



From network to services: A comparative accessibility analysis of the Spanish high-speed rail system



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ABSTRACT

High-speed rail (HSR) was originally conceived to connect large metropolitan areas in competition with air transport and suitable for distances between 400 km and 600 km. Since the opening of the first HSR, several studies have been undertaken to evaluate the increased accessibility HSR provides. The accessibility indicators used in these assessments consider the characteristics of the new transport system (speed, layout, stops, etc.) that are fundamentally related to the infrastructure itself. However, many studies on HSR have also highlighted the importance of providing services (timetables, frequencies, and fares). A high-performance infrastructure such as HSR may not reach its full potential in terms of accessibility and reducing travel times unless adequate services are provided.

Considering this service approach, the paper presents a comparative accessibility analysis of the Spanish high-speed rail network based on two indicators: one focused on the potential connectivity between stations (location-based measure) and the other based on actual HSR services (schedule-based measure). This latter calculation has been established taking into account the available time at the destination and the associated travel costs. The use of this measure to assess the accessibility of the Spanish HSR network provides a new perspective on the real usefulness of this infrastructure. Comparing these two measures helps us evaluate the extent to which the services provided in each city allow the HSR network to reach its full potential accessibility. The comparison also highlights many dissimilarities among cities. This method provides a useful tool for transport planning and improving city design strategies.

1. Introduction

Does a city offer good accessibility if it can be reached within very short travel times but is served by only one train per day? To answer this question, it is necessary to assess high-speed rail (HSR) networks from different perspectives. Since its first implementation, HSR has been analysed in transport geography from the perspective of the infrastructure and/or cities' location in the network. Most studies have been built on the concept of the 'shrinkage' of space HSR systems provide in relation to the remarkable reduction in travel times they enable (Spiekermann and Wegener, 1996). This location-based perspective is very useful for understanding changes in accessibility generated by a new infrastructure (Bruinsma and Rietveld, 1993; Monzón et al., 2013) and, especially, to assess the potential access given by the HSR system. Some of these analyses tend to assume that the influence of an HSR system on accessibility extends far beyond each station because these indicators are applied to extensive surfaces, which could be regarded as an overestimation of accessibility in spatial terms (Martínez and Givoni, 2012). When introducing HSR we can assume it will facilitate the ease of moving in and out of a place, but

accessibility, understood as the interaction between land use and the transport network, only increases in combination with services and operations in place (Boisjoly and El-Geneidy, 2017). In this debate, transport planning needs to focus on accessibility as a way of understanding the actual impacts of transport in spatial systems in a wider perspective.

In addition, the development of HSR systems from single lines to a complex transportation mode that encompasses many cities and connections, is leading to high heterogeneity in the quality of the services provided, in terms of the number of accessible destinations, and especially frequencies and ticket fares. In traditional accessibility analyses, the reduction in travel time yields an important improvement in access possibilities, but nowadays, having a faster train does not always imply having a good connection. The possibilities and requirements that the traveller has when using the HSR system must be considered because, from the users' point of view, aspects such as frequencies, fares, adequate schedules and, especially, the useful time required at the destination may become more relevant than the reduction in travel times provided by HSR.

The main objective of this paper is to analyse and compare HSR accessibility by reflecting on the difference between how a location can

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potentially be connected and how this connection is actually achieved by the services provided. This analysis evaluates the differences between accessibility measures, especially with regard to the extent to which the real opportunities the services supplied by the HSR system encompass the potential opportunities the infrastructure offers. This approach is applied to the cities included in the Spanish HSR, which is a relevant case study as the network is highly developed (more than 3100 km, six main lines and 31 stations in the year 2015) and there is a wide range of different services leading to a very heterogeneous situation in terms of the quality of the connections between cities (Moyano and Coronado, 2017). At present, it is not sufficient just to have an HSR station; it is also necessary to achieve a certain quality of operating services (Moyano and Dobruszkes, 2017), which will drive the potential contribution and, in general, the real utility of HSR to a city and its citizens.

This paper is organized as follows. Section 2 presents the approaches to accessibility assessment adopted in the paper, establishing the framework for the methodological procedure, which is developed in Section 3. Section 4 reports the main results and, finally, the paper ends with a discussion and several conclusions in Section 5.

2. Accessibility measures in transport networks

Accessibility is a key analytical concept related to the assessment of transport networks. It has become a hot topic in the field of transport especially with regard to spatial interactions that can be addressed using multiple approaches and conceptualisations. Accessibility is usually defined as a potential, reflecting the ease with which certain movements can occur under different conditions.

2.1. The location-based approach: networks

Indicators based on location focus on places and different access between them in a given transport system. Accessibility measures were commonly calculated based on potential expressions that struck a balance between the attractiveness of accessing a destination and the inconvenience (friction) imposed by the distance of that destination from the traveller's origin. Different indicators are used depending on the specific aim of the study (Bruinsma and Rietveld, 1998; Geurs and van Wee, 2004; Gutiérrez, 2001; Schürmann et al., 1997).

Travel cost measures refer to the degree of connection between two places. They represent the accumulated or weighted cost of travel from a fixed origin to other destinations in the network or a pre-defined set thereof. Such measures are particularly useful when assessing changes in accessibility resulting from new infrastructures or when comparing different scenarios. Spiekermann and Wegener (1996) represented the 'shrinkage' of space in relation to the reduction of travel times between pairs of cities with regard to changes in accessibility in Trans-European networks using what they called time-space maps. In these maps, the distances between cities are proportional not to the physical separation, as in topographical maps, but to the travel times between them. Another type of location-based measure is a *potential accessibility indicator*, in which accessibility is regarded as being proportional to a mass (typically, a population-based or economic index) and decreases with increasing distance, which is generally represented by travel time. Such indexes are usually called gravity-based measures and have appeared in the literature with various functional forms, including power-law, Gaussian and negative exponential functions (Bruinsma and Rietveld, 1993; Spiekermann and Wegener, 2006), and they are applied to assess the changes in accessibility (López et al., 2008; Monzón et al., 2013; Ortega et al., 2012) and to analyse the economic effects and spillovers (Condeço-Melhorado et al., 2011; Gutiérrez et al., 2010) caused by the establishment of a new infrastructure. Finally, *daily accessibility measures*, also known as contour or cumulative-opportunity measures, represent the number of opportunities that can be reached within the constraints of a given travel time, cost or distance (Gutiérrez, 2001; Páez et al., 2012; Spiekermann and Wegener, 1996). All these location-based indicators ultimately compare the potential of different locations in the areas to which

they are applied, thereby evaluating the spatial accessibility conditions provided by a given transport network.

2.2. The schedule-based approach: services

In recent decades, accessibility studies have been returning to the concept of 'time geography' (Hägerstrand, 1970) as a person-based approach to assessing transport networks, which means that the focus is placed on who is accessing the resources provided by the network. In time-space approaches, each individual describes a path, graphically represented by a 'daily prism' and a 'Potential Path Area (PPA)', which is defined by the constraints imposed by certain patterns of human activity (Miller, 1991; Neutens et al., 2010). This idea of *activity pattern* is also used in travel behaviour modelling and activity-based accessibility measures, which forecast people's travel during a whole day's schedule of multiple activities and trips (Bowman and Ben-Akiva, 2001). These activity-based measures incorporate the impact of trip chaining, the full set of activities pursued in a day, and the scheduling of these activities (Dong et al., 2006). Scholars have demonstrated the usefulness of these approaches for evaluating individuals' accessibility to the environment (Kwan, 2004; Schwanen and Dijst, 2003). However, difficulties arise when we need to combine this individual-based approach with network analysis because such a combined analysis needs more complex computations (Tong et al., 2015) and sometimes requires a priori hypotheses concerning traveller profiles. For this reason, in spatial analyses, location-based approaches are much more widely applied.

Several studies have combined both approaches in some manner by including elements that consider various aspects related to both locations and individuals. In schedule-based transportation systems such as transit, rail or air transport, access is limited to fixed timetables and, therefore, the level of service will change throughout the day, depending on the frequencies that will play an important role. On the one hand, the adaptability of the services' timetables to the travellers' needs, that is, the relation between the schedule-based and desired departure times will be a key element in the choice of transport mode (Cascetta et al., 2011). On the other hand, the differences in travel time in schedule-based systems depending on the time of day will have a high influence on accessibility. Many studies have introduced concepts drawn from the space-time approach in the traditional location-based formulations, such as weighted travel times (Shaw et al., 2014) or contour measures. The latter studies are developing continuous accessibility calculations which allow identifying the accessibility variations in different time windows (Fransen et al., 2015; Xu et al., 2015). These continuous measures are normally applied to transit systems, in an urban scale, and focus on identifying the time-dependent accessibility levels to certain facilities such as jobs or educational centres (Boisjoly and El-Geneidy, 2016; Owen and Levinson, 2015), supermarkets (Farber et al., 2014; Widener et al., 2015), health care services (Langford et al., 2016), etc. Even more, recent schedule-based approaches include aspects of social equity, analysing accessibility not only by travel time variations but also by transit costs (El-Geneidy et al., 2016). In general, all these approaches are a very useful tool for analysing schedule-based transportation systems and highlight the importance of the services supplied in accessibility analysis.

When considering long-distance networks, such as rail and air systems, on a national or even international scale, travellers usually buy their tickets in advance and organise their trip by choosing a specific service, as frequencies are not as high as they are in transit systems. In these cases, the accessibility analyses conducted in the literature are generally conditioned by the travellers' needs according to different travel purposes. The first examples are oriented to business trips and are based on the concept of 'contactability', which refers to the number of 'potential contacts' a business traveller can reach from a certain point of origin in a network (Törnqvist, 1970). This approach begins to introduce certain hypotheses regarding individuals' daily activities and their needs for the purpose of establishing an adequate time budget at a destination. Building on these considerations, as part of the European ESPON project, a similar indicator of the number of cities contactable by air and rail

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