultural development in metropolitan areas. However it has also facilitated a wide urban sprawl and produced a number of externalities. The growing number of car trips has reduced their effectiveness because traffic congestion minimizes speed which is one of their main advantages. Therefore there is big concern to achieve a more balanced modal split in urban areas. Many urban policies are oriented to increase trips in public transport, walking and bicycle. But it is not possible to provide reliable public transport services in some areas (low density) or to walk or cycle when distances are long. Therefore it is necessary to identify which is the actual potential of transferring trips from car in each urban area.

The paper proposes a methodology to calculate how many trips could be transferred to either public transport or soft modes in each origin-destination pair. This potential of transfer is determined without changing trips characteristics: trip time, possibility of multiple destinations trips, and total budget of time dedicated to travel in week days. In other words, the proposed methodology identifies which trips could be made in PT or soft modes, instead of car, without affecting drivers’ trip diary.

Many trips can not change their mode because either there is not a valid alternative, the driver is making a multiple destination trip or he/she is using car to carry other persons in the way. To consider all these conditions a decision-tree has been designed to be applied to each origin-destination relation in mobility surveys. It analyses the potential of transfer in a sequential way: trips that are not linked to car, capability of alternative modes, and daily budget of time. The method has been validated in the case study of Madrid city. This area has a good supply of public transport, is quite dense and has chronic traffic congestion.

The results show that the potential of transfer is not as big as expected. The potential of transfer accounts for 168,000 car trips each day (only 11% of total car trips). Among them, 75% could be transferred to PT, 15% to bicycle and 10% to walking. This figures could be higher if there were better facilities for PT, cycling or walking in some zones. They could also change according to the traffic conditions: more congestion would produce higher transfer and fluid conditions lower. The method allows also to design and to test targeted policies to improve the potential of transfer in those areas or corridors where results are poorer.

Finally, the paper presents a balance of externalities if the potential transfer were effectively made. Environmental benefits are relevant even though the potential in Madrid is rather low.
1. Introduction

Cars have gone from being luxury goods to everyday utility products, easy to operate and maintain influencing a substantial additional demand and replacing habitual short-distance travelling modes like walking or cycling (Mackett & Robertson, 2000; Rietveld, 2000; Thorson & Robusté, 1998; Pucher et al., 1999) as also public transport. In turn, they create significant impacts on the environment and foster population dispersal. The aim of this paper is to analyze the possibilities of reversing the process and going back to basing city-centre mobility on public transport and the so-called soft modes. In second place it will analyze the expected benefits of this potential mode transfer.

According to May et al (2003), the chief measures for achieving a lower use of cars and boosting public transport and journeys on foot and on bicycle in the centre of cities go through the design of tariff-related measures along with provision of information systems, traffic management, enhanced public transport vehicles and provision of the appropriate infrastructure and facilities so that non-motorized modes are a safe, convenient and relevant option.

However, the magnitude of the potential of the transfer in each place will depend to a certain extent on the social, geographical, economic and cultural peculiarities of each city and on certain variables such as the motorization rate, income, distribution of land uses and supply of each mode.

Figure 1  Transfer of trips from car to public transport and soft modes

2. Limits to transfer car trips to other modes

However, not all trips can be transferred from cars to more sustainable alternative modes, like public transport, walking or cycling. The conditions required for a transfer to take place are that the generalized cost (time and cost) is not significantly higher in the alternative mode and that the change of mode should not entail any limitation on carrying out the activities generating the trip.
2.1. Time Budget Limits

Journey time is the main limitation in the modal choice. This limit is particularly tight in the case of commuter trips. In fact, what normally happens is that any improvements to the road system foster a greater use of cars. It will only be possible to compete effectively with cars when good public transport is available and in transport relations in which trip distances are adequate for allowing modes alternative to cars to signify a sufficiently competitive supply. Consequently, only if journey times on alternative modes are appreciably similar will the modal transfer take place. As a result, the chief barrier confronting the modal change from private vehicle is journey time (Halden, 2003; Stradling, 2002), which on occasions turns into a real burden for public transport and non-motorised modes, both for the real amount of time employed and for the perception of even longer times than the actual ones (penalization of scenarios perceived as annoying).

Perception has a negative effect on the modes considered to be "less convenient and comfortable", which in the urban milieu correspond to public transport and non-motorised modes, meaning that a bias can easily be produced that systematically penalises all modes other than cars. However, individuals tend to set up a time budget for their journeys (Schafer&Victor, 2000), which forms the basis for setting up a limit for transferring from a car to other modes.

2.2. Constraints from the Activities Circuit

On an urban level, individuals make about three trips a day so will need to make the same number of decisions concerning the form and characteristics of their travel movements. A large part of these decisions are made for indispensable purposes, like studies or work, involving less reasoning, with individuals acting in a quasi automatic manner. But on many other occasions journey conditions are determined by earlier actions or by trips that can be made later (Bonnel&Caubel, 2002) or else by the characteristics of the journey itself - accompanying an elderly person, taking a child to school or shopping before returning home, etc. These circumstances may determine that the car is used which otherwise would not have been. To analyze these conditioning factors, the concept of a journey as a one-way travel movement from a point of origin, i, to a destination, j, has to be replaced by the circuit concept that would be the sequence of movements ending at the point of origin (home for instance). In circuits, if one movement requires the use of the car, the other movements are obliged to use this mode (Fig. 2).

![Diagram of interdependent journeys forming a circuit](image-url)
3. Methodology for Calculating the Potential for Journey Transfers

Having established the conditions for modal transfer from a car journey, an analytical methodology was devised for strengthening the transfer to each possible destination mode, in line with the diagram in Figure 1.

The application area should be a city centre zone where the public transport supply is good and where the average distances involved make it possible to make journeys on foot or by bicycle. All car journeys in the study area are analyzed for their possible transfer to other modes. The potential for transfer is quantified for each travel movement, according to its origin and destination, as a function of the journey characteristics and of the competitiveness of the alternative modes. The process follows the decisions tree illustrated in Figure 3. The starting condition is that the activities system must remain unaltered, meaning that travellers continue to go about their daily activities without any change whatsoever, i.e., maintaining established circuits and journey time. This analysis requires a disaggregated mobility survey. The disaggregating level should be sufficient to provide data by zone, time, age, purpose and mode, etc.

![Figure 3 Decisions tree to quantify the modal transfer potential](#)

Firstly, the activities or movements that cannot be made other than by car have to be identified. These include taking the car for regular consumer goods shopping as trips that tend to be less planned (Garling et al, 2000). Excluded from these are the journeys accompanying individuals with restricted autonomous movement possibilities such as the elderly and/or handicapped and minors, which dictate even short journeys (Mackett, 2003). Also excluded are night-time journeys where less public transport is available and security problems increase.
Having excluded these journeys, the transfer process is applied, consisting of seeking an alternative to replace the car on each journey not excluded from the study zone, following the iterative process illustrated in Figure 3.

3.1. Transfer Quantification According to Travel Distance

The main restrictions for non-motorized journeys - walking and cycling - are distance and journey time, which are interrelated and implicitly include aspects such as weather, inclines of the terrain and environs, etc. A maximum distance has to be set for journeys on foot or on bicycle and also an age limit for cycling owing to the physical condition and skills required. These limits need to be established as a function of the city characteristics and user profile.

The comparison will be made by time strata/journey distance. Whichever car journeys do not exceed the autonomous distance limit for alternative mode will be susceptible to transfer. If the distance to be travelled on foot for a specific journey exceeds the traveller’s autonomous walking capacity, the journey will not be able to be transferred to this mode, in which case the mode with the next biggest autonomous capacity would be turned to, such as the bicycle. In the event that this mode is not suitable either, the comparison will be made with public transport. On the contrary, if the mode does have sufficient autonomy for the particular journey concerned, then analysis would go on to assess competitiveness from the point of view of journey time.

3.2. Time-related Transfer Assessment

Three comparisons are made in relation to journey time. The first is personal autonomy (age and time), referring to the time an individual can comfortably walk or cycle. The second is the difference in journey time in the modes being compared, indicating the direct competitiveness of the mode offered as an alternative for the changeover. The third assessment checks whether the mode changeover would run over the daily time budget for travelling, making it possible to assess the potential for longer journey times without this affecting users carrying out the activities involved.

4. The Study Area- Madrid and its Metropolitan Ring

4.1. Study Area

Madrid is a city of 3.1 million inhabitants, surrounded by its metropolitan ring with a population of 2.3 million. Demographic density varies considerably. In the inner city Madrid has 51 inh./ha whereas in its metropolitan ring the density is only 10.3 inhabitants per hectare. These differences have a substantial effect on mobility. Figure 4 illustrates the changes to have taken place in mobility rates in each mode, comparing the rates from the last two mobility surveys (CRTM, 1998; CRTM, 2006). The first observation to make is that the mobility rate has been on the rise, increasing from 2.04 to 2.45 over the 1996-2004 period. Secondly, that public transport is the most important transport mode in the denser central city districts whereas it is the car in the suburbs. Thirdly, that the number of journeys on foot is on the rise in the city centre and is falling in favour of car use in the metropolitan ring. Very few journeys are made on bicycle, just 0.03%.
It is clear that modal split patterns depend greatly on the density of population but also on other variables such as trip time and length. As Baimborn et al (2003) say the choice of transit occurs when travellers feel that the transit option is superior to other choices in regard to time, cost, convenient, and comfort.

Figure 4  Modal split distribution in Madrid city and its Metropolitan Ring

We can conclude that Madrid City has a good mobility performance rating but that car trips are increasing at a faster rate than journeys on public transport or on foot. Car journeys predominate in the metropolitan ring and are growing very rapidly, which is a clear threat for the future (Bamberg, 2003). However, it is hard to know which trips currently made by car could be transferred to other modes, in other words, how many meet the transfer conditions analyzed in the previous Section.

The study area chosen was the Madrid Metropolitan Area and specifically trips with origin and/or destination in Madrid City. This means that the trips studied take place, at least partially, in the densest zone with the greatest public transport provision.

Figure 5  Study Area: Madrid Region and its zones
4.2. Transfer Limits

In line with several studies, the following limits were taken for the study area in the city of Madrid. Firstly, a time block between 6:00 am and 10:00 pm for security reasons. The maximum distance chosen for journeys on foot was 1.5 km, which is the average for existing walking journeys in the Madrid CBD (CRTM, 2006). For cycle journeys, the age limit set up was 18 to 50 year olds (ICE, 2000) and a distance of 3.5 km (DeMaio & Gifford, 2004). No distance was determined for the transfer of trips to public transport.

4.3. Modelling Process

To determine the number of trips, the basis used was the Madrid mobility survey which explained mobility patterns in Madrid in each zone of the case-study area. However, the iterative transfer calculation method requires knowledge of the journey times for each O-D pair on each individual transport network. This necessitated adapting the demand models for public transport and mobility by car. For reasons of the availability of the coded network, the EMME/2 model was used for public transport and VISUM for cars. Walking time was determined by applying the average speed obtained based on the mobility survey of 4.7 km/hour. Where cycling is concerned, the scant representativity of the sample meant data had to be taken from studies in other cities, adopting the rate of 9 km/hour (Bonnel & Caubel, 2002). The process is summarized in figure 6.

Figure 6  Modelling Process

Modelling of the trips between the different zones revealed differences in journey time between the different modes, as shown in Figure 7. The average time for walking trips is less than the average trip by car, which in turn is less than that on public transport modes. However, analyzing the range of variation in the values for each mode, we could prove that although the average for PT trips is greater than by car, in some journeys the opposite is the case, making the transfer from car to public transport possible. Similarly, not all car journeys can be transferred to walking trips, in inner areas, because the variation involved sometimes reverses the situation.
5. Potential for Transferring Trips to PT and soft modes

Having modelled journey times in all the ratios, the methodology applied was to determine the percentage of car trips potentially transferable to other modes. First, journeys on foot were determined, applying the condition that journey time was equal to or less than the time taken by car. The transfer limits were subsequently applied. All the journeys not transferable to walking mode were analyzed to see whether they could be transferred to cycling following the same procedure, and finally they were analyzed to see whether they could be made by public transport. The potential for transfer on each of the stages is summed up in the following Table 1. For distance limiting reasons, the transferability to walking analysis was only carried out in the CBD. For cycling, all the trips in Madrid City were analyzed and for transfer to public transport, all the trips in Madrid City and its metropolitan ring were analyzed.

<table>
<thead>
<tr>
<th>Trips to transfer to walking</th>
<th>$t_{\text{car}} \geq t_{\text{walking}}$</th>
<th>31,050</th>
<th>17.2</th>
<th>only trips inside CBD</th>
</tr>
</thead>
<tbody>
<tr>
<td>fulfill requirements for walking</td>
<td>16,197</td>
<td>9.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trips to transfer to biking</td>
<td>$t_{\text{car}} \geq t_{\text{biking}}$</td>
<td>44,907</td>
<td>21.9</td>
<td>trips inside Madrid city boundaries</td>
</tr>
<tr>
<td>fulfill requirements for biking</td>
<td>23,928</td>
<td>11.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trips to transfer to PT</td>
<td>$t_{\text{car}} \geq t_{\text{PT}}$</td>
<td>128,222</td>
<td>13.6</td>
<td>trips in Madrid and Metropolitan ring</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>168,347</td>
<td>18.0</td>
<td></td>
</tr>
</tbody>
</table>

These results can be analyzed according to the zone where the transfers are produced and also according to overall demand rates expressed in trips-km. The results are shown in Table 2. The most external the zone, the higher the number of
trips-km car saved. The environmental and other external benefits will be related to the number of car trips transferred to more environmental friendly modes.

<table>
<thead>
<tr>
<th>TABLE 2 Potential of transfer by zone and mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>zone</td>
</tr>
<tr>
<td>trips</td>
</tr>
<tr>
<td>within CBD</td>
</tr>
<tr>
<td>within Madrid City</td>
</tr>
<tr>
<td>within Metropolitan Area</td>
</tr>
<tr>
<td>TOTAL</td>
</tr>
</tbody>
</table>

To sum up, we can state that, without varying journey times, it is estimated that a potential does exist for transferring trips by car to alternative modes for journeys that at least start or end in the CBD, amounting to some 168,000 trips, equivalent to some 18% of all trips by car and some 11% of trip-km rates (1,227,268). Some 75% of these trips could transfer to public transport, 15% to cycling and 10% could be made on foot.

These results indicate that, even in cities with a high proportion of journeys on foot and on public transport, this patronage could rise even more by an adequate combination of urban transport policies, even greater restricting of car journeys and improving the provision and appeal of public transport and journeys on foot and by bicycle (Monzon, 2003). The concept of integrated transport strategies is not new (May et al, 2005), but few ‘local transport plans’ can be considered as truly ‘integrated’ as yet in their approach; there are limited in particular by the resources available, the unacceptability of demand management measures, the need to negotiate with the operators on public transport service levels and fares, the lack of understanding of interactions between transport and land use, and the timescale for implementing innovative solutions.

6. External benefits of transfer car trips

Externalities are different depending on each mode. In this analysis, we have considered the cost of accidents, climate change, pollution, noise and severance. Walking and cycling have no external costs. Metro trips produce energy consumption and then CO₂ emissions. Buses produce all kind of externalities but the main one is pollutant emissions. Car trips are those which produce higher externalities, with a high proportion of energy consumption and accidents. Table 3 shows the results of the calculation of externalities of each mode in the study Area, according to the values calculated by Monzón&Vega (2003) and Guerrero&Monzon (2003). We have also used data from the Madrid mobility surveys (CRTM 1998, 2006) and from other sources (Ministerio de Fomento, 1996). The results show that in the central part of Madrid, car externalities per transport unit account three times as in the bus trips, and almost twenty times than in metro ones.
TABLE 3 External costs of trips with Origin and/or Destination in Madrid CBD (€/1000 pass-km)

<table>
<thead>
<tr>
<th></th>
<th>Walk</th>
<th>Bike</th>
<th>Metro</th>
<th>Bus</th>
<th>Car</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>0.11</td>
<td>22.60</td>
</tr>
<tr>
<td>Climate Change</td>
<td>0</td>
<td>0</td>
<td>5.04</td>
<td>9.09</td>
<td>34.47</td>
</tr>
<tr>
<td>Pollution</td>
<td>0</td>
<td>0</td>
<td>0.46</td>
<td>17.13</td>
<td>14.31</td>
</tr>
<tr>
<td>Noise</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>5.09</td>
<td>14.15</td>
</tr>
<tr>
<td>Severance</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>2.20</td>
<td>12.28</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>0</td>
<td>5.51</td>
<td>33.63</td>
<td>97.80</td>
</tr>
</tbody>
</table>

Based on these unitary values, and taking into account the results from the previous section, we could calculate the external benefits that could be achieved if the whole potential of car trips transfer were really performed. The calculations account for a benefit of **97,520 euros/day**. This benefits would be got without increasing trip times, as explained in the methodology.

There are other benefits associated to avoiding 168,000 car trips, such a less cost of infrastructures (construction and maintenance), less economic costs (operating costs) and a lot more of space free for city uses. According to the Madrid mobility survey, 70% of car entering city centre for long stay trips (business and studies) use to park in the street. According to some studies (Alonso, 2004) the parking spaces dedicated to non residents in Madrid CBD range to 770,000 m2. Then the space “saved”, according to the rotation rate with the avoided trips would be some 140,000 m2, 18% of the total.

7. Conclusions

Car is the most appropriate mode, even in dense areas provided with good public transport, for certain journeys thanks to the shorter journey times involved and conditioning factors of a social nature (journeys accompanying other individuals, security, etc.). This forces travellers not only to make individual travel movements, but also to run-on travel circuits in which the unavoidable mode for one part of the journey conditions the mode used in the rest of the circuit.

Nevertheless, there is room for developing PT priority policies and soft mode trips in a way that will cut down car trips in dense city zones to a maximum extent.

A methodology has been developed to determine how many trips were susceptible to being transferred from car to more sustainable modes, following a transfer process to the mode with the lowest social cost - walking, cycling and, finally, public transport. The methodology is based on a disaggregated demand model for all travel modes enabling a comparison to be made between journey times in each transport ratio, transferring to alternative modes the trips in which journey time is less than or equal to the current car journey. Journeys made under certain specific conditions were not deemed to be susceptible to transfer, namely circuits with an unavoidable stage by car, journeys accompanying other individuals or made at night.

The case of the Madrid study, where PT patronage is very high, enables us to validate the methodology and determine the potential existing for transfer to sustainable modes. This potential points to an 18% of the travel movements currently made to or from the Madrid CBD being transferable in the proportion of 10% on foot, 15% by
bicycle and 75% on public transport, fulfilling all the conditions and without varying journey times.

There will be a clear social benefit of this policy. The direct externalities could be valuates as almost 100,000 €/day. There are also other social benefits in terms of reduction of infrastructure costs, operation and land dedicated to car flows.

The results show that if the prevailing automobile-oriented urban form can be reconfigured to become more friendly to transit, walking, and biking, traveller would more likely consider these non driving-modes for travel, which would eventually lead to reduced automobile use and its associated undesirable consequences, as Zang (2005) states. Thus results enable policy measures to be designed that are targeted at achieving a real transfer to the modes with less externalities.

8. References


Zhang, M. (2005). Intercity variations in the relationship between urban form and automobile dependence dissipagrate analysis of Boston, Massachusetts; Portland, Oregon; and Houston, Texas. Transportation Research Record, 1902.