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The impacts of congestion on automobile accessibility. What happens in large European cities?

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ABSTRACT

Every day, a significant part of the population in large cities suffers transport congestion. One effect of this is a change in the spatial distribution of accessibility, which may lead to people or businesses finding themselves temporally in areas where accessibility values are lower than either desired or required. This paper studies changes in automobile accessibility over the course of the day, as caused by congestion of the road network in eight metropolitan areas of the European Union: London, Paris, Madrid, Berlin, Barcelona, Rome, Hamburg and Milan. The study was carried out using millions of data points on real speeds on segments of the road networks gathered over the course of two years from TomTom® devices, which provided for the incorporation of a dynamic perspective of accessibility. In each of the areas studied, the different impacts of congestion on automobile accessibility can be observed from differences in the distribution of opportunities and the provision of infrastructures, as well as from differences in culture and customs. Despite these differences, all cities experience two peaks with a lower value during the morning and afternoon. However, results show differences in the intensity and form of the effects of congestion on accessibility in these metropolitan areas. London, Paris and Rome are the cities where congestion has the greatest impact on automobile accessibility, while the Spanish cities are hardly affected by it.

1. Introduction

Congestion is a problem of the land use/transport/society system. It is usually associated with large metropolitan areas, where the land is a very scarce and highly valuable resource, owing to the basis of their development: the high concentration of people, activities and services (Rode et al., 2014). Congestion seems to be inherent to agglomeration. Therefore, cities usually demand that the infrastructure networks, and their auxiliary venues, such as parking lots, consume the minimum but necessary land, in order to allow them to function properly. A notable aspect of this trade-off in land-use distribution is the tolerance of congestion, since this may become a major obstacle for the development of cities. Some authors assert that the limits of a city or urban region are determined by congestion (Gospodini, 2002; Turok and Mykhnenko, 2007) as the benefits from the concentration of activities may not be sufficient to compensate for the congestion costs (Batty, 2008; Louf and Barthelemy, 2014).

In 2011, each automobile commuter in the major cities of the United States spent 38 h and 19 gal (~72 l) of petrol as a result of congestion, a cost of $818 per traveller for the year (Schrank et al., 2012). In the largest cities of the European Union (EU), time spent due to congestion over the year for standard 30-minute automobile journeys in 2012 ranged from the 59 h, as observed in Madrid, to 97 h in Paris and in Rome (TomTom, 2013a). In economic terms, the annual cost of congestion in the EU was estimated to be 1% of the GDP (Christidis and Ibáñez Rivas, 2012).[1] Congestion also has other negative externalities, such as increased levels of noise, pollution and the potential for accidents and lower life cycles for vehicles (OECD, 1999) and the capacity of the network to cope with incidents (its resiliency). Although congestion is associated with private transport, it could severely affect public road transport services and the social groups dependent on them, as well.

Since the temporal imbalance between demand and infrastructure capacity creates congestion (Ortúzar and Willumsen, 2011), many solutions have been based on increasing network capacity, e.g. new lanes or roads. This type of solution may perpetuate the problem, and even exacerbate or spread it, to other parts of the network and relationships: the "vicious cycle" of congestion (Handy, 1993). It could also create new problems, interfere with bus and pedestrian itineraries, or damage natural ecosystems (Litman, 2014). Congestion could trigger some sort

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[1] All these values are based on free-flow speed, i.e. they are the upper congestion cost limit.

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of reaction in members of the system (Sweet, 2011): from changes in travel routes or schedules – short-term decision – to land use relocation to more resilient spaces – long-term decision (de Abreu e Silva and Goulias, 2009; Levinson and Kumar, 1994; Sweet, 2014). The conventional tools used to evaluate such solutions – that is, transport models – do not usually assess reactions, i.e. they omit the reaction and response times required by different members when faced with new situations (Gifford, 2003; Straatemeier, 2008).

It is essential to find land use and transport policies and suitable indicators that would be able to measure changes in the way the entire system functions and to make it more sustainable. But what are the policies that can achieve such objectives? How can their effects and results be measured? These questions are not to be taken lightly, as they may produce apparently good solutions that, in reality, have undesired effects (Levine and Garb, 2002).

Accessibility measurement could be a good tool to measure current and future situations. It is defined as "the extent to which the land use/transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport(s) mode(s)" (Geurs and van Wee, 2004, p. 128), "the ease with which activities can be reached, given a location, using a specific transport system" (Morris et al., 1979, p. 91), or the ease of interaction with a significant number of opportunities (Breheny, 1978; Bruinsma and Rietveld, 1998; Hansen, 1959). The interest of how transport networks and spatial interaction are related has grown exponentially, and accessibility analysis has played a central role in the agenda of regional and transport research for more than five decades (Reggiani and Martín, 2011). It has also gained ground on institutions that can most effectively wield it as a planning tool (Páez et al., 2012).

Accessibility is a dynamic attribute that changes over time due, for example, to changes in the transport network. Some of these bodies of research have begun using the opportunities offered by new data sources to dynamically analyse accessibility. The most-well known company is Google Maps and its data such as the General Transit Feed Specification (GTFS) for public transport (see Boisjoly and El-Geneidy, 2016; Farber et al., 2014), but that also provide information on the operation of company networks such as Inrix and TomTom. However, not much research has been performed with private transport networks. Previous car accessibility studies have shown the heterogeneous impact of congestion on the spatial distribution of accessibility (Bertolini et al., 2005; Lei and Church, 2010; Vandenbulcke et al., 2009). Out of these papers, of note are those carried out in Toronto by Sweet et al. (2015), using Inrix data. In turn, TomTom®'s data were used by Owen et al. (2016) to compare the impact of congestion on accessibility during morning peak hours in the 50 main cities of the United States of America and Moya-Gómez and García-Palomares (2015) to create dynamic maps, showing the impact of congestion on daily accessibility in the metropolitan areas of Madrid and Barcelona. In none of these cases were the data used to compare cities internationally.

The objective of this article is to analyse the impact of congestion on automobile accessibility values in eight large metropolitan areas in the EU. This paper focuses on a part of the accessibility measures: the effects of recurring congestion, i.e. that is produced despite the absence of incidents (Stopher, 2004). To this end, the TomTom® company's motorway network and its product Historical Speed Profiles® (TomTom, 2013b) was used.

This paper contributes to the literature on accessibility in several different ways. There is not much work that addresses a dynamic analysis of accessibility based on new data sources with global coverage. Here, the dynamic accessibility profile is obtained by calculating travel times for each link according to the time it is used for each route, and not the time when the trip starts ("fixed photo"). It is also possible to know with great accuracy, the temporal accessibility variations regarding the territory, and population. Moreover, the analysis is conducted for the eight large European metropolitan areas, which provides for drawing conclusions on the role of physical characteristics of urban areas (size, density distribution, infrastructure) or social characteristics related to "the use of time" (see HETUS database (Eurostat, 2009)).

This paper also contributes to the perspective of land planning and management. The impact of congestion in accessibility conditions the competitiveness of cities and the quality of life of their inhabitants. Knowing each city's situation in comparison with others encourages the performance of certain actions. In turn, knowing the local impacts of congestion on accessibility distribution inside each city, identifying the temporal profile for each zone, facilitates joint planning for the transport system and distribution of land and equipment use, following Dutch ABC's philosophy (Martens and van Griethuysen, 1999). This provides for planning according to accessibility needs throughout the day, but also for attempting to improve daily accessibility in each area, according to use needs therein.

The paper tried to answer the following research issues: 1) Is it worth using new sources of transport network data and the huge computing efforts of GIS dynamic the impact of congestion on urban accessibility 2) What impact does congestion have on daily accessibility for large European cities? 3) How does congestion affect the internal accessibility distribution in large European metropolitan areas? 4) How can the assessment of dynamic accessibility contribute to more efficient transport and land-use planning?

The paper is structured as follows: Section 2 shows the methodology used in this paper. Section 3 explains the characteristics of the study areas and the details of the data of the network used. The results obtained are given in Section 4. The last section discusses conclusions and possible future research.

2. Methodology

Congestion is a dynamic phenomenon that requires dynamic data and appropriate methodologies to properly study it (Ben-Akiva, 1985). Accessibility changes over time, either due to changes in the transport network or due to variations in the attractiveness of destinations to carry out activities. One of the challenges in the accessibility study is how to improve the introduction of the spatial-temporal dimension, especially analysing daily changes (Geurs and van Wee, 2004; Geurs et al., 2015; van Wee, 2016). However, this issue has hardly been addressed up until now, due to the limitations of traditional data sources.

Previous studies on automobile accessibility and its variation were limited to using static scenarios (see Tilahun et al., n.d.; Vandenbulcke et al., 2009). This methodology is suitable for studies in which all properties of the network links can be considered constant throughout the duration of any trip. It tends to not adequately include the consequences of congestion or its temporal dimension: travel time depends not only on the origin, destination, transport mode and route chosen but on the moment each link of the network is used and its temporal impedance. With new data sources and by adapting traditional methodologies to dynamic reality, it is possible to overcome the conceptual limitations of using static scenarios. As opposed to previous analyses, which only address extreme situations in network operation (peak hour and off-peak hour), incorporating this dynamic perspective provides a view of the temporal change that takes place over the course of the day in infrastructure performance. This is a much more realistic and precise vision of each city's situation. Dynamic accessibility is important for activities and for the population, especially those who are less flexible regarding the consequences of congestion.

In this paper, we used a potential accessibility (Hansen, 1959) zone-based indicator to measure the direct effects of congestion on territorial automobile accessibility, with a negative exponential function: its main point of interest is the transformation of all opportunities into potential units, and it avoids the self-potential problem (Frost and Spence, 1995). The temporal congestion component was only incorporated in the indicator through dynamic estimation of the shortest travel time route, for each origin-destination relationship and the different instances of departure: Results show accessibility values at departure time. They