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# **Measuring territorial cohesion impacts of High-Speed Rail at different planning levels**

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## **Abstract**

The conflict of efficiency vs. cohesion objectives is of particular interest in the transport planning field. If the only objective was the maximization of economic growth, the ‘most efficient’ policy would attempt to concentrate the economic activity in several strong regional centres and interconnect them with a high quality transport network, such as High-Speed Rail (HSR). However, this policy would have a negative impact on territorial cohesion, as it would lead to more polarized spatial development patterns.

In this context, this research work presents a methodology in which impacts on territorial cohesion of HSR investments are assessed using an accessibility approach. Cohesion impacts are assessed at different planning levels: local, regional, corridor and national levels, as well from the spillover effects perspective. Changes in the territorial distribution of accessibility are used as the main input variable in order to assess cohesion effects. Results are derived from the combination of graphical and statistical analyses, supported by a Geographical Information System (GIS).

The methodology is applied to the development of the Galician (North-western) HSR corridor, with nearly 600 km, included in the Spanish PEIT (Strategic Transport and Infrastructure Plan) 2005-2020. Results show positive cohesion effects at the national, corridor and spillover levels, whereas at the regional level polarization effects appear in some particular regions. Recommendations stemming from these results are included as part of the analysis.

## 1. Introduction

Transport assessment methodologies have traditionally focused in “efficiency impacts”, such as the measurement and monetization of reductions in cost or travel time, which are usually dealt with in cost-benefit or multicriteria analysis. However, other “wider policy impacts”, such as cohesion, (commonly referred to as equity impacts) are increasingly relevant for transport planners and policy makers, encouraged by the concern to include the three objectives of transport sustainability –i.e. economic, social and environmental- in the planning process.

Of particular importance is the inability of assessment methodologies to deal with the conflict of *efficiency* (economic) vs. *cohesion* (social) objectives. If the only objective was the maximization of economic growth, the best solution would attempt to concentrate the economic activity in several strong regional centres and interconnect them with a high quality transport network. However, this strategy would have a negative impact on cohesion, as it would lead to more polarized spatial development patterns (EC, 1999): richer regions would gain more and lagging regions would result in a comparative worse situation. How can assessment methodologies solve this conflict? Although this question is still on the research agenda, it is widely agreed that the design of transport strategies may need to be modified to ensure that both an acceptable degree of cohesion is retained, while economic growth is maximised (Button, 1993).

In the particular case of High-Speed Rail (HSR), according to efficiency objectives in isolation, HSR stations would be located in densely populated centres, whereas fewer stations would be located in lagging regions. In addition, the operation of the new HSR network may result in the closure of certain conventional rail services which will be no longer competitive. This will reinforce the aforementioned polarization pattern and therefore result in negative cohesion impacts. Aware of these polarization risks of HSR, transport policy documents at different administrative levels –from the local to the European scale- are increasingly demanding the inclusion of cohesion impacts in HSR assessment methodologies. However, there is no consensus on how these impacts should be measured.

In addition, cohesion impacts have a strong spatial component, i.e. they depend on the definition of the study area in which the impacts are measured. This spatial component is of special relevance in large scale transport infrastructure investments such as HSR, in which many administrative levels are involved. In other words, it is therefore important to define the planning level at which cohesion effects are measured, as it may occur that simultaneously e.g. both a positive effect at the regional level and a negative effects at the national level would take place when a new HSR corridor is implemented.

In this context, this paper moves one step forward in this research direction with the proposal of a methodology to assess territorial cohesion implications of transportation investments at different planning levels. The structure of the paper is as follows. The second section after this introduction includes some general concepts on cohesion and existing attempts to measure cohesion impacts through accessibility analysis. The third section describes the proposed methodology, which is subsequently applied in section 4 to a case study: the Galician HSR corridor, included in the Spanish Strategic Transport and Infrastructure Plan 2005-2020 (PEIT). Finally, a discussion and future research directions are included in section 5.

## 2. The measurement of cohesion effects

### 2.1. Conflicts at different planning levels

The definition of transport planning objectives may raise conflicts both at a ‘vertical’ level, i.e. between the different stakeholders involved, and at a ‘horizontal’ level, i.e., between the different systems interrelated with the transport system (Bröcker et al., 2004).

This paper focuses on the first ‘vertical level’, in which the increased promotion of the public consultation stage has allowed for the involvement of individuals (experts, political entrepreneurs) or specific organizations (ad hoc structures, citizen organizations), which have different priorities. This demands a more transparent and open procedure for the definition of planning objectives (Voogd and Woltjer, 1999) which balances the information needed by different stakeholders.

Furthermore, there is a risk of disagreement, lack of congruence and different preference strength between DMs of the different territorial levels of competencies involved, which may achieve the degree of political concerns (Tsamboulas et al., 1998; Beinat, 1998; Ollivier-Trigalo, 2001). Furthermore, any transport policy involves significant spillovers (Pereira and Roca-Sagales, 2003) and creates further risks of overlapping benefits and double counting at different stages of the appraisal process (Grant-Muller et al., 2001), which require a certain degree of ‘multi-level’ coordination (Bröcker et al., 2004). In this sense, the transport planning process of the trans-European transport networks (TEN-T) constitutes a successful example of integrating conflicting European, national, regional and even local objectives (Turró, 1999; Button, 1993).

### 2.2. The inclusion of cohesion impacts in transport assessment methodologies

Improvement of transport infrastructure leads both to a reduction of transport costs and substantial redistribution effects among social groups and regions. This issue is linked with the trade-off between ‘generative vs. *distributive* growth’ (Rietveld and Nijkamp, 1993), ‘efficiency vs. *equity*’ (Bröcker et al., 2004), or ‘competitiveness vs. *cohesion*’ (EC, 2004) effects of transport infrastructure. The three terms: distributive, equity and cohesion impacts are used as almost synonyms in the literature.

Cohesion motivations have provided the main justification for financing infrastructure investments in peripheral and/or landlocked regions at the EU level, as stated in different EU policy documents (see e.g. EC, 1999; EC, 2004). However, their inclusion in appraisal methodologies is uneven and scarce, as most CBA studies concentrate on *efficiency* considerations. However, it has been suggested that some allowance for distributional impacts should be incorporated in CBA studies (Button, 1993), or in a MCA framework complementing the CBA (Banister and Berechman, 2003).

The first difficulty in measuring cohesion stems from the vagueness of the definition of the term. Not even in official European Community documentation is there a precise description of what is behind cohesion. Moreover, it is frequent to find other related terms, such as ‘convergence’ in EU policy documents, which aims at the gradual reduction of regional differences (EC, 2004). This vagueness frequently gives rise to methodological problems in the evaluation stage. In broad terms, improved cohesion means a reduction of disparities or differences of economic and social welfare between regions (i.e. spatial equity) or groups (i.e. social equity). Effects on cohesion are thus *distributional* effects of transport policies related with the social dimension of sustainability.

Cohesion impacts fall under the category of wider policy impacts, which is frequently carried out with the support of spatial impact models and subsequently included as a *complementary analysis*

to a ‘conventional’ appraisal method, such as CBA. This complementary analysis enables a wider view to be taken of the investment proposal and therefore it is claimed that it should become an integral part of all evaluations at strategic levels (Banister and Berechman, 2003). Furthermore, it is argued that this more complex type of analysis seems to be increasingly important where there is already a high quality transport network, as the ‘conventional benefits’ may be providing an ever decreasing proportion of the total returns (Rietveld and Nijkamp, 1993). According to a proposal by Banister and Berechman (2003) this complementary analysis would include the assessment of distributional impacts.

The term “territorial cohesion” is used when cohesion refers to the spatial distribution of impacts (López et al., 2008). In spatial policy terms, the objective is to avoid territorial imbalances by making both sector policies which have a spatial impact and regional policy more coherent (EC, 1999). The concern is also to improve ‘territorial integration’ and encourage cooperation between regions or countries when a new infrastructure is planned.

### 2.3. The use of accessibility analysis for cohesion measurement

Regional development studies have traditionally been based on the assumption that the uneven spread of development is a function of spatial inequalities in accessibility (EC, 1996). Accessibility is therefore seen as an added value of a location and an important factor of quality of life (Schürmann *et al.*, 1997), and in a sense 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, 1995). Hence, the assessment of the distributive impacts described above may be carried out using accessibility as the variable that should be equally distributed.

*Accessibility analysis* has particular strengths as a support tool for transport assessment methodologies. Accessibility analysis allows defining how transport and development impacts are distributed across geographical areas (Martín et al, 2004, López et al, 2008) or population groups (Talen, 1998), therefore including compatibility with cohesion objectives. In other words, if we translate the “efficiency vs. cohesion” conflict in terms of accessibility improvements, the conclusion is that transport planners should simultaneously combine the maximization of two objectives: the improvement of accessibility and the achievement of an equal distribution of accessibility among regions.

Early examples of the use of accessibility to assess cohesion impacts date back to late 1970s, such as the study by Domanski (1979), who relates the increase of accessibility to spatial concentration. This author uses accessibility as a measure to represent spatial equity, essentially by applying the potential formula to a hypothetical spatial system. Under this general approach, accessibility is often considered in regional planning as a means to economic activity and cohesion, rather than a desirable good by itself (Vickerman *et al.*, 1999). However, the conclusions are sensitive to the conceptualization and measurement of accessibility and equity used in the analysis (Bruinsma & Rietveld, 1998; Talen, 1998).

Recent research approaches suggest analyzing distributive impacts in terms of spatial cohesion impacts via changes in the spatial distribution of accessibility among regions (Schürmann *et al.*, 1997; Martín *et al.*, 2004; Bröcker *et al.*, 2004; López *et al.*, 2008). Results obtained from these studies show that certain investments, such as HSR, may lead to increasing rather than reducing regional disparities in accessibility, i.e. to a more polarized distribution of accessibility.

### 3. Methodological approach

#### 3.1. Structure of the methodology

An outline of the proposed approach is included in **Figure 1**. The whole procedure is supported by a Geographic Information System (GIS). The starting point is the creation of the input data geodatabase, which includes both land use and transportation data. Cohesion effects are measured analyzing the distribution of accessibility benefits of a given HSR investment, when compared with that of the ‘do-nothing’ network. Land use characteristics are remained identical between the ‘do-nothing’ and the HSR networks, in order to isolate the effects of the transportation investment under consideration from those derived from changes in the land use system.

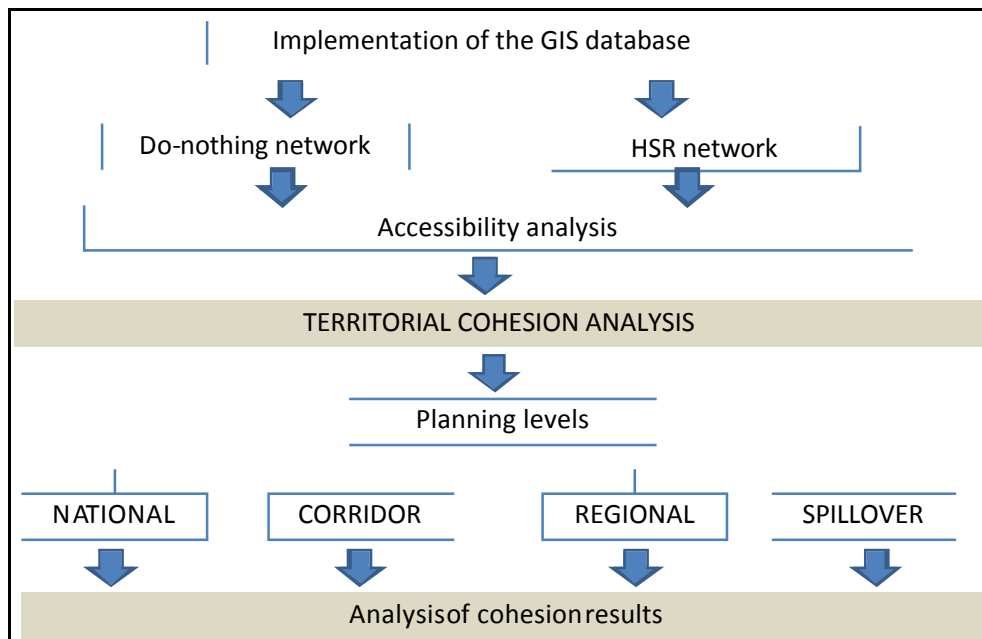


Figure 1: Outline of the methodology

#### 3.2. The accessibility analysis

There is a wide spectrum of existing formulations which attempt to measure the concept of accessibility. Extensive reviews and existing classifications of accessibility indicators/measures can be found in Baradaran and Ramjerdi, 2001; Bruinsma and Rietveld, 1998; Handy and Niemeier, 1997; Reggiani, 1998 and Geurs and Ritsema van Eck, 2001.

The selection of the appropriate indicator for a particular case is a complex task. Moreover, there is evidence that the formulation chosen, mainly the choice of the distance decay function, has a strong influence in the results obtained (Baradaran and Ramjerdi, 2001). In general there is no single best ‘ideal’ indicator, but it is argued that the analysis is enriched if a set of indicators is computed and their results analyzed in a complementary way (see e.g. Gutiérrez, 2001; Martín *et al.*, 2004; Schürmann *et al.*, 1997). When planning infrastructure extensions to achieve improved cohesion, the implications of the selection of the accessibility indicator need to be discussed and consequently chosen from an agreement between planners and decision-makers. The enhanced interpretability of results deriving from cohesion mapping constitutes a valuable tool in order to reach this consensus.

The methodology described in this research work suggests the utilisation of the *economic potential accessibility formulation*, given its proved consistency and applicability in transport planning studies at strategic levels (Schürman *et al.*, 1997; Martín *et al.*, 2004). The potential indicator falls

under the category of gravity indicators. From the many formulations of potential indicators available, the one described in Equation 1 has been selected for its adequate balance between complexity and interpretability, as well as for its proven validity (Martín *et al.*, 2004; López *et al.*, 2008).

$$PP_r = \sum_j \frac{P_j}{I_{ij}} \quad (1)$$

in which  $P_j$  represents population at the destination  $j$ , and  $I_{ij}$  travel impedance (usually measured as travel time or generalized travel cost) between each origin-destination pair.

### 3.3. Territorial cohesion analysis

The territorial cohesion analysis is based on the computation of a well known statistical index –the coefficient of variation (CV)- of the accessibility values across regions, using their population as their weighting variable. This index has been previously used for this purpose in similar studies (see e.g. López *et al.*, 2008; Martín *et al.*, 2004; Schürmann *et al.*, 1997). Hence, an increased CV value means a reduction in cohesion, -i.e. a negative cohesion effect- whereas a reduction in the CV value means a positive cohesion effect, i.e. a more balanced spatial distribution of accessibility. In order to assess the influence of the planning level used, territorial cohesion impacts are analyzed at four different planning levels, i.e. national, corridor, regional and spillover levels.

First, at the national level, changes in the distribution of accessibility for the whole national territory are analyzed. Second, at the corridor analysis level, its study area is built following the borders of the administrative NUTS region divisions crossed by the HSR corridor. Third, at the regional level, cohesion impacts are measured independently in each of the NUTS regions crossed by the HSR infrastructure. Finally, at the spillover level, cohesion impacts are measured in NUTS regions adjacent to the previously defined corridor level.

Finally, maps are included in the methodology as a support tool to give indications of the spatial imbalances accessibility patterns. Moreover, they are also included to support the interpretability of results for the non technical audience, as they constitute a useful planning tool as a starting point for discussion among planners, policy makers and potential stakeholders involved in the planning process.

## 4. Case study: the Galician HSR corridor

This section includes an example on how the methodology should be applied and their results analyzed. The infrastructure investment under consideration (the “HSR network” in Figure 1) is the Galician HSR corridor, with nearly 600 km, as included in the Spanish Strategic Plan of Transport and Infrastructure 2005-2020 (PEIT). Figure 2 shows the HSR corridor with the location of HSR stations. Following the terms included in Figure 1, the ‘do-nothing’ network corresponds to the situation in 2005, i.e. the base year of the Spanish PEIT. The land use characteristics of both network situations are identical and correspond to a prognosis for the 2020 situation, i.e. the planning time horizon of the PEIT.

The study area and the level of zonification for the analysis basically comprises the Spanish mainland at the NUTS-5 level (municipalities) and its corresponding cross-border regions in neighboring countries, which include Portugal and the three southern French NUTS-2 regions. In order to calculate accessibility values, a dense rail and road network was modeled with the support of a GIS; in this case the ArcGis software was used. The road network is necessary as a complement to the rail network in order to obtain a more dense distribution of results than the one derived from

accessibility values at the rail stations. Accessibility values are obtained for each node of the network, which coincide with the nodes of the road network, which are nearly 12,000. The accessibility calculations were made using a network accessibility analysis GIS toolbox (Mancebo, 2006). The GIS accessibility calculation process is described in Ortega (2009).

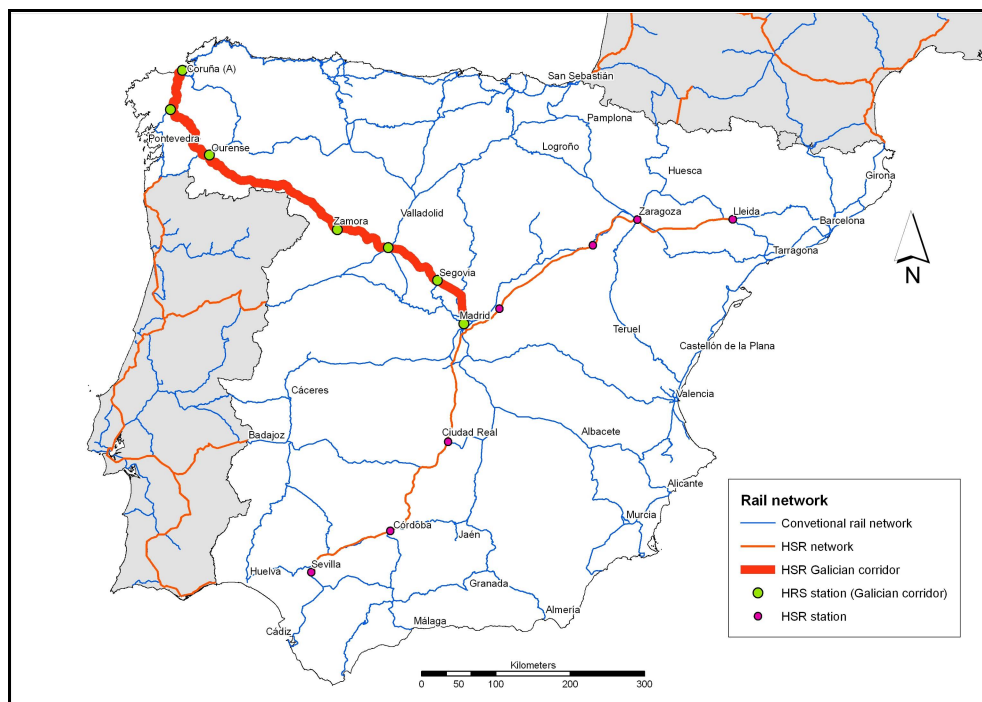


Figure 2: Rail network

The first task consisted in modeling the transport network of the do-nothing network and the HSR network. A vectorial GIS was used, in which the network is modeled as a graph with a set of nodes and arcs. For each arc on the road network, the length, estimated speed according to the type of road (120 km/h for highways, 110 for expressways, 90 for interregional roads, 80 for other roads and 50 for urban roads) and resulting travel time were also recorded, as used in previous similar studies (López *et al.*, 2008). For the rail mode, each arc is given a commercial speed according to both infrastructure and quality of service characteristics. Rail network modeling tasks are significantly more complex than those of the road mode, as it is necessary to include track gauge (Iberian/UIC) data, the location of the stations and frequency of service information in order to calculate travel times, as described in López (2007).

The population is the selected variable to measure each destination's attractiveness in the accessibility model. The potential accessibility values of each origin centroid  $i$  is computed, using Equation (1). Intermediate calculations include the measurement of each  $i$ - $j$  travel time, using minimum-path algorithms embedded in the GIS.

Regarding the spatial distribution of population of the study area and as shown in Figure 3, the Galician corridor suffers from a rather polarized spatial distribution of population. The two main urban agglomerations are Madrid and La Coruña, whereas less populated areas are located in inner and/or rural areas, which furthermore suffer from progressive population falls. The total population of each of the NUTS-3 divisions crossed by the HSR corridor is included in Table 1.



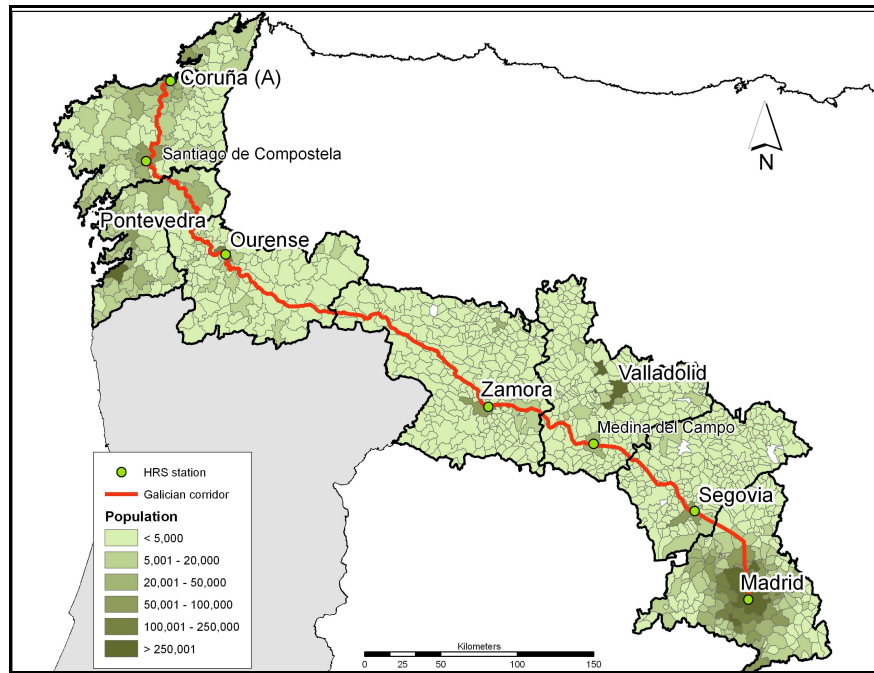


Figure 3: Distribution of population in Galician corridor

### *Accessibility analysis*

The presence of marked spatial imbalances in rail accessibility is illustrated in Figure 4, which shows accessibility contours for the rail mode in the HSR network, when computing the potential accessibility indicator. In addition, Figure 5 shows percentage accessibility changes between both networks. In this Figure 5 it is easy to observe the ‘network effect’ caused by the HSR corridor: those areas near the HSR network in 2005 –the Seville-Barcelona diagonal- are highly benefited by the construction of additional HSR extensions, whereas isolated areas, not linked with the HSR network, benefit from lower accessibility gains. Subsequent conclusions in terms of balancing or increasing disparities arise from this first overall analysis and are included below.

The interpretation of the results provided by the potential indicator needs to be carried out taking into account the joint effect of distance (travel time) and attraction masses (destination’s population) in the relations of each node with activity centres. In addition, the location of HSR stations play a crucial role in the final accessibility value of each node. Hence, those nodes with better accessibility conditions (a higher potential) will presumably be those nearer to and better linked with major densely populated areas and close to HSR stations.

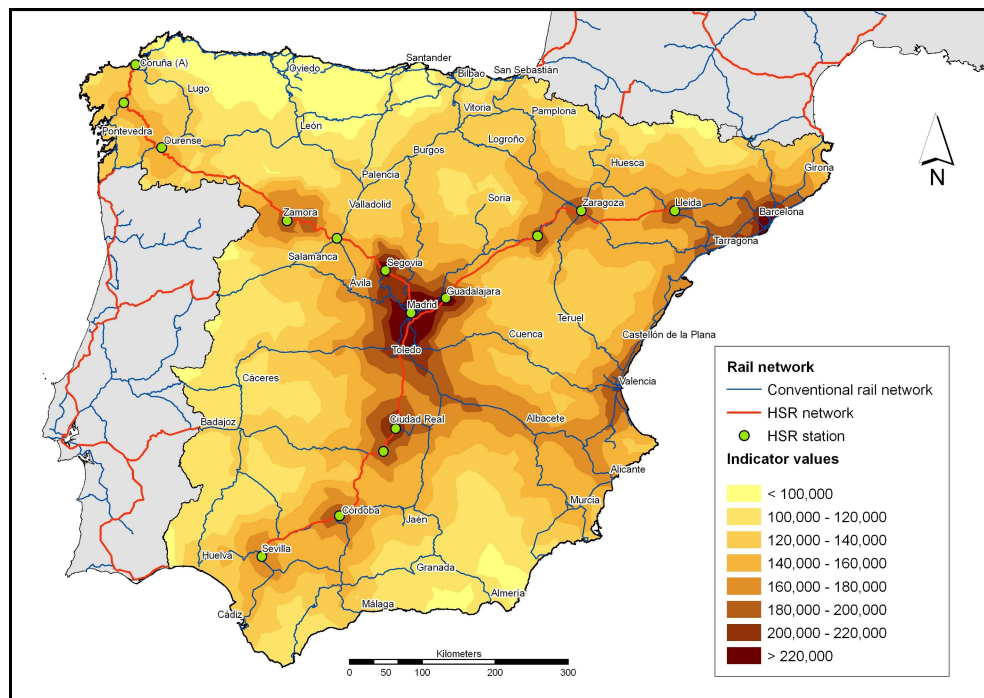


Figure 4: Accessibility: economic potential in the Galician HSR network

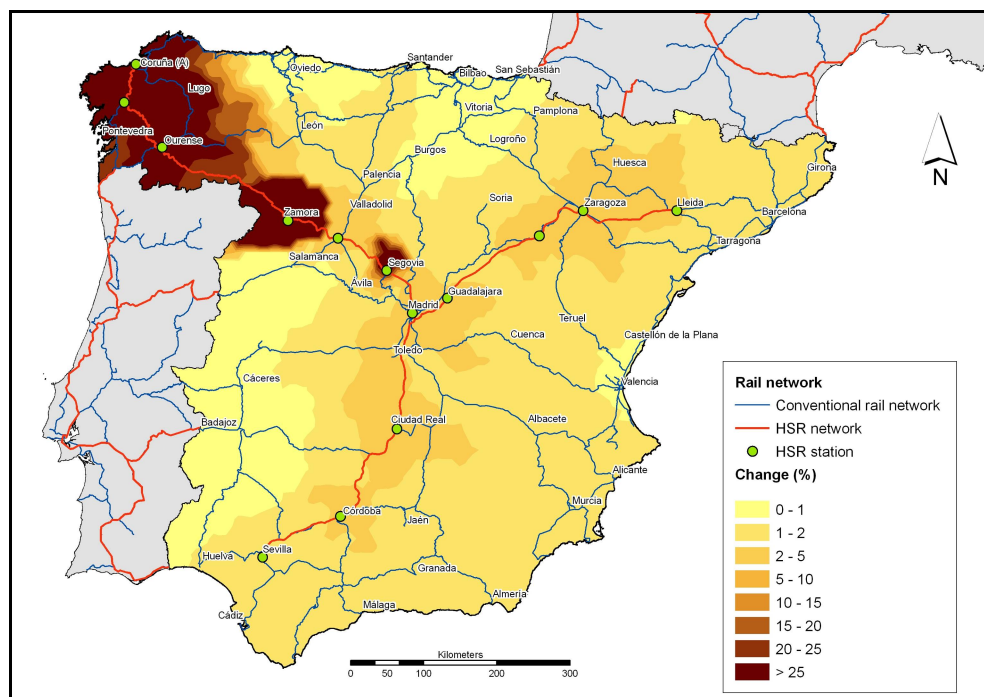


Figure 5: Accessibility improvements: do-nothing vs. HSR network (%)

### *Territorial cohesion analysis*

Cohesion impacts are assessed via the comparison of CV values corresponding to the do-nothing and the HSR network of the set accessibility values (as suggested by e.g. Martín *et al.*, 2004; López *et al.*, 2008). This comparison is carried out at the different planning levels described in Section 3. The resulting changes in the CVs are included in Table 1. In addition, as a complementary analysis, the mean accessibility increase in each level has also been computed and included in Table 1.

The analysis at four different planning levels (Figure 6). First, the impact of the Galician corridor on cohesion has been analyzed at the national level. This analysis at a macro level intends approaching

cohesion impacts from a strategic perspective. Indeed, it is the national level (the Spanish Ministry of Public Works) the administrative level in which decisions on the extension of the Spanish HSR network are taken. The construction of the HSR corridor represents a nearly 3% increase (2.86%) in accessibility for the national territory. In cohesion terms, a positive effect appears, with a reduction in the CV of a 2.94%. These results are coherent with the accessibility patterns observed in the accessibility maps, which showed lower accessibility levels in the Galician HSR corridor.

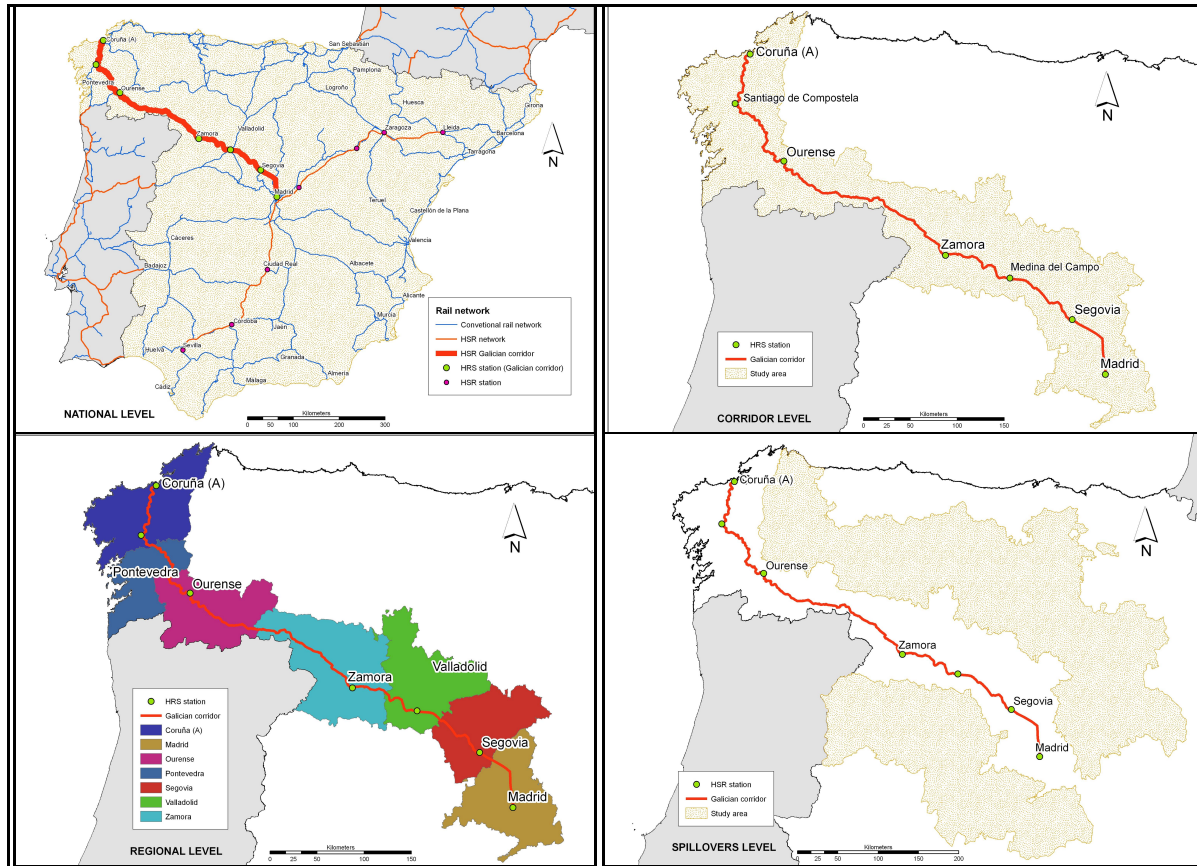


Figure 6: Analyzed planning levels

Second, cohesion results are assessed at the corridor level. The limits of the corridor area are defined from the borders of the NUTS-3 administrative levels crossed by the rail network (provinces in the case of Spain). The corridor benefits from a 5.84% increase in accessibility, along with a significant positive cohesion effect: a 12.83% reduction in the CV. This reduction is mainly due to the fact that there were important imbalances in the do-nothing network, with Madrid having high accessibility values, and the remaining regions of the corridor suffering from strong accessibility deficiencies.

Third, cohesion impacts are assessed independently for each of the six NUTS-3 regions of the corridor crossed by the rail infrastructure, i.e. Madrid, Segovia, Valladolid, Zamora, Ourense and La Coruña. This analysis is aimed at investigating whether there may be increasing or reduced cohesion impacts at this micro level, and the potential variables driving these differences. Significant accessibility improvements appear in nearly all provinces, with a maximum value of a 48.84 increase in La Coruña region. However, significant negative cohesion effects appear in four of the six abovementioned provinces: La Coruña, Ourense, Segovia and Zamora. These results are explained mainly by the combination of information from population density (Figure 3) and the location of HSR stations. A more detailed analysis at this micro level should be conducted in each province, as it is out of the scope of this paper to draw independent conclusions applicable to each of the six regions. Nevertheless, the existence of these negative cohesion effects should be

addressed at the corresponding planning level and the most appropriate policy measures to reduce these effects should be adequately investigated.

Planning level	Population	Network	Accessibility			Coefficient of variation	Change CV (%)
			Mean	Change (%)	Standard deviation		
National	47.433.868	“Do-nothing” network	187.601	2,86	80.722	0,430	2,94
		Galician HSR	192.958		80.588	0,418	
Corridor (region)	11.011.396	“Do-nothing” network	258.172	5,84	117.757	0,456	12,87
		Galician HSR	273.254		108.600	0,397	
Regional	La Coruña	“Do-nothing” network	92.253	48,84	8.045	0,087	-35,69
		Galician HSR	137.310		16.249	0,118	
	Madrid	“Do-nothing” network	322.016	2,12	79.709	0,248	0,28
		Galician HSR	328.845		81.173	0,247	
	Orense	“Do-nothing” network	104.317	46,56	6.245	0,060	-110,84
		Galician HSR	152.884		19.297	0,126	
	Pontevedra	“Do-nothing” network	110.496	25,26	11.860	0,107	16,06
		Galician HSR	138.408		12.470	0,090	
	Segovia	“Do-nothing” network	163.934	25,58	18.982	0,116	-91,65
		Galician HSR	205.876		45.688	0,222	
	Valladolid	“Do-nothing” network	149.632	3,37	12.354	0,083	0,62
		Galician HSR	154.677		12.691	0,082	
	Zamora	“Do-nothing” network	117.604	41,48	13.564	0,115	-104,15
		Galician HSR	166.389		39.177	0,235	
Spillovers	2.926.759	“Do-nothing” network	147.857	4,12	42.531	0,288	10,30
		Galician HSR	153.949		39.720	0,258	

Table 1. Cohesion analysis at different planning levels

Fourth and lastly, at the ‘spillovers level’, cohesion impacts in NUTS-3 regions adjacent to the corridor level are computed. These spillovers account both for a 4.12% mean accessibility increase and a 10.30% reduction in the CV, i.e. a positive cohesion effect in this ‘buffer’ of nearby regions.

## 5. Discussion and further research needs

The importance of the planning level under consideration and the utility of accessibility indicators as a planning tool to measure cohesion impacts at strategic levels have been highlighted in this paper. We believe this approach could be used as a valuable instrument for decision making processes at strategic levels, such as in the case of HSR projects. It is precisely in these large scale transport projects where the inclusion of cohesion effects are increasingly demanded by policy makers and where conflicts may potentially arise between different administrative levels.

An interesting research direction stemming from this paper refers to the definition of a procedure to integrate these results into a cost-benefit or multi-criteria analysis framework. For this purpose, it would be necessary to monetise cohesion effects or the definition of their weight when compared with other criteria, respectively. Other considerations may only be solved at the political level, but information on cohesion impacts, measured as suggested in this research work, could constitute a starting point for further discussion and definition of planning alternatives.

In addition, this analysis can be complemented with the inclusion of the results from other accessibility measures, such as the location and the network efficiency indicator (see e.g. López *et al.*, 2008). The selection of the most appropriate accessibility indicator depends on the perspective under which cohesion should be assessed. If the objective is a more balanced distribution of economic potential, a gravity indicator, such as the Hansen type proposed in this paper is more appropriate. Other approaches may select different formulations. Among these, if the objective is to

achieve a more equitable distribution of network efficiency, a network efficiency indicator (Gutiérrez *et al.*, 1998) should be used, whereas if the objective refers to a more balanced distribution of travel times, in which a travel cost indicator, such as the location indicator (López *et al.*, 2008) is suggested.

Other extensions of the methodology refer to the computation of a set of inequalities, although current evidence show no differences in the direction of the cohesion effect when the inequality index is changed (López, 2007). Moreover, this analysis could be extended to include different transport alternatives, in order to compare and rank them. These complementary analyses would allow taking advantage of the potential of the methodology as a support tool in decision making processes.

Finally, some implications for transport policy making apply. The first relates to the need to define policy measures to reduce negative impacts on cohesion derived from the implementation of HSR lines. These measures may include an improvement of the access to the new HSR stations from these locations which suffer from a relatively worse situation after the HSR is implemented. The improvement of secondary networks –with conventional rail links- or the provision of increased accessibility by the road network may reduce increasing disparities created by the HSR. These measures should be complemented with other sectoral policies other than transport policy, such as regional development measures, aimed at reducing the risk of concentration of economic activity in the surroundings of HSR stations, at the expense of a decrease in economic activity and population in those areas not directly served by the new infrastructure.

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