Territorial cohesion impacts of high-speed rail under different zoning systems

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ABSTRACT

Large-scale transport infrastructure projects such as high-speed rail (HSR) produce significant effects on the spatial distribution of accessibility. These effects, commonly known as territorial cohesion effects, are receiving increasing attention in the research literature. However, there is little empirical research into the sensitivity of these cohesion results to methodological issues such as the definition of the limits of the study area or the zoning system. In a previous paper (Ortega et al., 2012), we investigated the influence of scale issues, comparing the cohesion results obtained at four different planning levels. This paper makes an additional contribution to our research with the investigation of the influence of zoning issues. We analyze the extent to which changes in the size of the units of analysis influence the measurement of spatial inequalities.

The methodology is tested by application to the Galician (north-western) HSR corridor, with a length of nearly 670 km, included in the Spanish PEIT (Strategic Transport and Infrastructure Plan) 2005-2020. We calculated the accessibility indicators for the Galician HSR corridor and assessed their corresponding territorial distribution. We used five alternative zoning systems depending on the method of data representation used (vector or raster), and the level of detail (cartographic accuracy or cell size). Our results suggest that the choice between a vector-based and raster-based system has important implications. The vector system produces a higher mean accessibility value and a more polarized accessibility distribution than raster systems. The increased pixel size of raster-based systems tends to give rise to higher mean accessibility values and a more balanced accessibility distribution. Our findings strongly encourage spatial analysts to acknowledge that the results of their analyses may vary widely according to the definition of the units of analysis.

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1. Introduction

One of the key goals of transport policy is to achieve cohesion, which is intimately linked with economic and social policy concerns. At the strategic planning level, cohesion motivations frequently justify the construction of high-speed rail (HSR) projects (Chen and Hall, 2011; Garmendia et al., 2011; Gutiérrez et al., 2010, 2011; López et al., 2008). These projects – with the trans-European networks (TEN) as a prime example – are aimed at reducing the disadvantages supposedly triggered by poor accessibility in peripheral and/or landlocked locations (Bröcker et al., 2010; Gutiérrez et al., 2011; López et al., 2008).

In transport-related studies, cohesion impacts refer to the changes elicited by a new infrastructure on the distribution of a given variable – frequently the accessibility to certain destinations. A positive effect appears if this distribution becomes more balanced; the opposite holds if the new infrastructure results in a more polarized distribution, therefore increasing disparities (López et al., 2008; Ortega et al., 2012; Ribeiro et al., 2010). This distribution is usually investigated from two main perspectives, i.e. social and spatial. On the one hand, the distribution of accessibility is investigated among different groups of people, and refers to concepts of “social equity” and/or “social exclusion”. These studies follow an “individual” perspective, and are mostly carried out at micro levels, such as at the urban or metropolitan scale. On the other hand, when the focus is on the distribution of accessibility between locations, the concepts used are “spatial equity” or “territorial cohesion”. In this paper, we will use the term “territorial cohesion” – following our previous research (López et al., 2008; López and Monzón, 2010; Ortega et al., 2012) – to refer to the degree of dispersion of the spatial distribution of accessibility.

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Transport planners and spatial analysts acknowledge the risk that high-speed rail (HSR) projects may produce negative territorial cohesion impacts. The methodologies developed to assess the polarizing risks of HSR are the subject of several important recent works of research (Campos and de Rus, 2009; Chen and Hall, 2011; Chang and Lee, 2008; Martin and Reggiani, 2007; Martínez and Givoni, 2009; Monzón et al., 2013; Ortega et al., 2012; Ureña et al., 2009). Most of these studies evaluate cohesion impacts of HSR using spatial analysis tools to assess changes in the spatial distribution of accessibility. These studies compute the accessibility indicators by applying the latest spatial analysis techniques, generally implemented in Geographic Information Systems (GIS) (Higgs et al., 2012; Páez and Scott, 2004; Páez et al., 2012).

Our research work investigates the influence of alternative spatial representations on the measurement of territorial cohesion results, focusing on high-speed projects. Given the scope of this research topic, and due to space limitations, we have chosen to present our research findings in two different articles. In our previous paper (Ortega et al., 2012) we investigated the influence of the choice of scale on the territorial cohesion results of HSR, and found significant differences depending on whether the assessment was carried out at the regional, corridor, national or spillover planning levels. This paper completes our research work by addressing the question: to what extent are territorial cohesion impacts influenced by the zoning system configuration and contains a methodological approach that defines different alternative zoning configurations. We applied this methodology to a case study of a 670-km HSR corridor in Spain. The sensitivity of the territorial cohesion results is assessed using five alternative zoning systems. The paper is structured as follows. The next section provides a background to the investigation, with the review of the research into the importance of zoning issues in spatial analysis models. Section 3 describes the methodological approach used in this paper, integrated in a GIS. The methodology is tested in Section 4 in a case study: the Galician HSR corridor, part of the Spanish Strategic Transport and Infrastructure Plan 2005–2020 (PEIT) (Ministério de Fomento, 2005). Finally, Section 5 contains the conclusions of our analyses and the corresponding recommendations for spatial planners.

2. Research review

2.1. The selection of the zoning system

Any exercise in spatial analysis involves two main decisions on how the space continuum will be implemented, and how its characteristics will be stored in the spatial analysis model: the first is the scale of analysis or planning level - i.e. the definition of the boundaries of the study area; and the second is the particular zoning system configuration, i.e. how the study area will be structured and modelled.

When confronted with the above two decisions, the analyst faces the so-called "modifiable areal unit problem" - MAUP - (Fotheringham and Wong, 1991; Openshaw and Taylor, 1984). Actually, these two choices correspond to the two MAUP components of scale and resolution. The wide array of definitions available for these two components leads to misconceptions and confusion. As defined by Lam and Quattrochi (1992), the scale component refers to the "extent" of the map size, sometimes called the "geographic scale"; while "grain" is the spatial resolution of a map, which refers to the definition of areal units - also called "zones", or "units of analysis".

The work by Taaffe et al. (1963) provides an early example of the implications of the MAUP in transportation-related studies. These researchers were confronted with the definition of the "modifiable areal reporting units" when measuring transport expansion in underdeveloped countries. As they state: "(...) Internal variations in size of reporting units affect the degree of apparent correlation between variables. Even if the sizes of reporting units were uniform, different correlations and different regression equations would be obtained for different levels of areal aggregation (a grid cell of 10 square miles as opposed to 100 square miles, for instance)" (Taaffe et al., 1963, p.517).

There are two main options for defining the limits of areal units: raster and vector-based methods. In raster methods the space is mostly modelled as a grid of square cells of a given size. The choice of cell size is generally left to the analyst and refers to the resolution of the analysis. In vector-based methods, the space is modelled as a set of contiguous polygons which may vary in size and shape. The boundaries of these polygons are frequently selected from already existing administrative configurations, such as census tracts or zip codes. This process results in the configuration of a particular zoning system. In addition, in many cases values are available for only some of the locations, so these values need to be "extended" throughout the whole territory. The methodology used for this process also influences the zoning system. The usual practice is to apply the interpolation techniques present in the GIS. Interpolation methods based on dasymetric approaches are crucial for population density maps (Petrov, 2012), and are being rapidly improved with new techniques (Mennis and Hultgren, 2006; Silverman, 1986).

The research on the implications of the selection of this zoning system in transport-related studies is reviewed below.

2.2. Zoning issues in transport-related spatial analysis models

There is a wide array of spatial analysis models - working with GIS - that are sensitive to the choice of zoning system (see e.g. Fotheringham and Wong, 1991; Kwan and Weber, 2008; Páez and Scott, 2004), some of which are commonly used in research disciplines related to transport planning. Recent contributions in this field are reviewed below.

A first related discipline involves mapping sciences research and landscape pattern analysis models. Significant research on landscape models has addressed the implications of the choice of "grain size" (see e.g. Baden et al., 2007; Lam and Quattrochi, 1992; Qi and Wu, 1996; Wu, 2004, for a review). There have been important methodological advances in this field, such as e.g. the work by Nakaya (2000), who proposes clustering areal units according to explanatory variables. He successfully applies this methodology to map elderly men's mortality patterns in the Tokyo metropolitan area.

Another relevant discipline is traffic demand modelling. There is empirical evidence to suggest that model results are influenced by the arbitrary delimitation of the units of analysis, i.e. traffic analysis zones (TAZs) (see e.g. Chang et al., 2002; Martínez et al., 2009; Viegas et al., 2009). The definition of the size and boundaries of TAZs significantly affects travel demand estimates (Ding, 1994, 1998; Kwan and Weber, 2008), particularly when the number of TAZs is small. For example, in a study of travel mode choice in Boston, Zhang and Kudadja (2005) found that predictions of travel demand were sensitive to the choice of data aggregation methods of urban form variables such as population density. Another example is the work by Chang et al. (2002), which used different zoning structures and levels of network detail to assess the effects of zoning structure and network detail on traffic demand modelling.

Spatial interaction models also suffer from the delimitation of areal units (Putman and Chung, 1989). This is the case of location-allocation (LA) models, as the output of the models - i.e. the locations of "services" - are sensitive to the zoning structure used for input data and travel cost calculations (Guo and Bhat, 2004, 2007). An interesting contribution to
this research gap is the work by De Palma et al. (2007), who investigated aggregation bias and zoning-related issues in recent research in the Paris metropolitan region. They first assessed the degree of inequity of the local amenities at three geographical levels – district, commune and grid cell – and developed a residential location choice model at the grid cell and commune level. They found the model fits the data moderately better at the smaller grid cell scale than at the commune level.

Another relevant example is the multiscale approach by Guo and Bhat (2004), used for residential location choice modelling. Using a similar approach, Boussauw et al. (2011) measured spatial separation processes related to commuting. They recommend the combined utilization of two different spatial entities in order to capture the full range of spatial transformation processes. A final example is the research by Guo and Bhat (2007), which represented “neighbourhoods” in a residential location choice analysis. They used three alternative ways of operationalising the representation of residential neighbourhoods and recommended the best option based on their findings.

Finally, the influence of zoning issues has barely been assessed in accessibility studies, despite the long list of studies on accessibility from the perspectives of spatial and social equity (see Monzón et al., 2013 for a detailed review). Most of the few notable exceptions have been conducted at micro levels, and tend to be related to urban facilities such as accessibility to healthcare delivery (Langford and Higgs, 2006), dialysis service centres (Yang, 2006), urban parks (Omer, 2006) or food access (Sparks et al., 2011). These studies mainly concentrate on accessibility to certain amenities or facilities where a particular service is provided (such as a healthcare facility), or where some utility is obtained (e.g. urban parks or green spaces).

The next section describes our contribution to this research field, and outlines a methodological approach for assessing the degree of spatial cohesion of HSR accessibility under a set of alternative zoning configurations.

3. Methodological approach

Accessibility measures have been used to address the territorial cohesion effects of a new HSR corridor and how they are influenced by the configuration of the zoning system (Gutiérrez et al., 2010, 2011; López et al., 2008; Ortega et al., 2012). The proposed methodology comprises of two stages, as shown in Fig. 1. The first stage calculates the accessibility improvements caused by HSR, and the second analyses the impact on territorial cohesion under different zoning systems. The whole procedure is supported by a GIS.

Stage 1 includes the accessibility calculations. A new HSR project (in red in Fig. 1) modifies the characteristics of the transport network from \(T^0\) (without HSR, i.e. Scenario 0) to \(T^S\) (with HSR, i.e. Scenario S). The corresponding accessibility values \((PA^0\) and \(PA^S\)) are calculated.

Stage 2 evaluates the impact on territorial cohesion, and calculates the dispersion of the accessibility values in Scenario 0 and Scenario \(S-PAD^0\) and \(PAD^S\), respectively. Finally, the impact is calculated by evaluating the change between them \((TC^S-0)\).

The aim of this research work is to assess the influence of the choice of zoning system on the resulting cohesion impacts; stage 2 is therefore repeated for a series of zoning systems.

3.1. Stage 1: Accessibility calculations

The accessibility calculations are the same as those in Ortega et al. (2012). An economic potential accessibility \((PA)\) formulation (Eq. (1)) was selected, as this is considered the most suitable due to its proven consistency and applicability in transport planning studies at strategic levels (Gutiérrez et al., 2011; López et al., 2008; Martín et al., 2004).

\[
PA_i^n = \sum_{j} \frac{P_j}{I_{ij}}
\]

(1)

where \(PA_i^n\) represents accessibility for each origin \(i\) to \(j\) destinations in scenario \(n\), \(P_j\) is the population at the destination \(j\), and \(I_{ij}\) is travel impedance (in our case, travel time) between each origin-destination pair. A detailed description of the generalized travel time calculation is given in López (2007) and Ortega (2009). GIS process calculation is shown in detail in Ortega et al. (2011).

The accessibility values \((PA^0\) and \(PA^S\)) are calculated in Scenarios 0 and S, and are denoted \(PA^0\) and \(PA^S\), respectively.

3.2. Stage 2: Territorial cohesion analysis under different zoning systems

As in López et al. (2008), López and Monzón (2010) and Ortega et al. (2012), the statistical index selected to measure the dispersion of accessibility values is the coefficient of variation. In Ortega et al. (2012), this is denoted the Potential Accessibility Dispersion index \((PAD)\), and we maintain this name here. Its formulation is shown in Eq. (2).

\[
PAD^z = \sigma^z \frac{\sigma^z}{\sum PA^z}
\]

(2)

where \(PAD^z\) is the coefficient of variation in scenario \(z\) using zoning system \(z\) and \(\sigma^z\) is the standard deviation of \(PA^z\) values, weighted by the population \(P_i\). Higher \(PAD\) values represent more polarized
accessibility distributions, whereas lower PAD values show more balanced accessibility patterns.

The method of calculating PAD values depends on the zoning system used.

The definition of each type of zoning system depends on the available data and how they represent the territory. This will depend on the method of data representation used (vector or raster), and the level of detail (cartographic accuracy or cell size). In our case, the data representation method determines the method of calculating PAD values.

With a vector model, the accessibility calculation provides a value for each origin. Each origin also has a population value. The PAD index is calculated from these values according to Eq. (2), and has as many PA* and P-values as origins.

With a raster format, values are given to all the cells into which the territory is divided. Once the population and accessibility values are "extended" throughout the territory using CIS capabilities, the territory is divided. The accessibility calculation provides a value for each origin. Each origin also has a population value. The PAD index is calculated from these values according to Eq. (2), and has as many PA* and P-values as cells into which the territory is divided.

Finally, the change in territorial cohesion between Scenario S and Scenario 0 due to the new HSR project is measured by means of the Territorial Cohesion index (TC), following Eq. (3):

\[
TC_{z}^{S-0} = \frac{PAD_{z}^{S} - PAD_{z}^{0}}{PAD_{z}^{0}} \times 100
\]

where TC_{z}^{S-0} values are calculated for each aggregation method z from PAD_{z} values (PAD_{z}^{0} in Scenario 0 and PAD_{z}^{S} in Scenario S, respectively). In any given zoning system, a positive TC value indicates an increase in territorial cohesion between scenarios; whereas a negative TC value signals a polarizing effect, i.e. a reduction in territorial cohesion.

In summary, Fig. 2 shows the methodology proposed for Stage 2 for each data zoning system. The influence of the zoning system on the resulting territorial cohesion impact can be seen by comparing the TC_{z}^{S-0} values.

4. Case study: the Galician HSR corridor in Spain

This section contains an example of the application of this methodology and an analysis of the results. The infrastructure investment under consideration (the "HSR project" in Fig. 1) is the same as in Ortega et al. (2012), namely the Galician HSR corridor (Fig. 3), with nearly 670 km and a commercial speed of 220 km/h, included in the Spanish Strategic Plan of Transport and Infrastructure 2005-2020 (PEIT) (Ministerio de Fomento, 2005). Approximately 60% of the corridor is already in operation, and the remainder is currently under construction.

The population distribution is quite dispersed. The main urban agglomerations (Madrid and La Coruña) are at the ends of the corridor, whereas less populated areas are located between them. The corridor is characterized by agglomerations with low populations; only 11% of the total agglomerations (1105) have more than 10,000 inhabitants. The average size of the municipalities is 48 km², giving a population density of 212 inh./km². However if we consider the agglomerations with less than 10,000 inhabitants (89% of the total), the population density decreases to 29 inh./km².

4.1. Stage 1. Accessibility calculations

Fig. 3 shows the HSR corridor with the location of the HSR stations. It also shows the main roads present in the study area. The 7° network corresponds to the situation in 2005 – i.e. the base year of the Spanish PEIT – and the 7° network corresponds to the situation in 2005 plus the Galician HSR corridor. The land-use characteristics of both situations are identical and follow the prognosis for the 2020 situation, i.e. the planning time horizon of the PEIT.

The study is focused at the corridor planning level, delimited by the borders of the NUTS-3 regions crossed by the HSR project. This approach was selected because the most important accessibility improvements are concentrated in the proximity of the HSR project (Ortega et al., 2012).

The accessibility values are calculated for 1105 municipalities within the study area, which are also the possible destinations. The accessibility value for each origin is calculated considering all destinations. Using a dense GIS-based road and rail network, for each arc, the length and travel time (according to the type of road or railway) were also recorded, as in previous similar studies (López et al., 2008; Ortega et al., 2012).

The road, conventional railway and HSR networks are considered to be independent. Municipality centroids – which serve as the population and accessibility values as origins.
the starting and destination points – and stations are also independent. The integration of the networks with population centres and stations is as follows: the municipality centroids are displaced to the nearest road, using a snapping CIS tool. The stations have also been displaced to the nearest road. The railway lines then subsequently need to be displaced to coincide with the stations. Finally the road network, the conventional railway network and the HSR network were linked together to create the network nodes. The change of transport modes occurs at the railway stations.

The travel time is equal to the sum of the times of the arcs travelled, along the minimum path, according to Dijkstra’s (1959) algorithm. The total travel time is calculated as the sum of three travel times: (a) the travel time by road from the origin (municipality centroid) to the nearest station; (b) rail travel time; and (c) the travel time from the station nearest the destination to the destination itself. Displacement along the railway network is subject to a series of impediments, such as the frequency of service.

The potential accessibility value \( PA_i \) of each municipality \( i \) is computed using Eq. (1). Accessibility was calculated using two GIS network accessibility toolboxes,\(^3\) which operate in ArcInfo. The GIS accessibility calculation process follows the method described in Ortega et al. (2011).

Fig. 4 shows percentages of change in accessibility between both scenarios in the corridor. This reveals a very significant improvement in accessibility along the whole corridor, and indicates that cities with a HSR station obtain a high improvement because their initial accessibility values were low. Madrid, the location of more than half the population in the corridor, has a very high influence. The extension of the areas with the greatest improvement depends on their distance to Madrid and on the quality of the transport network (rail or road) from other cities to the HSR station.

4.2. Stage 2. Analysis of territorial cohesion impacts under different zoning systems

4.2.1. Description of the zoning systems

Cohesion impacts are assessed using five zoning systems at the corridor planning level. One is a vector-based system and the other four are raster-based systems. The zoning systems affect the way the values of population and accessibility – necessary to measure \( PAD \) values – are used. For each case, \( PAD_Z \) (Eq. (1)) is calculated taking into account the municipalities included in the planning level in Scenario 0 and Scenario 5 in order to calculate \( TC_{Z} \) (Eq. (2)).

The alternative zoning systems are built as follows (see Table 1):

1. Population and accessibility values are assigned in the centroid of the municipality (vector). Named: “centroids”.
2. Population is evenly distributed within the municipality (raster). Named: “homogeneous population”.
3. Population is dasymetrically distributed\(^4\) within the municipality (raster). Named: “dasymetric population”.

In addition, two different cell sizes have been selected in the raster methods: 5 km and 10 km. These pixel sizes represent 25 km\(^2\) and 100 km\(^2\) respectively. The average area of the municipalities in the corridor is 48 km\(^2\). These two pixel sizes thus allow different levels of detail to be compared in the representation of the municipalities.

We therefore have five zoning systems. The systems have advantages and disadvantages. Usually population and accessibility data are in the vector format, but a vector system may provide a less satisfactory representation of the territory than raster systems, which may offer more accurate estimates.

\(^3\) AccesTüs.aml (Network Accessibility Analysis Toolbox), developed by Santiago Mancebo in 2007 and TITIM-GIS tool (Transport Infrastructure Territorial Impact Measurement GIS tool), developed by Emilio Ortega, Santiago Mancebo and Isabel Otero in 2010. Not published.

\(^4\) Dasymetrically distributed: A thematic cartography technique that allows the use of underlying ancillary data to enhance population distribution and density maps. It permits attribute data to be accurately distributed in the territory.
than vector zoning systems. The "Homogeneous population" raster system supposes that uniform distribution is a valid assumption. In a densely-populated city this may be so, but in a rural setting the population is almost certainly concentrated into small settlements surrounded by unoccupied land (Langford and Higgs, 2006). "Dasymetric population" offers a more realistic representational model in a large territory as it considers that population decreases with the distance from the centre of the urban settlements. In a rural situation, dasymetric population maps provide a better picture of the places people actually reside as they redistribute variables within the limits of their tabulation zone and thereby ensure that the map reflects the real population distribution (Langford and Higgs, 2006), assigning most of the population to the urban settlement and little or no population to natural or agricultural areas.

In our case, in the vector-based system, the population and calculated accessibility values of the municipalities are assigned to the municipality centroid (Monzón et al., 2013; Ortega et al., 2011; Ortega et al., 2012). There is therefore one accessibility value per municipality (see Fig. 5-left), and 1105 values in the corridor.

Raster-based zoning systems consist of allocating both the population and the accessibility values in the whole area of the municipality. Only the accessibility and population values are in the centroids. In these systems the information format is a grid, and values therefore need to be assigned to each cell in the whole territory. The assigned population and accessibility value in the municipalities' centroids are distributed using GIS capabilities throughout the whole area of the municipality.

In both raster systems, the accessibility values for the whole territory are obtained using interpolation techniques from the municipalities' centroid values. Inverse distance weighted (IDW) interpolation from ArcGIS 9.X was selected. IDW determines cell values using a linearly-weighted combination of a set of sample points. The weight is a function of inverse distance. The output value for a cell is limited to the range of the values used to interpolate (Watson and Philip, 1985).

The difference between the two raster systems is based on population distribution. In the "homogeneous population" system, the population is divided by the number of cells in the municipality, and the population value assigned to each cell is the same in all the cells in the municipality (see Fig. 5-centre).

In the "dasymetric population" system, the population distribution follows interpolation density GIS tools, which assigns population values throughout the territory depending on population agglomerations and the distance to them. In this case, the ArcGIS 9.X kernel density tool was used. It is based on the quadratic kernel function described in Silverman (1986). It calculates a magnitude per unit area from point features to fit a smoothly tapered surface to each point. This assigns high population values to the cells close to densely populated areas, and no population to cells located in areas without population (see Fig. 5-right).

### Table 1

<table>
<thead>
<tr>
<th>Zoning systems considered.</th>
<th>GIS format</th>
<th>Zoning system</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VECTOR</td>
<td>Population concentrated in the centroids</td>
</tr>
<tr>
<td>2a</td>
<td>RASTER</td>
<td>Homogeneous population distribution</td>
</tr>
<tr>
<td>2b</td>
<td></td>
<td>Pixel 10 km</td>
</tr>
<tr>
<td>3a</td>
<td></td>
<td>Dasymetric population distribution</td>
</tr>
<tr>
<td>3b</td>
<td></td>
<td>Pixel 10 km</td>
</tr>
</tbody>
</table>

4.2. Results. Corridor level analysis

The effect on territorial cohesion (TC) at the "corridor level" is evaluated for the five zoning systems. The resulting changes in the PAD values are shown in Table 2. Table 2 includes – in each aggregation method – the mean accessibility values and the corresponding accessibility changes between scenarios.

Comparing the accessibility change and TC values using zoning systems for "homogeneous population" and "dasymetric population", the results show that the choice of one of these systems has little influence on TC and accessibility change. Considering a pixel size of 5 km, the accessibility change values are 19.69% and 18.55% respectively, implying a difference of 5.8%; in the case of TC the corresponding values are 21.97% and 21.06% (a difference...
Fig. 5. Population distribution in each zoning system. Left: municipality centroid contains the population value. Centre: population is evenly distributed within the municipality. Right: population is dasymetrically distributed within the municipality.

Table 2
Territorial cohesion analysis under different zoning systems.

<table>
<thead>
<tr>
<th>Zoning system</th>
<th>Number of data/average area</th>
<th>Scenario</th>
<th>Accessibility (PA)</th>
<th>Territorial cohesion impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Min. value</td>
<td>Max. value</td>
</tr>
<tr>
<td>Centroids</td>
<td>1105</td>
<td>0</td>
<td>20,733</td>
<td>26,226</td>
</tr>
<tr>
<td>Homogeneous population</td>
<td>Pixel 5 km</td>
<td>2121</td>
<td>0</td>
<td>16,620</td>
</tr>
<tr>
<td></td>
<td>Pixel 10 km</td>
<td>530</td>
<td>0</td>
<td>22,131</td>
</tr>
<tr>
<td>Dasymetric population</td>
<td>Pixel 5 km</td>
<td>2121</td>
<td>0</td>
<td>16,620</td>
</tr>
<tr>
<td></td>
<td>Pixel 10 km</td>
<td>530</td>
<td>0</td>
<td>22,131</td>
</tr>
</tbody>
</table>

The values are similar with a pixel size of 10 km, and produce a difference of 1.9% in accessibility change values and 1.9% in TC values. These values point to the conclusion that the choice of either of these zoning systems and the pixel size has little influence on the results.

For each pixel size, the maximum and minimum values are identical in these two raster zoning systems. This is because the accessibility value calculations do not vary from one system to another. Differences can be observed when comparing values for different pixel sizes. For a 5 km pixel size, the extreme values are not smoothed by the nearest values, as occurs for the 10 km pixel (its value aggregate 4 pixel of 5 km). The maximum and minimum values are thus higher and lower, respectively, than for the 10 km pixel.

The results differ depending on the size of the municipality. If the municipality is larger than the pixel size, the population, accessibility and TC values are close to reality. However, if the municipalities are smaller than the pixel size, the population, accessibility and TC values are obtained by aggregating the values of several municipalities, resulting in a loss of information.

A preliminary comparison between the values obtained with the vector zoning system “centroids” – commonly used in the most important accessibility studies (Garmendia et al., 2011; Gutiérrez et al., 2010; Monzón et al., 2013; Ortega et al., 2011, 2012; Ribeiro et al., 2010) – and raster-based systems reveals important differences. The “centroids” system produces a higher mean accessibility value than any of the four raster alternatives. Raster systems provide changes in accessibility values of between 18.55% and 19.69%, around 22% higher than “centroids”, which increase the amount by 15.23%. The comparison of the impact on territorial cohesion (TC<sub>−0</sub>) shows that the “centroids” value is 16.51% and the raster systems value is between 21.06% and 21.97%, implying a difference of over 27%. These data point to the conclusion that there are clear differences when using either a vector or raster format.

The results also differ depending on the distribution of the population in the municipality. In sparsely populated municipalities, the “homogeneous population” zoning system is suitable. However, in most municipalities the population tends to be concentrated and to decrease with distance. Therefore the closest zoning system to reality is “dasymetric population 5 km”, as it assigns
population values throughout the territory with density techniques which depend on population agglomerations and the distance from them. A comparison of the values obtained using the “centroids” system highlights important differences. Improvements in accessibility differ by 21.8%, and there is a 27.6% difference between TC values.

5. Conclusions

The relevance of the selection of the zoning system has not been sufficiently assessed in the methodologies for calculating accessibility. Zoning choices have been claimed to have important implications for accessibility results. These implications apply not only to accessibility values, but also to their spatial distribution – i.e., territorial cohesion issues. This paper further investigates these issues by evaluating the sensitivity of accessibility computations to alternative zoning systems. In particular, major research efforts are being devoted to investigating the potential risk that HSR may induce imbalances in the distribution of accessibility (López et al., 2008; Monzón et al., 2013). The selection of the Galician HSR corridor as our case study responds to these concerns about the polarizing risks of HSR.

The findings in this paper are consistent with our previous article on the relevance of scale issues (Ortega et al., 2012). Evidence from both research pieces strongly encourages planners to conduct an analysis of the sensitivity of cohesion results to changes in MAUP parameters, i.e., in scale and zoning configurations (Fotheringham and Wong, 1991; Openshaw and Taylor, 1984). The incorporation of this analysis would result in a range of cohesion results, rather than just a single value, thus providing planners with information on the extent to which results are sensitive to the selection of the zoning system. The advisability of this analysis is borne out by recent research pieces on the implications of MAUP in accessibility studies (see e.g., De Palma et al. (2007), Higgs et al. (2012), Langford and Higgs (2006), Ortega et al. (2012) and Yang (2006)). The research in this paper follows this approach and includes this analysis of sensitivity to alternative zoning systems.

We calculated the accessibility indicators of the Galician HSR corridor under five alternative zoning systems and then assessed their corresponding territorial distribution. The results show that the choice between a centroid-based and a raster-based system has important implications which affect both the resulting accessibility values and their spatial distribution. The “centroid” system produces a higher mean accessibility value and a more polarized accessibility distribution than any of the four raster alternatives. Centroids are defined as the points concentrating the whole population within given administrative boundaries. Hence, accessibility tends to be higher in the area around centroids, as highly dense areas tend to have better access to the transport infrastructure network. A consequence of this is that in the “centroids” system both the accessibility improvement value and territorial cohesion improvement change are lower than in the raster systems. The results fall from approximately 19% to 15% – in terms of relative accessibility improvements –, and from 21% to 16% – in terms of cohesion change – when using a centroid or raster system, respectively. It can therefore be concluded that centroid-based methods tend to show more polarized results than raster-based alternatives.

In the case of raster-based alternatives, we examine both the influence of the population allocation method and the pixel size. On the one hand, the choice of alternative population distribution methods – “homogeneous” vs. “dasymetric” – does not have significant implications on mean accessibility values, relative improvements or territorial cohesion impacts. However, for a given scenario, the “homogeneous” allocation of population tends to result in lower mean accessibility values than with “dasymetric” methods. This is because “dasymetric” distributions concentrate more population mostly in pixels with higher accessibility – i.e. near the centroids. On the other hand, increased pixel size tends to result in higher mean accessibility values and a more balanced accessibility distribution, and selecting a larger pixel size tends to “smooth” the distribution of accessibility values, as the differences between the extreme values of the distribution are narrowed. Lastly, mean accessibility improvements and territorial cohesion impacts between scenarios do not show significant sensitivity to the choice of pixel size. Our findings support the fact that – despite their differences – no generalized conclusions can be reached on the effects of the choice of population distribution method and pixel size when implementing raster systems.

The proposed approach can be applied both at earlier planning stages and once the HSR is in operation. Evidence from this paper suggests that the magnitude of the deviations due to the choice of zoning system will depend on the specific characteristics of each case study: mainly population distribution, location, and the quality of the access to HSR stations. An ad hoc analysis of the sensitivity of cohesion results to alternative zoning systems is therefore highly recommended at any stage of the planning. Depending on the stage at which the methodology is applied, planners and practitioners will be able to design different policy measures to minimize HSR polarization risks. These may include changes in the location of HSR stations, improvements in the transport infrastructure connecting to particular HSR stations, or an increase in public transport services to HSR stations.

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References
