IMPACTS OF INNER AND OUTER ORBITAL MOTORWAYS ON INTRA-METROPOLITAN ACCESSIBILITY: EFFICIENCY AND EQUITY. A CASE STUDY OF MADRID

Juan Carlos Martín,* Juan Carlos García-Palomares*, Javier Gutiérrez* and Concepción Román*

*Departamento de Geografía Humana, Universidad Complutense de Madrid, 28040 Madrid, Spain.

*Departamento de Análisis Económico Aplicado, Universidad de Las Palmas de Gran Canaria, 35017 Las Palmas G.C., Spain

Abstract.- Orbital motorways are major structuring elements in the metropolitan areas of developed countries. They can be considered as key components within the transport network of the large urban agglomerations, funneling a great amount of intra- and inter-metropolitan traffic. This paper explores the effects of orbital motorways on accessibility, using the beltways of Madrid as a case of study. It is well known that orbital impacts are quite different depending on its location within the metropolitan area (inner and outer) as well as the activity distributional performance (agglomeration vs. decentralization of activities). The effects are going to be analyzed from a twofold perspective: equity and efficiency. These topics have been scarcely addressed in previous works. The paper extracts some policy considerations with respect to the accessibility disparities within metropolitan areas comparing the relative changes from the spatial perspective.

Keywords.- Orbital motorways, accessibility, Geographic Information Systems (GIS), transport planning.

JEL classification: R12, R41, R58

* Author for correspondence. e-mail: jcmartin@daeulpgc.es.
Acknowledgements. Financial support from MICINN (TRA2005-06619/MODAL) are gratefully acknowledged.
IMPACTS OF ORBITAL MOTORWAYS IN METROPOLITAN AREAS ON ACCESSIBILITY: EFFICIENCY AND EQUITY. A CASE STUDY OF MADRID

1. INTRODUCTION

Orbital motorways are major structuring elements in contemporary metropolitan areas. Empirical evidence shows that the building of beltways, together with an increase in congestion in the centre, has brought about substantial changes in the distribution of intra-metropolitan accessibility. The most accessible points by car are no longer the centre of the city; accessibility is often highest along the orbital corridors, so that much of the suburban decentralization process has gravitated toward beltway corridors (Muller, 1986). Prior to the proliferation of beltways, most of the movements of goods, services, and people between suburban locations on the highway had to be made via the central city. As a result, central city locations were preferred for many commercial and office functions. The construction of beltways has allowed functions historically dominated by the central business district (CBD) to locate outside of the central city without losing connectivity within the urbanized area (Sutton, 1999). Therefore, these transport infrastructures, by improving suburban accessibility, also favor decentralization and a polycentric dynamic. With the development of a ubiquitous transport system and the decentralization both of residences and business, accessibility has been greatly increased and become more homogenous over time (Giuliano, 1986).

Es bien conocido el hecho de que la construcción de autopistas orbitales modifica dramáticamente la distribución de la accesibilidad en el interior de las áreas metropolitanas. Sin embargo hasta la fecha los trabajos empíricos sobre el impacto de las nuevas orbitales en la accesibilidad intrametropolitana son muy escasos. Lineker and Spence (1992a, 1992b) se ocuparon de analizar el impacto de la M-25 de Londres en la accesibilidad inter-metropolitana. Sólo el trabajo de Gutiérrez y Gómez (1998) sobre la M-40 de Madrid se ocupó de estudiar los efectos en la distribución de la accesibilidad intra-metropolitana, utilizando varios indicadores y diferenciando entre la accesibilidad a la población y al empleo (pero no entre distintos tipos de actividades económicas). This paper goes further than the one by Gutiérrez and Gómez (1998), contributing to the existing literature on accessibility impacts of orbital motorways in the following ways:
• First, the effects on accessibility are analyzed according to the location of the orbital motorways (inner and outer).
• Second, the relationship between the geographical activity distribution and the accessibility gains is investigated studying whether agglomeration or decentralization plays any significant role.
• And finally, a twofold perspective is used in order to evaluate the different effects of inner and outer orbital motorways: efficiency and equity.

Our prior hypothesis is that outer orbitals are less used by intra-metropolitan interactions, but they play a very important role in interaction of peripheral municipalities. Besides, outer orbitals usually favour those decentralized activities that have a significant importance in the periphery, and its effects on the accessibility to the core activities of the central business district (CBD) are more modest. On efficiency considerations, it is interesting to evaluate orbitals according to those that produce more accessibility gains studying which activities are more favoured. But, it is also interesting to address equity considerations investigating whether new orbitals favour or not inequalities on accessibility between transport zones, which can influence decisively metropolitan structure development.

The paper is organized as follows: After this brief Introduction, Section 2 presents a brief literature review of orbital motorways and accessibility. Section 3 shows the accessibility indicator used, the scenarios considered and the data. Section 4 analyzes the impacts of the construction of two orbital motorways (M40 and M50) on accessibility using a gravity-based indicator. The results are obtained using a Geographic Information System (Arc/GIS). And finally, Section 5 concludes.

2. ORBITAL MOTORWAYS AND ACCESSIBILITY

2.1 Orbital motorways

Extensive population and employment decentralization have occurred in virtually all metropolitan areas in the developed world (Giuliano and Small, 1999). As a result of this decentralization process, flows between suburbs has increased dramatically, largely channeled through the orbital motorways, which provide the only high capacity circumferential traffic routes in many major cities. And the orbital motorways, in turn, improve the accessibility of suburban municipalities, thus increasing the value of their location and making them more attractive to investors, which brings about even further decentralization. Thus, orbital motorways favor the decentralization of activities at the same time as the increased flows between suburbs causes progressive congestion of these infrastructures, giving rise to a need to build new, more distant orbitals. There is
no specific cause-effect relationship, but a constant interaction between transport and metropolitan structure.

Orbitals were originally conceived as a means of diverting through traffic away from congested, central-city areas, but beltways took more and more local traffic, resulting in a shift in the role of beltways from inter-urban routes to intra-urban arterials (Sutton, 1999), so that they have increasingly become integral parts of the intra-metropolitan highway system in areas where they have been constructed (Giuliano, 1986).

Despite the fact that the orbital motorways are major structuring elements in metropolitan areas, they have so far been given scant attention in academic literature, particularly in the last decade. Of course, there are a few papers that deal with specific aspects of orbital motorways: origin and evolution (Hall, 1990); operational control (Wootton, 1990); traffic jam formation in ring roads (Guan and Hu, 2005); effects on traffic and mobility (Kroes et al., 1996; Lian, 2005); impacts on property values (Langley, 1976 and 1981; Palmquist, 1980); land use and urban development impacts (Baerwald, 1978; Payne-Maxie Consultants, 1980; Lathrop and Cook, 1990; Sutton, 1999; van Nes, 2001; Mattsson and Sjölin, 2002; Gago et al., 2004); regional development effects (Linneker and Spence, 1996); environmental impacts (Monzón and Villanueva, 1996; Li and Tao, 2004). Sólo Linneker and Spence (1992a, 1992b) y Gutiérrez and Gómez (1998) se han ocupado de evaluar los efectos de las orbitales en la accesibilidad (intermetropolitana e intrametropolitana, respectivamente). This investigation extends the state of the art by comparing the accessibility effects of inner and outer orbitals, taking into account the decentralization degree of activities within the metropolitan area.

2.2 Accessibility and equity

For transport planners the concept of “accessibility” has gained its momentum for more than 40 years. Handy (2002) commented how almost all transportation plans in the US highlighted improving accessibility as a key element in the goals section. However, Levinson and Krizek (2005) sustained that the term accessibility is often misused and confused with other terms such as mobility. In contrast to the term “mobility”, which refers to the movement of passengers or goods over space, accessibility refers to the facility to reach a destination or ensemble of destinations from a given place using a transport system. According to Hansen (1959), accessibility can be defined as “the potential of opportunities for interaction”.
Accessibility has been traditionally analyzed using different indicators which serve to encapsulate different aspects of this multifaceted concept. Van Wee et al. (2001) classifies accessibility indicators into four groups:

- **Infrastructure** indicators are based on the main characteristics of the infrastructure and its use: for example, speeds on motorways, travel times by train, density of the networks in some specific area, such as municipalities or regions, and so forth.
- **Location-based** measures analyze accessibility at locations, typically on a macro-level, in order to describe the level of accessibility to spatially distributed activities, such as the number of jobs within 30 min travel time from origin locations.
- **Person-based** accessibility measures are founded in the space–time geography and analyze accessibility from the viewpoint of individuals incorporating spatial and temporal constraints.
- **Utility-based** accessibility measures analyze the economic benefits that people derive from access to the activities, interpreting accessibility as the outcome of a set of transport choices. Utility theory addresses the decision to purchase one discrete item from a set of potential choices, all of which satisfy essentially the same need.

This paper evaluates the effects of the orbital motorways in Madrid using a location-based measure: the economic potential, the most common accessibility indicator. It can be interpreted as the volume of economic activity to which a location has access, after the cost/time of covering the distance to that activity has been accounted for. Economic potential is a gravity model that takes into account two different variables: mass and distance. In our work, distance has been measured as the travel time and mass as the total number of employments, i.e.:

\[
P_i = \sum_{j=1}^{n} \frac{m_j}{t_{ij}},
\]

where \(P_i\) is the economic (market) potential of node \(i\), \(m_j\) is the mass (in our case, employments in each of the economic activities considered) of the centroid \(j\), \(t_{ij}\) is the travel time by the minimum-time route along the network between origin \(i\) and

---

1 This paper does not explore the literature on how accessibility has been theoretically analyzed, and whether such methods might be used as useful tools to study the performance of a metropolitan transport system. There are excellent revisions about the weakness and usefulness of different accessibility measures proposed in the literature, see, for example, Black and Conroy (1977), Handy and Niemeier (1997), Jones (1981), Reggiani (1998), and Van Wee et al. (2001).
destination \( j \), and \( x \) is a parameter that reflects the effect of the distance decay function. In this paper, as in the majority of accessibility studies, the value of the parameter \( x \) is 1.

Accessibility is not only important from the economic point of view, but also from the social perspective. Accessibility to work, health, education and services is one of the key components when it comes to evaluating the level of welfare of the population (Leck et al., 2008). Accessibility can be seen as a proxy for measuring welfare, if we accept that the welfare of individuals is related with the ease which they can access essential services (Hay, 1993). An improved accessibility provides the individual with a wider set of opportunities in order to select that which best matches their needs and preferences (López et al, 2008).

Accessibility allows us to establish links between transportation and equity. Equity is concerned with the spatial distribution of income and resources which affect people’s opportunities and quality of life (Leck et al., 2008). Increase or reduction of disparities can be measured by some of the inequality indices employed in economic literature (Cowell, 1995), as for example the coefficient of variation. Many studies analyze the disparities of social groups to access services and employment (for example, Pickup and Giuliano, 2005; Pucher and Renne, 2003; Dobbs, 2005). But others tackle this issue properly from the point of view of the accessibility inequalities between places. Their underlying assumption is that transport infrastructure investments will result in positive (negative) equity effects if they reduce (increase) existing disparities/inequalities in the spatial distribution of accessibility (for example, Gutiérrez and Gómez, 1999; López et al. 2008). This approach is particularly relevant from the point of view of metropolitan development. New infrastructure, such orbital motorways, can produce important impacts on metropolitan structure because a reduction in the accessibility disparities between transport zones favours urban sprawl and decentralization. By reducing travel times between the origins and the destinations linked by the new orbital, peripheral municipalities become more accessible, so that more activities will be attracted to these areas as a result of the increased level of accessibility, some of which may have shifted from formerly favored locations (Giuliano, 1986). This trend can be unsustainable because the associated environmental costs can be really high. In this paper we analyze the accessibility impacts of inner and outer orbital motorways from this second approach (disparities between places).

3. DATA, SCENARIOS AND METHODOLOGY
A Geographic Information System (Arc/GIS) is used to store the socio economic and network data and to calculate the accessibility indicators. A relatively dense road network has been used taking into account specific attributes of the arcs like length, number of lanes, speed and travel time. The network consists of 1312 arcs and 609 nodes which covers the whole metropolitan area of Madrid. All the roads of the metropolitan area were taken into account, as well the main streets of the city of Madrid. Figure 1 shows the road network considered.

**Figure 1. Road network of Madrid.**

The area was divided in 69 zones, corresponding to the 21 districts of the municipality of Madrid and the 48 suburban municipalities. Population and employment data were stored for each of the centroids of the zones. The 69 zones have been grouped into four different rings, in order to present a summary of the results of our analysis, according to the relative position to the orbitals under analysis:

- First ring (Inner Madrid).
- Zones within the M30 (central districts of the municipality of Madrid).

2 Given the spatial nature of accessibility, GIS has become a useful tool for accessibility analysis, which provides capabilities for data collection, data management and manipulation, spatial analysis, network analysis, and graphical presentation of accessibility measures.
- Second ring (Outer Madrid).- Zones between the M30 and the M40 (peripheral districts of the municipality of Madrid).
- Third ring (Inner ring of suburban municipalities).- Zones between the M40 and the M50.
- Fourth ring (Outer ring of suburban municipalities).- Area outside the M50.

It is clear that economic potential of a transport zone can change with orbitals construction, but this change is really different and depends on the use of this infrastructure for all the interactions with the rest of transport zones. This is what we want to assess using and comparing different scenarios. Thus, in order to simulate the effect of the orbital motorways, three evaluation scenarios were considered:

- M30 (the only orbital motorway in the network is the M30),
- M40 (two orbitals, M30 and M40, are taken into account) and
- M50 (the three orbital motorways of the metropolitan area are considered).

Changes between scenarios M30 and M40 shows the contribution of the M40 to the intra-metropolitan accessibility; comparison between M40 and M50 scenarios offers changes in accessibility brought about by the construction of the M50 orbital.

These three scenarios are used to evaluate how new orbitals have produced accessibility changes within the metropolitan area without considering land use changes, that is the impacts are measured using some static point regarding the information on employment, and therefore the historical evolution of accessibility in the metropolitan area of Madrid using the dynamic variables is out of the scope of this paper. In order to clarify each scenario, the following assumptions are made:

- **Scenarios.**- The scenario M40 is the central scenario of our analysis and is the only one which corresponds to a real scenario, where mass and impedance variables are coetaneous (year 1996, when the M40 was completely finalized). From this basic scenario, the evaluation (what if) scenarios M30 and M50 were developed eliminating all the links of the M40 or adding the new links of the M50, respectively. Thus, keeping the mass variables fixed, the impedance variables are changed according to the different networks (orbitals) considered in our analysis. In our analysis, many other links that have been constructed in the period have not been included just trying to isolate the changes in accessibility that can be accrued to the construction of the orbitals.
- **Speeds and travel times.**- The average speed for each arc was recorded for the central scenario M40 according to the available official data. In the case of arcs without official data (urban streets and non-principal roads), average speed was estimated taking into account the type of road and the average level of congestion. In order to analyze the structural changes on accessibility, it has been assumed that the speeds on the orbitals do not change with the opening of an outer orbital because, according to our experience in Madrid, speed increases do not last a long period of time (Gutiérrez and Gómez, 1999). The aim of this paper is not to evaluate short-term changes on accessibility due to temporal alleviation on congestion levels (in terms of travel times), but to analyze the structural changes on accessibility due to the evolution of orbitals construction in Madrid.

- **Mass variables.**- The mass variables are the employment in each transport zone according to different economic activities: industry, retailing, services and public administration. Employment data correspond to the year 1996 (M40 scenario) and they have been kept constant for the rest of scenarios, just in order to analyze the isolated changes that can be accrued to the construction of new orbitals (M40 and M50). The information is based on a mobility survey that was carried out in that year, so urban district and municipality data could be obtained. Accessibility to employment is important for workers, but also for business-oriented companies, which sale intermediate goods and services to other companies.

In summary, there are three different scenarios: M40 (real scenario), M30 and M50 (what if scenarios, developed to compare accessibility changes). Thus, the evaluation of orbitals impacts on accessibility are done considering only the changes on the networks keeping the rest of the elements constant. Intencionadamente no se consideran los cambios en los usos del suelo (que parcialmente son consecuencia de la construcción de la orbital). La atención se centra en los cambios en los tiempos de acceso producidos por la construcción de la nueva infraestructura, no en los derivados de la relocalización de actividades como consecuencia de las nuevas condiciones de accesibilidad creadas.

Our prior hypothesis is that the impacts of orbitals on accessibility depend highly on the location of the orbitals (inner or outer) within the metropolitan area. But, the effects are also different attending to the activities considered. Therefore, four different types of

---

3 A floating vehicle of the Madrid Council regularly records specific speed data of the sections of the main streets and roads, avoiding extreme traffic conditions (peak hours and valley hours). Average speed of each section is calculated for several time periods (as years) from the individual speed data of the section.
employment have been considered taking into account their different level of agglomeration of activities. Table 1 shows how the level of employees working for the Public Administration and Services is highly concentrated on the first ring (CBD). On the other hand, the industry employment is the most dispersed (high level of decentralization), and finally the employment on the Retail Sector shows an intermediate level of agglomeration which is similar to total employment.

Table 1. Employment Ring Distribution in Madrid metropolitan area.

<table>
<thead>
<tr>
<th>Rings</th>
<th>Total</th>
<th>Industry</th>
<th>Retailing</th>
<th>Services</th>
<th>Public Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>759675</td>
<td>35803</td>
<td>138764</td>
<td>110418</td>
<td>125547</td>
</tr>
<tr>
<td>Second</td>
<td>364571</td>
<td>29729</td>
<td>82046</td>
<td>33797</td>
<td>35846</td>
</tr>
<tr>
<td>Third</td>
<td>308112</td>
<td>38269</td>
<td>66513</td>
<td>24393</td>
<td>20918</td>
</tr>
<tr>
<td>Fourth</td>
<td>27891</td>
<td>44924</td>
<td>64471</td>
<td>16774</td>
<td>22978</td>
</tr>
<tr>
<td>Total</td>
<td>1460249</td>
<td>148725</td>
<td>351794</td>
<td>185382</td>
<td>205289</td>
</tr>
</tbody>
</table>

Percentage

<table>
<thead>
<tr>
<th>Rings</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>44.4</td>
</tr>
<tr>
<td>Second</td>
<td>21.3</td>
</tr>
<tr>
<td>Third</td>
<td>18.0</td>
</tr>
<tr>
<td>Fourth</td>
<td>16.3</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
</tr>
</tbody>
</table>


The accessibility indicator was calculated according to the following procedure. First, travel times through the network from each of the origin nodes to each of the 69 centroids were calculated for the three scenarios. The accessibility of each transport zones was calculated by relating travel times with employment data according to the formula of the indicator (equation 1), using the value 1 as exponent of the travel time. And finally contour maps were generated by interpolation and graphs were elaborated by aggregation of the values of each ring. We will see how the construction of the different orbital motorways has changed the accessibility pattern of all the centroids. It is clear that the changes will be more pronounced for those centroids whose interaction with the rest looking at the minimum-time routes includes more links of the orbitals under analysis.

4. CHANGES IN ACCESSIBILITY DUE TO THE CONSTRUCTION OF INNER AND OUTER ORBITAL MOTORWAYS ACCORDING TO ECONOMIC SECTORS: EFFICIENCY AND EQUITY

This section presents the results of the accessibility analysis. We are trying to determine the different patterns on accessibility gains for each of the orbitals (inner and outer) and
sectors considered (from Public Administration where agglomeration of activities is more pronounced to Industry which is characterized by more dispersed activities). This issue has not been previously studied but it seems clear that the location of the orbital within the metropolitan area and the level of agglomeration of activities could influence the changes on accessibility. For the ease of exposition, the results are presented in tables and maps according to the nomenclature of rings that has been previously explained (Section 3). Efficiency and equity are analyzed using the average and the coefficient of variation of the gravity based accessibility indicator –respectively- within the metropolitan area of Madrid. The interpretation of changes in the gravity-based accessibility indicator average is clear: the higher the values, the more efficiency from the point of view of accessibility to the employment. However, decreasing values in the coefficient of variation suggest that spatial equity in terms of accessibility to employment improve, since inequalities between transport zones tend to be lower.

Analyzing the evolution of the accessibility to the total employment (Table 2), it can be seen that the average increase (12.3 %) produced by the construction of the orbital M40 is higher than the one induced by the construction of the orbital M50 (2.6%). Under equity considerations, it can be observed that the behaviour of both orbitals is also very different: M40 does not change significantly the previous scenario and it even increases the polarization of the spatial distribution of accessibility (the coefficient of variation is increased by 0.8%); but M50 produces more equity between transport zones because the coefficient of variation decreased by 6.5 per cent.

The analysis of the coefficient of variation by sector presents some peculiarities. First, in the scenario M30, it can be seen that accessibility to different type of employment is not homogenous: agglomeration activities like Public Administration present more polarization than Industry ones (Table 2). This can be explained because differences in values in economic potential are more remarked in those activities that present more economies of agglomeration like Public Administration and Services. In these activities, employment tends to be located in the first ring, and accessibility values tend to decrease steeply from the first ring to the forth one. Meanwhile, industry activities tend to be located more homogenously, so that less disparities (between the different rings) in the distribution of accessibility are observed (Table 3).

The construction of M40 improves accessibility to the employment for each of the sectors considered (Tables 2-3), but improvements are not homogenous, being more important for the activities with a greater level of decentralization like the industry (13.9%). The gains for more centralized activities are more modest like for example Public Administration (10.8%). The most significant improvements in accessibility
terms are located in the surrounding areas of the orbital (second and third rings, respectively) and in the more decentralized activities (Figures 2-3).

Accessibility changes after the construction of new orbitals (M40 in this case) could produce more or less spatial equity, depending on which are the transport zones more affected by the new infrastructure. However, at first, it can be thought that all orbitals tend to produce more equity between transport zones in terms of accessibility by its own conception in comparison with the radial highways which tends to favour CBDs. However, the results for M40 present a counterfactual example of this hypothesis because, in fact, the spatial distribution of accessibility is more polarized under its construction. This is partly explained by the intrinsic characteristics of the metropolitan area of Madrid because this orbital can also be considered an internal orbital which benefit those transport zones which were already really accessible before its construction (second ring), but the effects on the transport zones with poor accessibility (fourth ring) or good accessibility (first ring) are almost negligible.

However, looking at each sector separately, the conclusions are very different. For example, it can be seen that M40 reduces spatial disparities in the sectors that are more centralized, like Public Administration (-1.2%), but increases inequalities in the more dispersed activities like Industry (+5.5%). It is evident, that this different behaviour is due to the distribution of employment: more than half of the industry employees are located in the peripheral rings (third and forth rings) in contrast to Public Administration where most of the employment is located in the first ring. In summary, M40 is like an inner transport infrastructure for the more decentralized activities like Industry (producing less spatial equity in the accessibility to the industrial employment), but it is like an external one for the activities that are more centralized like Public Administration (reducing inequalities in the spatial distribution of accessibility to the Public Administration employment).
Table 2. Accessibility and coefficients of variation (CV). Scenarios and Sectors.

<table>
<thead>
<tr>
<th>Total</th>
<th>M30</th>
<th>M40</th>
<th>M50</th>
<th>Dif M30-40</th>
<th>Dif M30-40 (%)</th>
<th>Dif M40-50</th>
<th>Dif M40-50 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility</td>
<td>86745</td>
<td>97434</td>
<td>99983</td>
<td>10688</td>
<td>12.3</td>
<td>2549</td>
<td>2.6</td>
</tr>
<tr>
<td>CV</td>
<td>34.40</td>
<td>34.69</td>
<td>32.41</td>
<td>0.29</td>
<td>0.84</td>
<td>-2.28</td>
<td>-6.57</td>
</tr>
<tr>
<td>Industry</td>
<td>Accessibility</td>
<td>7356</td>
<td>8384</td>
<td>8721</td>
<td>1028</td>
<td>13.97</td>
<td>336</td>
</tr>
<tr>
<td>CV</td>
<td>27.92</td>
<td>29.46</td>
<td>26.99</td>
<td>1.54</td>
<td>5.52</td>
<td>-2.47</td>
<td>-8.38</td>
</tr>
<tr>
<td>Retailing</td>
<td>Accessibility</td>
<td>17931</td>
<td>20224</td>
<td>20838</td>
<td>2292</td>
<td>12.78</td>
<td>614</td>
</tr>
<tr>
<td>CV</td>
<td>32.86</td>
<td>33.42</td>
<td>30.96</td>
<td>0.56</td>
<td>1.70</td>
<td>-2.46</td>
<td>-7.36</td>
</tr>
<tr>
<td>Services</td>
<td>Accessibility</td>
<td>9710</td>
<td>10796</td>
<td>11010</td>
<td>1085</td>
<td>11.18</td>
<td>214</td>
</tr>
<tr>
<td>CV</td>
<td>39.77</td>
<td>39.11</td>
<td>37.16</td>
<td>-0.66</td>
<td>-1.66</td>
<td>-1.95</td>
<td>-4.99</td>
</tr>
<tr>
<td>Public Administration</td>
<td>Accessibility</td>
<td>10373</td>
<td>11502</td>
<td>11724</td>
<td>1129</td>
<td>10.89</td>
<td>222</td>
</tr>
<tr>
<td>CV</td>
<td>39.09</td>
<td>38.62</td>
<td>36.80</td>
<td>-0.47</td>
<td>-1.20</td>
<td>-1.82</td>
<td>-4.71</td>
</tr>
</tbody>
</table>

Table 3. Gravity based accessibility: averages according to Scenarios, Sectors and Rings.

<table>
<thead>
<tr>
<th>Scenario M30</th>
<th>Rings</th>
<th>Total</th>
<th>Industry</th>
<th>Retailing</th>
<th>Services</th>
<th>Public Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>136256</td>
<td>9588</td>
<td>26874</td>
<td>16956</td>
<td>18198</td>
<td></td>
</tr>
<tr>
<td>Second</td>
<td>118772</td>
<td>9555</td>
<td>24353</td>
<td>13478</td>
<td>14301</td>
<td></td>
</tr>
<tr>
<td>Third</td>
<td>94487</td>
<td>8233</td>
<td>19604</td>
<td>10342</td>
<td>10947</td>
<td></td>
</tr>
<tr>
<td>Fourth</td>
<td>63622</td>
<td>5885</td>
<td>13464</td>
<td>6790</td>
<td>7304</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario M40</th>
<th>Rings</th>
<th>Total</th>
<th>Industry</th>
<th>Retailing</th>
<th>Services</th>
<th>Public Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>146885</td>
<td>10521</td>
<td>29132</td>
<td>18153</td>
<td>19445</td>
<td></td>
</tr>
<tr>
<td>Second</td>
<td>134097</td>
<td>11057</td>
<td>27692</td>
<td>14989</td>
<td>15910</td>
<td></td>
</tr>
<tr>
<td>Third</td>
<td>113029</td>
<td>10032</td>
<td>23596</td>
<td>12182</td>
<td>12856</td>
<td></td>
</tr>
<tr>
<td>Fourth</td>
<td>69763</td>
<td>6481</td>
<td>14764</td>
<td>7418</td>
<td>7949</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario M50</th>
<th>Rings</th>
<th>Total</th>
<th>Industry</th>
<th>Retailing</th>
<th>Services</th>
<th>Public Administration</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>146966</td>
<td>10548</td>
<td>29143</td>
<td>18156</td>
<td>19452</td>
<td></td>
</tr>
<tr>
<td>Second</td>
<td>134334</td>
<td>11092</td>
<td>27743</td>
<td>15001</td>
<td>15928</td>
<td></td>
</tr>
<tr>
<td>Third</td>
<td>116044</td>
<td>10446</td>
<td>24290</td>
<td>12424</td>
<td>13115</td>
<td></td>
</tr>
<tr>
<td>Fourth</td>
<td>73309</td>
<td>6938</td>
<td>15570</td>
<td>7725</td>
<td>8260</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Gravity based accessibility changes (%) between scenarios M30 and M40. Public Administration and Industry.

Figure 3. Gravity based accessibility changes (%) between scenarios M30 and M40. Sectors and Rings.
It can be seen that M40 produces significant increments on the metropolitan accessibility for all sectors, but M50 has a softer impact because in its surrounding area the employment is less significant. However, this situation could change in the near future when new office developments occurred. The most significant improvements are observed in those activities that were more decentralized like industry and retailing. Similarly to the M40 case, the more important benefits are located in the areas nearby the orbital, being especially important in those nodes located in the fourth ring. On the contrary, the effects of the new orbital are almost negligible in the two inner rings (Table 3 and Figures 4-5).

For that reason, it can be concluded that the effects of M50 on the overall accessibility of the metropolitan area of Madrid is not really significant in terms of efficiency. However, this orbital improves considerably the average accessibility of the transport zones that showed lower levels of accessibility previously, so that it increases spatial equity between transport zones. In all the sectors, the coefficient of variation is reduced and the reduction is more significant in those activities that are decentralized. The reduction range goes from Industry (-8.3%) to Public Administration (-4.7%). In summary, it can be concluded that from equity considerations, the effects of M50 are more important than those observed by the construction of the orbital M40, because it produces more spatial equity between transport zones within the metropolitan area of Madrid for all the sectors independently of the degree of agglomeration of the activities.
Figure 4. Gravity based accessibility changes (%) between scenarios M40 and M50. Public Administration and Industry.

Figure 5. Gravity based accessibility changes (%) between scenarios M30 and M40. Sectors and Rings.
5. CONCLUSIONS

In this paper, we have studied accessibility changes due to the construction of orbital motorways (M40, M50) in Madrid using a gravity-based accessibility measure. This type of infrastructure has been a predominant investment in large metropolitan areas in recent years. In fact, most of the metropolitan areas of the cities of developed and developing countries have constructed this type of transport infrastructure in the last twenty years. The construction of orbital motorways over a radial system of the past has created radial-concentric structures. These infrastructures have dramatically changed the accessibility patterns and the spatial interaction among all the municipalities inside the metropolitan areas.

In our case, the metropolitan area of Madrid, it has been shown that the effects of new orbitals on accessibility depend intensely on two basic issues: its location and the spatial distribution of the sectors under study. Inner orbitals, like M40, are used for multiple interactions, and so many important changes are observed in terms of efficiency. However, the effects on equity are almost negligible and, in some cases, it can even reinforce the spatial disparities within the metropolitan area. On the contrary, the effects of outer orbitals (M50) are just the opposite, because its impacts on efficiency terms are much softer but in equity terms are really important. This can be explained because the new orbital benefits more to those municipalities with lower levels of accessibility.

Analyzing the overall impact of both orbitals, it can be concluded that M40 and M50 have changed dramatically the accessibility of the metropolitan area of Madrid taking into account both perspectives: efficiency and equity.

It has also been shown that the spatial distribution of activities in the metropolitan area under analysis is also important. One orbital can play two distinct roles for different activities. M40 could be considered an inner orbital for decentralized activities, but an external one for centralized activities. In the first case, the observed changes would be very important in terms of efficiency and almost negligible in terms of equity. The opposite result can be concluded for the second case, that is, not very significant changes in terms of efficiency but very important changes in terms of equity.

Urban planners could have used these results straightforwardly. Inner orbitals tend to be more effective taking only into account efficiency considerations and financial burdens tend to be lower because the length of the infrastructure is lower. Considering the structure of the metropolitan area, the most external transport zones hardly benefit from these type of orbitals. So, when urban planners try to keep the advantages of the CBD against the suburban areas, this is the type of orbitals that need to be constructed. On the other hand, outer orbitals like M50 are not only more expensive but less efficient in
terms of improvements of accessibility when only efficiency considerations matter. These orbitals induce also more decentralization of activities and housing in the metropolitan area, because they favour particularly external transport zones, increasing equity (between transport zones) in the distribution of the accessibility to the employment. Taking into account whether the metropolitan area is more sustainable or not, there exists nowadays an important controversy because the outer orbitals are usually the cause of important environmental costs. First, these infrastructures consume directly important land areas and they indirectly cause new house and office developments in low density areas. Second, this trend favours the urban sprawl making households more dependant on private vehicles which producing again more environmental costs.

In Madrid, as in many other cities of the developed or developing world, the new orbitals are causing many housing and office developments in the vicinities areas of the orbitals, modifying significantly the existing metropolitan structure (Gago and al., 2004). There is some evidence that the construction of this type of infrastructure led to the relocation of headquarters from the CBD to some well-connected areas near the new orbitals. Just as example, it has been observed that Telefonica headquarters have been moved to a new location near the M40 (10000 employees), and Santander Bank headquarters has also moved to a location near the M50 (7000 employees). This is a new phenomenon in the metropolitan area of Madrid, because so far the headquarters of the big Spanish firms were located in the CBD of Madrid near the offices of the Public Administration.

Orbital motorways are major elements of the metropolitan network. They produce important impacts on the distribution of intra-metropolitan accessibility and play, therefore, an important role in the evolution of the structure of cities. However, in this paper some evidence has been obtained about how different the impacts can be depending on two basic characteristics: orbitals’ location and the degree of agglomeration of the activities. Trying to reconcile different objectives which promote more livable and sustainable metropolis will be the primary aim of land use planners in the coming future.
References


Kroes, E., Daly, A. Gunn, H. and Van Der Hoorn, T. (1996): The opening of the Amsterdam Ring Road. Transportation, 23 (1), 71-82.


