SOCIAL IMPACTS OF HIGH SPEED RAIL PROJECTS: ADDRESSING SPATIAL EQUITY EFFECTS

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ABSTRACT

Equity issues are increasingly included among social impacts of transportation investments. Equity implications take into account the distribution of effects among different societal groups (social equity) or regions (spatial equity). The analysis of the spatial distribution of effects is crucial, as certain transportation investments may contribute to increase imbalances between regions, i.e. negative spatial equity impacts.

The planning process of a new high speed rail (HSR) corridor should take into account these equity considerations. HSR specific features make it a serious candidate to result in negative equity impacts. These are mainly the significant differences in commercial speeds between HSR and conventional rail, and the spatial separation between HSR stations.

In this context, this paper describes and validates a methodology to assess spatial equity impacts of HSR based in the calculation of accessibility indicators. Accessibility analysis is a special type of spatial analysis technique which is increasingly used to assess spatial equity impacts of transportation investments. The proposed methodology is intended to support transport planners when confronted with the task to optimize efficiency and equity objectives. The validity of the methodology is tested with its application to alternative corridor developments of the Spanish HSR network based on the 2020 scenario included in the Spanish Strategic Transport and Infrastructure Plan 2005-2020 (PEIT).

The case study application shows that the results are heavily influenced by the selection of the accessibility indicator, each one providing a complementary perspective on equity measurement. In addition, results highlight the important role played by the selection of the commercial speed. In particular, increasing commercial speeds from 220 km/h to 300 km/h in a given corridor results in significant negative impacts on spatial equity, as differences between locations with and without a HSR station are highlighted.

Keywords: *spatial equity, social impacts, high speed rail impacts*

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1. INTRODUCTION

Transport planning involves making optimal decisions on the improvement and expansion of a network system. Transport assessment methodologies have traditionally focused in the measurement and monetization of reductions in cost or travel time, which are usually dealt with in cost-benefit or multicriteria analysis. However, other objectives, such as equity, are increasingly relevant for transport planners and policy makers, encouraged by the concern to include the three objectives of transport sustainability -economic, social and environmental- in transport assessment methodologies.

Among these concerns, of particular importance is the inability of assessment methodologies to deal with the conflict of efficiency (economic) vs. equity (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 equity, 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 equity is retained, while economic growth is maximised (Button, 1993).

In this context, accessibility analysis has particular strengths as a support tool for assessment methodologies. On the one hand, accessibility measures are capable to measure the achievement of efficiency objectives, as they allow assessing network efficiency improvements (Gutiérrez and Monzón, 1998). On the other, 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 equity objectives. In other words, if we translate the efficiency vs. equity 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.

Despite the above mentioned advantages of accessibility analyses, it is widely claimed that the potential of accessibility analysis for transport planning purposes such as the assessment of equity effects is not fully exploited (Halden, 2003; Geurs and Ritsema van Eck, 2003). Indeed, although the concept of accessibility has been widely reported in geographical studies, it has rarely been used for policy evaluation. Moreover, accessibility analysis has major presentational advantages by describing the impacts of transport investment in terms that people can easily understand, which is an added value given the increasing influence of public opinion on these issues. This lack of practical applications of accessibility analysis in transport appraisal methodologies is mainly due to concerns about double counting of effects, the perceived complexity of their formulations and their resulting difficulty of interpretation (Geurs and Ritsema van Eck, 2001, 2003).

In this context, this paper moves one step forward in this research direction with the proposal of a methodology to assess both equity and efficiency implications of transportation investments. The structure of the paper is as follows. The second section after this introduction includes some general concepts on equity and existing attempts to measure equity impacts through accessibility analysis. The third section describes the proposed methodology, which is subsequently applied in section 4 to a case study: a set of 10 scenarios designed from the Spanish Strategic Transport and Infrastructure Plan 2005-2020 (PEIT). Finally, a discussion and future research directions are included in section 5.

2. EFFICIENCY, EQUITY AND ACCESSIBILITY ANALYSIS

2.1. The inclusion of equity in transport assessment methodologies

Improvement of transport infrastructure leads both to a reduction of transport costs and substantial redistribution effects among social groups and region. 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.

Equity 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 equity 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 equity. Moreover, it is frequent to find other related terms, such as 'cohesion' or '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 equity 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 equity are thus distributional effects of transport policies related with the social dimension of sustainability.

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. In the social equity arena, policy objectives are mostly focusing on social exclusion issues and most empirical studies have been applied at urban scales. At the project level, the social dimension generally refers to objectives such as accident reduction,

noise abatement, or local emissions reduction. This approach is rather limited at the level of transport policies/plans. In general, impacts on social equity will depend on the distribution of costs and benefits between different groups of individuals (Alsnih and Hensher; 2003). The distribution among regions is usually analyzed under the 'cohesion' term (López et al., 2008). Equity 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: analysis of the distribution of impacts among regions and/or social groups.

2.2   The use of accessibility analysis for equity 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.

Early examples of the use of accessibility to assess equity 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 equity 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 may lead to increasing rather than reducing regional disparities in accessibility, i.e. to a more polarized distribution of accessibility.

Changes in the distribution of accessibility values among individuals or groups of individuals are useful in order to assess social equity impacts. For this purpose, it is important to take into account that the spatial distribution of improvements in accessibility and the spatial distribution of socioeconomic characteristics should be consistent, i.e. higher accessibility gains should concentrate in lower income regions, whereas high income regions should

benefit from the lower accessibility benefits. However, this approach is more widely used at a local level, given the large amount of information that the disaggregation of the population requires according to their socio-economic characteristics (Talen, 1998). These studies are related to the assessment of social exclusion issues of transport policies (Lucas, 2006). For this purpose, accessibility is usually dissagregated by population groups, what allows focusing in the situation of disadvantaged sectors of the population, such as aging population or low income workers. Recent examples are: Lucas, 2006; Preston and Rajé, in press; and Alsnih and Hensher, 2003. Other applications focus in the situation of population of rural areas and low density zones (Nutley, 2003), equity mapping (Talen and Anselin, 1996; Talen, 1998), distribution of job accessibility (Geurs and Ritsema van Eck, 2003), or social changes (Halden, 2002; Bröcker et al., 2004).

Finally, a remark on the potential of GIS as a support tool for accessibility is included here. The capability of GIS to provide, at any time, appropriate information regarding trade-offs and efficiency of proposed solutions has created an increase in their popularity in recent years. Key approaches use GIS to support accessibility calculations, environmental assessments, network demand models, traffic congestion studies, or regional and urban spatial planning models (Wegener, 2001). The development of GIS has exerted a deep on-going impact on modern decision analysis, enabling the design of interactive user-oriented multiple criteria decision models (MCDM) (see e.g. Malczewski, 1999) or Decision Support Systems (DSS) (Colorni et al., 1999) especially useful in transport decision-making processes, where the stakeholders can be a large and diverse group. However, the 'communicative' abilities of GIS due to their capabilities to create high standard visual images could be more fully exploited in order to stimulate discussion and evaluation of different project designs in new and more informative ways. In this sense, a more integrated work of spatial analysis, transportation and GIS research communities could have a substantial positive impact on the theory and practice of transportation analysis and planning (Miller, 1999; Wegener, 2001). This constitutes a current challenge for the research community.

2.3. The relationship between accessibility and equity

There is a wide variety of existing approaches to the concept and measurement of accessibility. Morris et al., (1979) define accessibility as "some measure of spatial separation of human activities, which denotes the ease with which activities may be reached using a particular transportation system".

Accessibility can be seen as a proxy for measuring welfare, if we accept that the welfare of individuals is related with the ease which they can access essential services (Hay, 1993). An improved accessibility provides the individual with a wider set of opportunities in order to select that which best matches their needs and preferences. Following this rationale, accessibility can be considered an added value of a location and an important factor of quality of life (Schürmann et al., 1997), while lack of accessibility is undesirable because it is considered partly responsible for lagging economic development.

Since the first definitions of accessibility were developed in the early 50's, there has been a continuous evolution of the theoretical foundations of accessibility indicators, resulting in a

wide range of available formulations (Morris et al., 1979; Bruinsma and Rietveld, 1998; Reggiani, 1998; Geurs and van Wee, 2004). However, although the concept of accessibility has been widely reported in geographical studies, it has rarely been used for policy evaluation, and thus it has had little practical impact on policies (Handy and Niemeier, 1997). This is mainly due to concerns about double counting of effects (Beuthe, 2002), the perceived complexity of their formulations and their resulting difficulty of interpretation (Geurs and Ritsema van Eck, 2003).

Recent research has identified the role and application of robust quantitative approaches, allowing accessibility measures to take a more central role within transport appraisal (Halden, 2003; Geurs and van Wee, 2004). In land-use/transport planning, accessibility is often considered as a means to economic activity and social cohesion, rather than a desirable good by itself (Vickerman et al., 1999). Traditionally, regional development studies have been based on the assumption that the uneven spread of development is a function of spatial inequalities in accessibility (CEC, 1996). However, the regional economic development implications of transportation improvements are highly complex and difficult to determine methodologically.

Despite the debate on the effects of accessibility on economic development, spatial distribution of accessibility is one of the variables used to measure the existing disparities among regions. In fact, it is one from a long list included in the periodical Cohesion Reports of the EU (CEC, 2004), among which are included macroeconomic indicators such as GDP per capita, employment levels or R&D investments. The rationale behind the inclusion of accessibility in this list is that the "equality of access" to "services of general economic interest" is considered a key condition for territorial cohesion (CEC, 2004). Special interest is placed in regions with geographical handicaps characterized by problems of accessibility and integration with the rest of the EU. Infrastructure investment is thus considered a key factor in order to provide a fair distribution of accessibility to all its regions and to reduce existing disparities in accessibility between them (Schürmann et al., 1997). However, transport investment and increased cohesion do not follow a casualty relationship. Some scientists even argue, that better transport links between strong and competitive centres and economically weak peripheries may increase polarisation instead of cohesion (Hey et al., 2002; Peters, 2003; Vickerman, 1995a).

In this context, our approach is to analyze changes in the spatial distribution of accessibility values as a tool to measure regional cohesion effects of transport infrastructure investments. This approach could be used to enrich the planning process, by providing assessment methodologies with a complementary "cohesion" tool. Hence, the decision-maker will have the information on whether the existing regional disparities in accessibility are increased (i.e. reduced cohesion) or reduced (i.e. increased cohesion) as a result of the implementation of the new infrastructure.

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 GIS. The starting point is the creation of the input data geodatabase, which includes both land use and transportation data. Equity effects are analyzing the distribution of accessibility benefits of a given transportation investment (s), when compared with that of the 'do-nothing' situation (0). The implementation of the transportation investment modifies the characteristics of the transport network, from T_0 to T_s in the Figure. The corresponding changes in accessibility (A) have been represented as A_0 and A_s. Land use characteristics are remained identical between the 'do-nothing' and the investment alternatives, in order to isolate the effects of the transportation investment under consideration form those derived from changes in the spatial system.
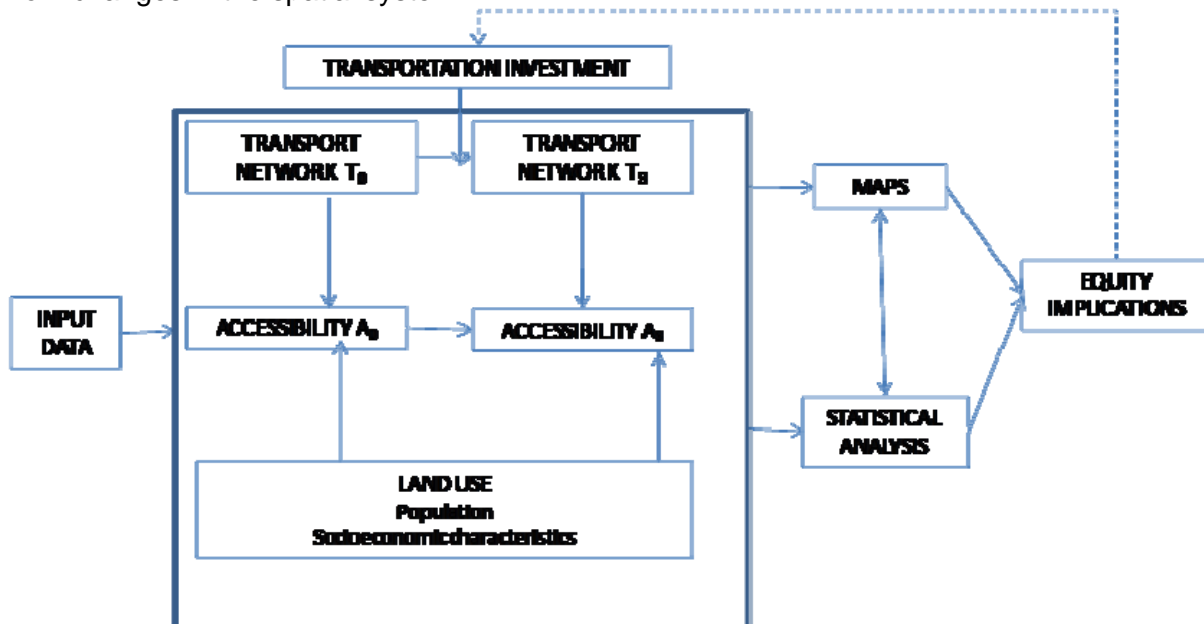

Figure 1: Outline of the methodology

Equity effects are consequently assessed from the combination of graphical and statistical analyses. First, maps are built showing the spatial distribution of accessibility benefits. Second, a set of statistical measures –cohesion measures- are computed. These are explained in the case study application.

Maps are included in the methodology to give indications of the spatial imbalances in accessibility and the changes introduced by each infrastructure investment. 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.

Finally, and as represented by the dotted line in the Figure, the methodology constitutes an interactive and iterative process. These conclusions in terms of efficiency and equity implications may constitute a feedback for the definition of new alternatives for the transportation investment under consideration.

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; Gutiérrez, 2001; Handy and Niemeier, 1997; Reggiani, 1998; Geurs and Ritsema van Eck, 2001 and Geurs and van Wee, 2004).

Simplest accessibility indicators only consider the characteristics of the transport network of the area under consideration. Transport literature is increasingly claiming a 'paradigm shift' from the more traditional infrastructure-based measures towards more complex accessibility indicators, also called 'activity-based' which take into account not only the characteristics of the transport network but also those of the land use system which the network is intended to connect. Despite their perceived complexity, their added value is that they provide complementary information for more comprehensive analyses, as they allow testing the efficiency of both land-use patterns and transport network configurations and their interdependencies.

Each indicator has specific advantages and drawbacks, although a general observation is that there seems to be a trade-off between 'soundness', i.e. theoretical and empirical insights, and 'plainness', i.e. ease of understanding of existing formulations (Bertolini et al., 2005). Furthermore, potential improvements in the theoretical foundations of most popular indicators may imply a loss of their interpretability and therefore they are not being implemented in most practical accessibility studies (Geurs and Ritsema van Eck, 2001).

Hence, 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 equity, 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 equity mapping constitutes a valuable tool in order to reach this consensus.

The methodology suggests three different accessibility formulations, chosen for their proved consistency and applicability in transport planning studies at strategic levels (Schürman et al, 1997; Martín et al, 2004; López et al, 2008): the location, the potential and the network efficiency accessibility indicators. Their formulation is included below.

Location indicator

The location accessibility indicator falls under the category of 'travel cost indicators'. The location indicator (L_i) is computed as the average travel time (I_{ij}) to the set *j* of destinations, using the population of each destination (P_j) as the weighting variable. The formulation is included in Equation 1.

$$L_i = \sum_j \frac{I_{ij} \cdot P_j}{\sum_j P_j}$$

(1)

Economic Potential indicator

The potential indicator falls under the category of gravity indicators. From the many formulations of potential indicators available, the one described in Equation 2 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).

$$PP_r = \sum_j \frac{P_j}{I_{ij}}$$

(2)

Network Efficiency indicator

The network efficiency accessibility indicator (E) (Gutiérrez and Monzón, 1998; Gutiérrez, 2001), is computed using Equation 3.

$$E_i = \sum_j \frac{\frac{I_{ij}}{II_{ij}} \cdot P_j}{\sum_j P_j}$$

(3)

This indicator is used to calculate, for each *i-j* pair, a weighted mean of ratios between travel time using the network (I_{ij}) and an 'ideal'[1] travel time (II_{ij}). The population of each destination (P_j) has been selected as the weighting factor.

According to each indicator formulation, the sign of its corresponding results is different. Lower values of the Location and Economic Potential indicators mean higher accessibility levels. On the contrary, Network Efficiency values have direct relationship with accessibility increases.

There is a wide consensus in the significant influence of how accessibility is measured on the results obtained (see e.g. Talen, 1998; Martín et al., 2004; López et al, 2008). In terms of the three indicators described above, the following remarks apply. If our purpose is to analyze equity among socioeconomic groups in the travel times they employ to reach large populations, a travel cost indicator should be used. If we want to assess the degree of equity in the distribution of the access to opportunities, accessibility should be measured with a potential indicator. If we want to eliminate the effect of the geographical location and achieve

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[1] Measured as travel time 'as the crow flies'

equity in the efficiency of the transport network, a network efficiency indicator is an appropriate measure.

4. CASE STUDY: HIGH SPEED RAIL CORRIDORS IN SPAIN

4.1. Introduction

The study is aimed at validating the methodology described in the previous section for the assessment of efficiency vs. regional equity effects of high speed rail corridors. For this purpose, a planning exercise has been carried out, in which a set of 10 possible scenarios of rail corridors has been designed.

These scenarios have been designed based in the rail network infrastructure extension included in the Spanish Strategic Transport and Infrastructure Plan (PEIT) 2005-2020. Table 1 includes the set of 10 scenarios that will be assessed. The scenarios basically include different combinations of the existence or not of two corridors: the Mediterranean corridor and the Galician corridor. They have been mapped in Figure 2. If an * is included, the corresponding corridor has a 300 km/h commercial speed, otherwise, it corresponds to a 220 km/h speed. The plus and minus signs correspond to an addition or a removal of the corresponding corridor to the do-nothing (#1) or PEIT (#10) scenarios. The PEIT scenario has been represented in Figure 3.
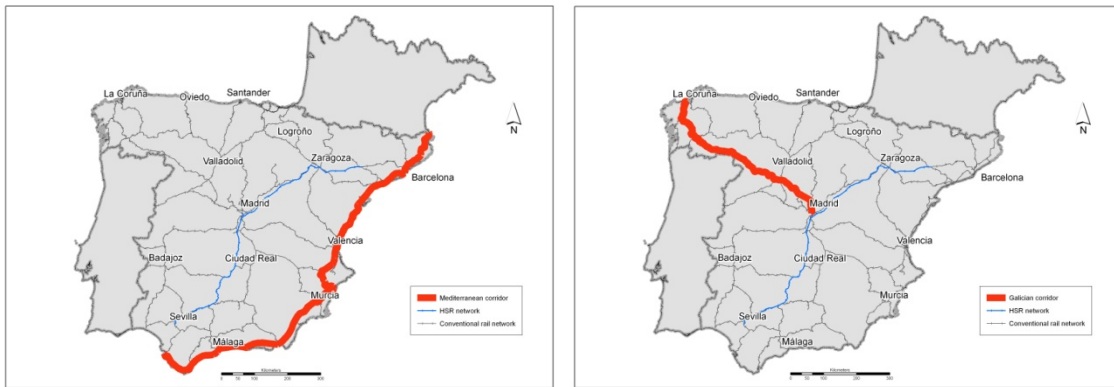

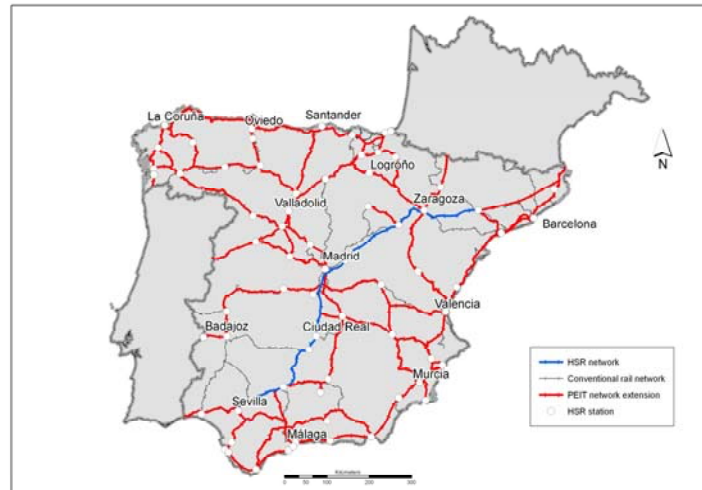Figure 2: Mediterranean (left) and Galician (right) corridors

Figure 3: PEIT Scenario

The rationale behind this scenario design is the assessment of the contribution that specific corridor developments has in the overall country accessibility and the equity in the resulting accessibility distribution. Additionally, the inclusion of "* scenarios" enables the measurement of the sensitivity of the results to changes in commercial speed.

Scenario	Short name	Number
Do-nothing	000	1
Do-nothing + Galicia	0+Gal	2
Do-nothing+ Galicia*	0+Gal*	3
PEIT -Galicia	PEIT-Gal	4
PEIT +Galicia*	PEIT+Gal*	5
Do-nothing + Mediterranean	0+Med	6
Do-nothing+Mediterranean*	0+Med*	7
PEIT -Mediterranean	PEIT-Med	8
PEIT +Mediterranean*	PEIT+Med*	9
PEIT	PEIT	10

Table 1: Definition of assessment scenarios

The assessment is carried out for the PEIT time planning horizon (2020). Following the outline included in Figure 1, this means that the rail networks of the 'do-nothing' alternative (0) and each of the nine 'investment alternatives' (s) correspond with the 2005 and each of nine (9) scenarios networks, respectively, whereas the land use characteristics of all the alternatives are identical and correspond to a prognosis for the 2020 situation.

Spain was selected as a case study for many reasons. The first is that in the Spanish mainland there exists significant disparities in the spatial distribution of accessibility and socioeconomic variables. The reduction of these differences has been in the agenda of the Spanish Ministry of Public Works in the last decades, in particular when planning the extension of the high capacity transport networks. The second is that, in order to achieve equity goals, Spain has received substantial support from European Funds for its infrastructure development in the last two decades. The result has been a progressive

convergence of disparities in Spanish network endowment and of GDP per capita values with the rest of the EU.

4.2. Application of the methodology

The study area and the level of zonification for the analysis basically comprises the Spanish mainland at the NUTS-5 level and its corresponding cross-border regions in neighboring countries, which include Portugal and the three southern French NUTS-2 regions.

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). In order to calculate accessibility values, a dense intermodal (road and rail) network was modeled with the support of a GIS; in this case the ArcGis software was used.

Accessibility values are obtained for each node of the network, which coincide with the nodes of the road network, which is nearly 12,000 km. Using interpolation techniques, aggregated NUTS-5 values in Spain, and NUTS-3 values in Portugal and France, are derived from node values.

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 (following López et al, 2008; Martín et al, 2004; Gutiérrez, 2001 and Holl, 2007 these speeds were 120 km/h for highways, 110 for expressways, 90 for interregional roads, and 80 for other roads) and resulting travel time were also recorded.

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), which is not possible to detail in this paper for space reasons.

Land transport infrastructure networks in Portugal and France correspond to the estimates of the European Commission for 2020. This way the effects from the Spanish network extension can be isolated from those derived from the development of socio-economic variables and the infrastructure extension in neighbouring countries in the period 2005-2020. In the accessibility calculations with origins in Spain, populations in France and Portugal have been reduced by a factor of 0.25, to take into account that destinations in neighbouring countries are visited less than national ones. The value for this reduction factor is the one used in similar studies (Gutiérrez and Monzón, 1998; Martín et al, 2004; López et al., 2008; Holl, 2007).

The population is the selected variable to measure each destination's attractiveness in the accessibility model. The accessibility values of each origin centroid i are computed, using Equations 1, 2 and 3. Intermediate calculations include the measurement of each i-j travel time, using minimum-path algorithms embedded in the GIS.

4.3. Accessibility results

The network efficiency indicator has been selected as the formulation to be represented in the accessibility maps, due to lack of space reasons. In order to give an overall view of the starting situation (Scenario 1) and the PEIT Scenario (Scenario 10) in terms of network efficiency, the corresponding values have been mapped in Figure 4 and Figure 5, respectively.
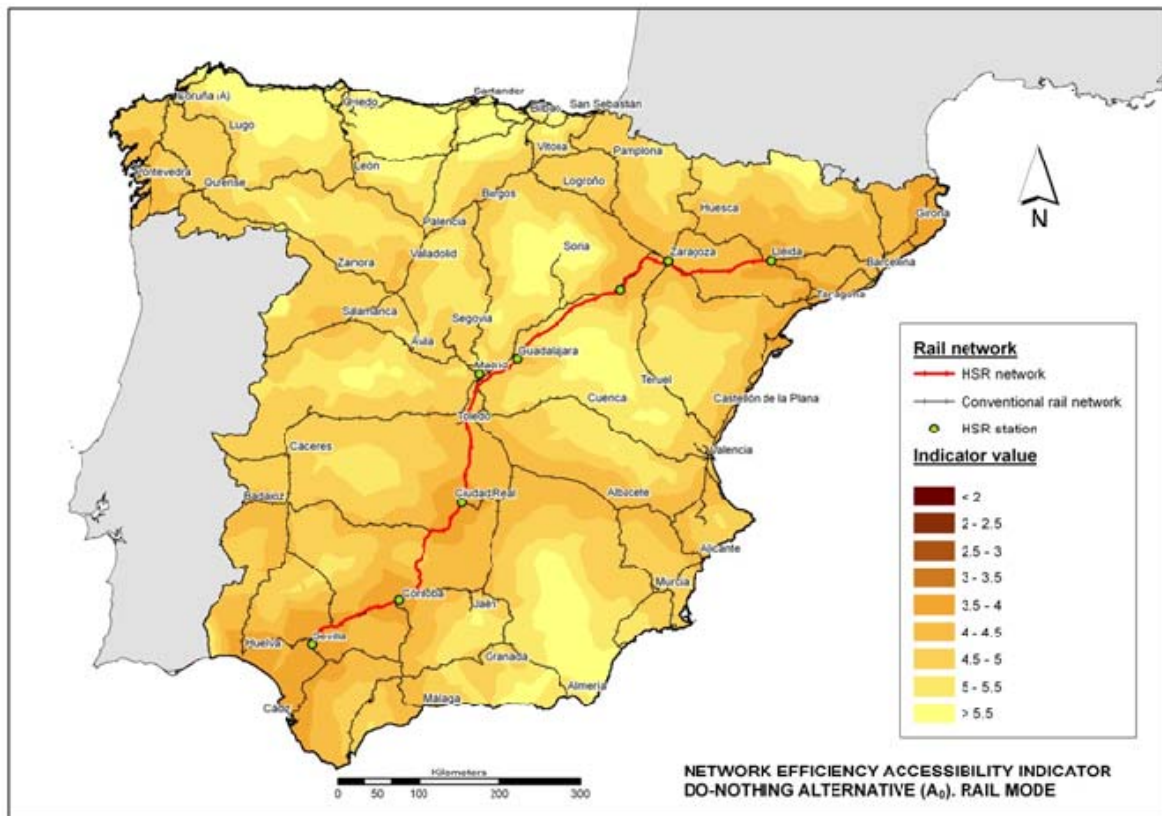

Figure 4: Network efficiency of the do-nothing scenario (Scenario 1)

It can be observed in Figure 4 that the values of the accessibility indicator a large range of variation: HSR Madrid-Sevilla and Madrid-Lleida corridors (along with those areas indirectly served by them) appear highlighted as zones with significantly higher accessibility levels than the rest of the territory. Furthermore, the good results obtained in the Mediterranean and Madrid-Valencia corridors, which enjoy efficient train services, are also highlighted. As happened with the road mode, given that the network efficiency accessibility indicator eliminates the influence of the geographic location, more accessible regions do not necessarily coincide with centraly located ones. This is the case, for example, of western Andalucía or eastern Cataluña, which despite of being located in the geographic periphery of the Iberian Peninsula, enjoy good accessibility levels.

It can also be observed that the location of the stations has a strong influence in the resulting spatial patterns of rail accessibility. On the one hand, the spatial distribution of train stations, mainly those of the HSR network, determine the presence of 'islands' and 'corridors' with better accessibility than their surroundings. On the other hand, interstitial areas within corridors suffer from the 'tunnel effect' (point accessibility) (Plassard, 1991; Plassard, 1992),

characteristic of HSR lines, as higher accessibility points (stations) alternate with lower accessibility areas in the stretches between stations. This tunnel effect can be observed in Figure 4 in the HSR corridor Madrid-Sevilla.
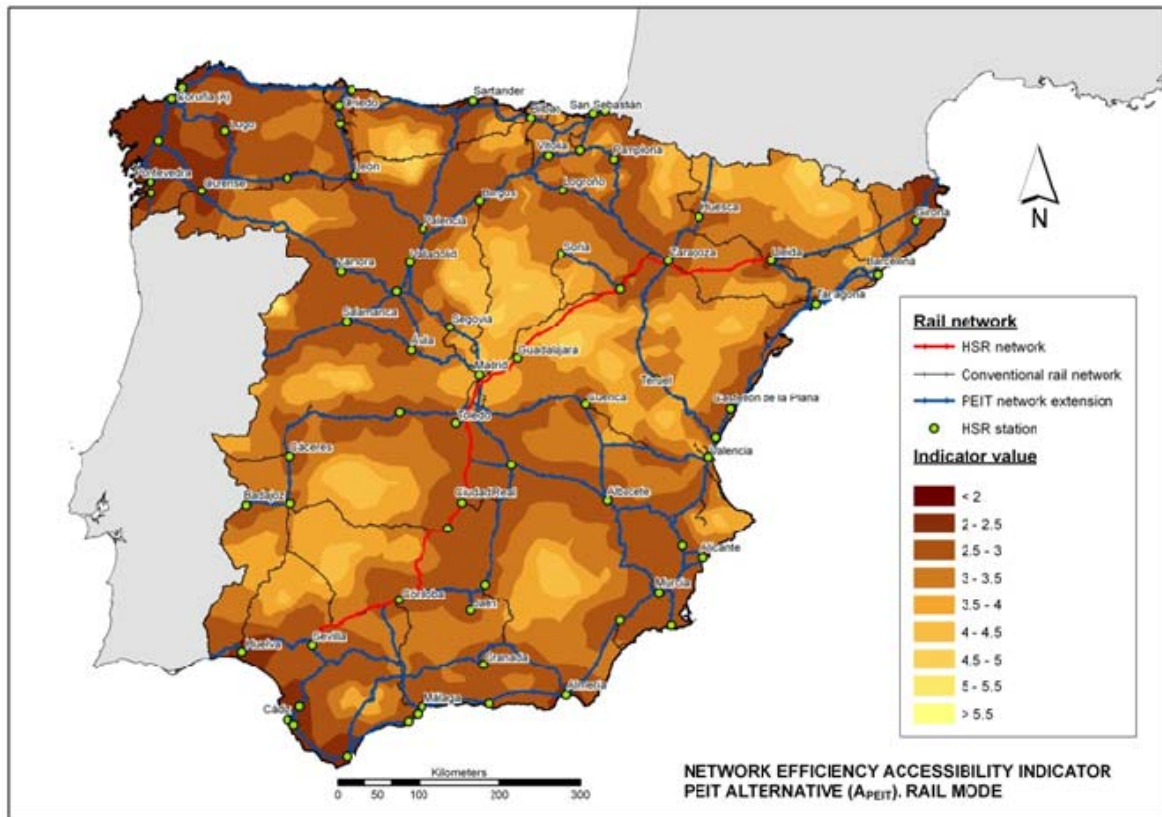

Figure 5: Network efficiency of the PEIT scenario (Scenario 10)

This situation experiences a significant improvement with the extension of the HSR network included in the PEIT alternative, as Figure 5 shows. The location of the stations has a strong influence in the final results, therefore resulting in a highly marked tunnel effect (see e.g. the Zaragoza-French border stretch). In general, best accessibility results appear concentrated in the surroundings of HSR stations, except in those of very large urban agglomerations, such as Madrid . Some inner areas in Extremadura, Castilla y León and Aragón still appear as landlocked areas. They correspond mainly to areas which are not crossed by HSR infrastructure.

Table 2 includes the accessibility results obtained in each scenario, for each of the three accessibility formulations chosen. The accessibility value is included both in absolute terms (mean column), and in relative terms (compared with the do-nothing scenario). The inclusion of both values enables an easier comparison of the results obtained in each scenario, and the comparison of percentage change values among different accessibility indicators.

The values included in Table 2 show, as expected, that Scenario 9 obtains the best accessibility scores, whereas the do-nothing scenario (Scenario 1) is the one with worse accessibility performance. As expected, differences in the percentage change vary among

indicators, given the different approach that each formulation has in its measurement of accessibility, as concluded in similar studies (Martín et al, 2004; López et al, 2008).

Scenario		Accessibility indicator					
		Economic Potential		Location		Network efficiency	
Short name	Number	Mean	Relative	Mean	Relative	Mean	Relative
000	1	187,601.12	100.00	324.33	100.00	7.15	100.00
0+Gal	2	192,958.23	102.86	311.03	95.90	6.94	96.97
0+Gal*	3	194,978.82	103.93	307.28	94.74	6.87	96.06
PEIT-Gal	4	258,768.59	137.94	220.51	67.99	5.13	71.76
PEIT+Gal*	5	269,263.98	143.53	209.42	64.57	4.94	69.00
0+Med	6	199,423.09	106.30	302.87	93.38	6.75	94.33
0+Med*	7	208,750.41	111.27	290.92	89.70	6.48	90.56
PEIT-Med	8	250,212.80	133.37	227.37	70.10	5.31	74.21
PEIT+Med*	9	278,961.35	148.70	202.80	62.53	4.76	66.56
PEIT	10	265,289.54	141.41	213.03	65.68	5.00	69.94

Table 2: Accessibility results by scenario

It is also interesting to analyze the results in terms of the percentage change in accessibility that each corridor represents, as well as the distribution of these changes. An example of this type of analysis can be made from the observation of Figures 6 to 9. They represent percentage change improvements in network efficiency between scenarios, when compared with the do-nothing scenario.

For example, the analysis of Figure 6 enables to draw conclusions on the spatial distribution of the improvements that the construction of the Galician corridor produces in terms of network efficiency. These are not homogeneusly distributed along the HSR corridor, but unevenly spread, mainly due to the also uneven distribution of the HSR stations, but also due to the existing rail connections between the Galician corridor and the other HSR links. This effect is easily shown by some examples, such as e.g. that the northern corridor or western Extremadura, which are situated relatively near the Galician corridor, receive lower accessibility improvements than other areas located further away, such as Cataluña or Andalucía. Additionally, the differential changes that an increase in the Galician corridor speed-from 220 km/h to 300 km/h- can be analysed if Figure 7 and Figure 6 are compared. It can be seen how the darker areas are extended to other regions, such as e.g. the surroundings of the Segovia HSR station. Again, this extension does not follow a pattern of proximity to the HSR corridor. The above are specific characteristics of HSR links, which do not appear when High Capacity Road corridors are analyzed (López et al, 2008).

Similar analyses can be made for the Mediterranean corridor, from the values mapped in Figures 8 and 9. In this case, the comparatively better situation of the Mediterranean area enables that changes are extended to larger areas than in the Galician case. Another interesting planning exercise can be made if the difference between the PEIT and the "PEIT except" scenarios (#4 and #8) are mapped.
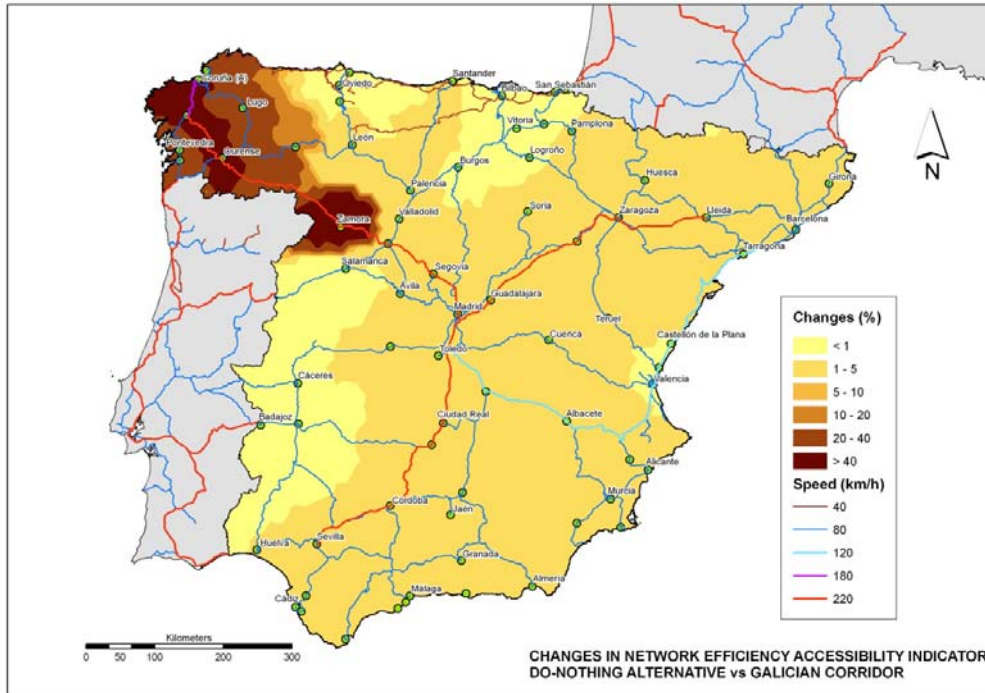
Figure 6: Do-nothing scenario (#1) vs. Galician corridor scenario (#2)
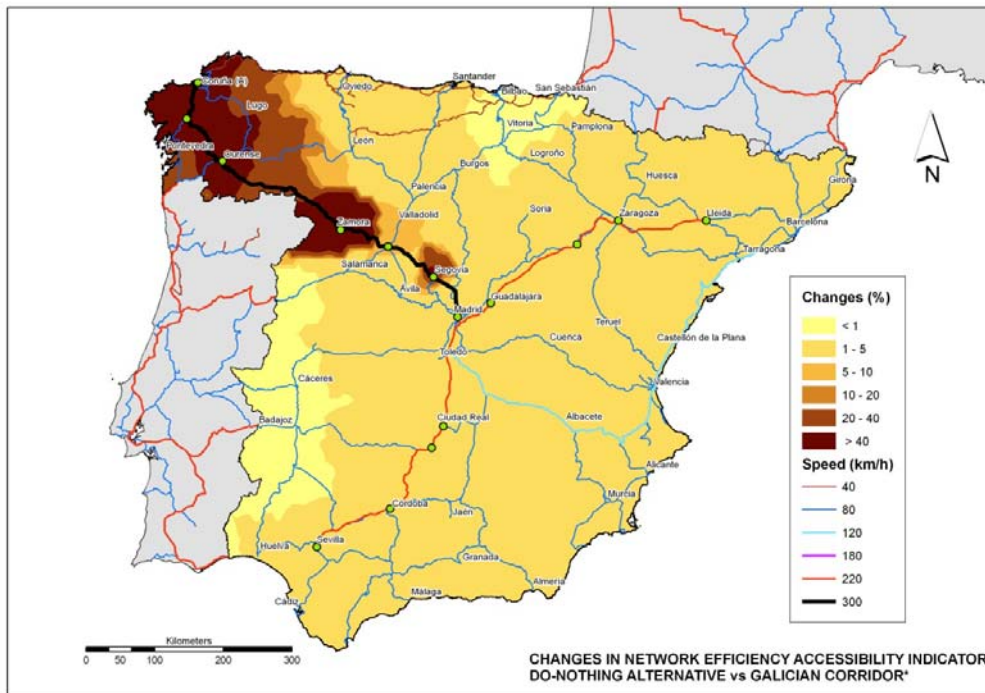
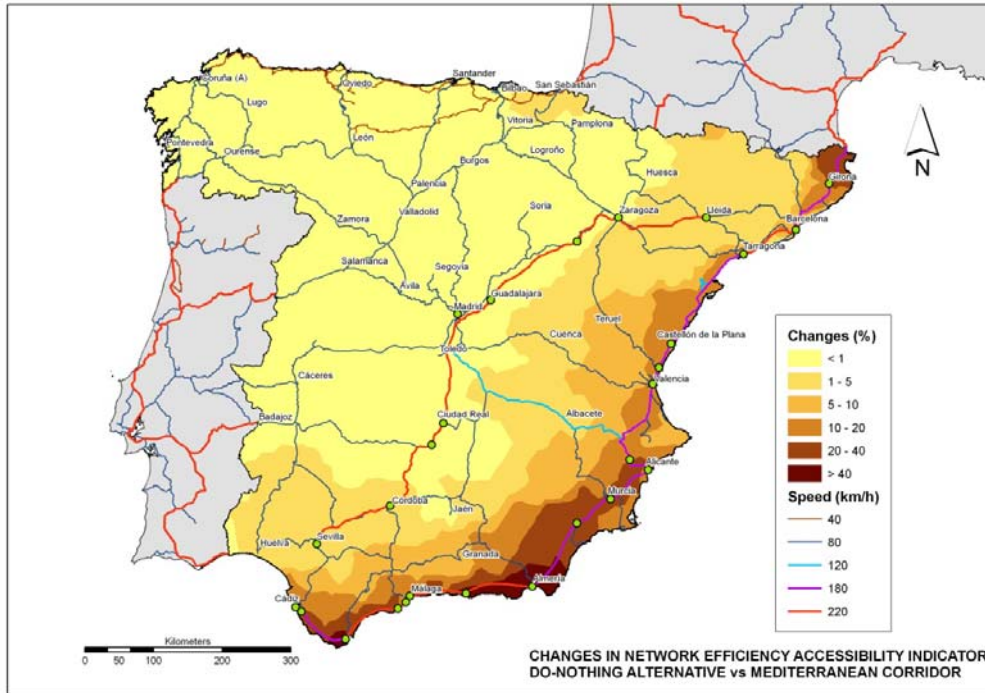Figure 7: Do-nothing scenario (#1) vs. Galician corridor* scenario (#3)

Figure 8: Do-nothing scenario (#1) vs. Mediterranean scenario (#6)

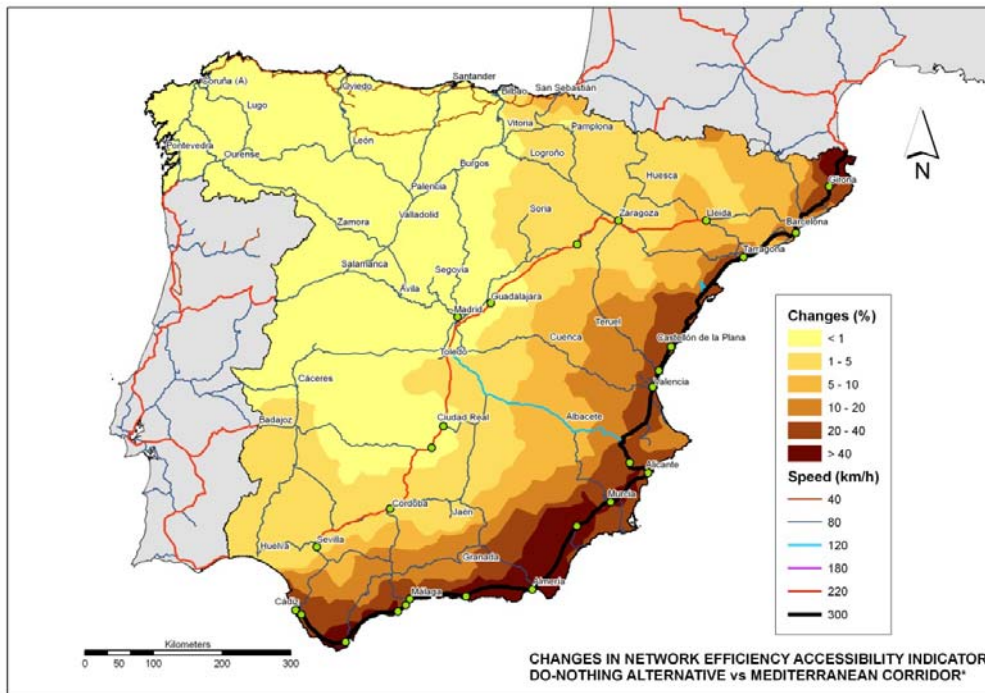
Figure 9: Do-nothing scenario (#1) vs Mediterranean scenario* (#7)

4.4. Analysis of equity effects

Equity effects are frequently measured in terms a set of statistical indices of the spatial distribution of accessibility values. The selection of equity indices was carried out on the basis of their proven efficiency in previous studies (Martín et al., 2004; Bröcker et al., 2004; López et al, 2008; Schürmann et al., 1997). These authors agree that there is no "ideal" equity index and therefore suggest computing a set of them in order to analyze their results in a complementary way.

As this paper deals with the conflict between efficiency and equity, the presentation of the results of different inequality indexes would require excessive space[2]. Therefore we have selected among them the coefficient of variation, as the most appropriate for the discussion of results in this paper. The values of the coefficient of variation have been included in Table 3. The inequality index is computed over the sample containing the accessibility results. The sample contains near 8,000 records of accessibility values, one for each of the municipalities (NUTS-5 aggregation level) existing in Spain. The population of each municipality has been used as the weighting variable for the calculation of the cohesion indices.

		Coefficient of variation					
		Economic Potential		Location		Network efficiency	
Short name	Number	Mean	Relative	Mean	Relative	Mean	Relative
000	1	43.03	100.00	36.82	100.00	28.21	100.00
0+Gal	2	30.56	71.03	26.46	71.87	37.12	131.57
0+Gal*	3	41.76	97.06	34.41	93.47	29.64	105.07
PEIT-Gal	4	41.53	96.53	34.23	92.97	30.18	106.97
PEIT+Gal*	5	31.59	73.42	29.00	78.76	35.88	127.20
0+Med	6	30.27	70.36	25.98	70.58	37.76	133.84
0+Med*	7	40.01	92.99	37.93	103.03	29.79	105.60
PEIT-Med	8	39.02	90.68	40.08	108.86	31.15	110.42
PEIT+Med*	9	32.95	76.58	26.74	72.63	37.26	132.08
PEIT	10	29.52	68.61	27.66	75.13	37.53	133.02

Table 3: Inequality index across accessibility indicators

The choice of the accessibility indicator is foreseeable to have a strong influence on the coefficient of variation results (López et al, 2008; Martín et al, 2004). Gravity-based and cumulative opportunity indicators have been proven to result in more polarized distributions than weighted distance and network efficiency indicators (Schürmann et al., 1997; Baradaran and Ramjerdi, 2001; Martín et al., 2004). The values in Table 3 confirm this point. The different nature of the accessibility indicators is responsible for these differences: potential indicators express their results in population/income units, whereas location and network efficiency indicators provide their results in terms of transport costs, introducing population/income only as a weighting factor.

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[2] Their detailed formulation and a comprehensive review on inequality measurement can be found in Cowell (1995)

In order to correctly interpret these changes, it is important to bear in mind that each of the selected accessibility indicators provide different and complementary information; therefore each one shows different spatial accessibility contrasts:

- The *location* indicator mainly results in marked core-periphery patterns (distorted by both the alignment of higher quality infrastructure and the location of major economic activity centers).
- The *economic potential* indicator particularly highlights contrasts between large urban agglomerations with a HSR station and remote rural areas.
- The *network efficiency* indicator emphasizes contrasts between major transport infrastructure corridors (HSR links) and the areas located between them ("shadow areas").

The values of the coefficient of variation included in Table 3 confirm this point: it may happen that a reduction in accessibility differences between core and periphery areas (location indicator) correspond to an increase in differences between HSR corridors and shadow areas (network efficiency indicator), or to a more balanced distribution of accessibility between large urban agglomerations with a HSR station and remote rural areas (potential indicator).

The main lesson that can be learned from these results is that the perspective with which accessibility is computed has a strong influence in the conclusions on the equity effect of a new HSR corridor. It is out of the scope of this paper to investigate the specific characteristics of each scenario that influence these results. Despite this fact, the values included in Table 3 constitute an example of the apparently contradictory results that may appear if different accessibility indicators are used. Hence, the choice of accessibility indicators should be made in accordance with the approach driving the spatial equity objective. This necessarily requires a consensus with decision makers on the definition of the strategic objectives of the transport Plan under consideration.

5. CONCLUDING REMARKS

The trade-off between equity and efficiency objectives is far from been translated into assessment methodologies. This paper introduces a procedure to take into account these two objectives via the calculation of a set of accessibility and equity indicators. The underlying assumption is that a convergence in accessibility levels implies improved equity, i.e. an increase or reduction of spatial disparities in accessibility will result in a negative or a positive equity effect, respectively.

The paper has proven the importance of finding appropriate measurement tools depending on the planning objective under consideration. Accessibility indicators may have an important role to play as useful tools for this task, but significant research is still to be done before a consensus can be reached on which indicator should be used for each purpose. The case study included in this study constitutes an example of the ample variety of perspectives under which efficiency and equity effects of rail infrastructure investments can be assessed. The translation of the trade-off between both effects into the planning process requires the collaboration between decision makers and transport planners. This collaboration would extend to the remaining strategic impacts present in the evaluation of large scale transport infrastructure investments, such as Transport Master Plans (López et al, 2008; López, 2007).

The application of the suggested procedure to a set of 10 scenarios of rail network extension provides evidence from the Spanish case study, and has made it possible to identify the role played by the different factors involved in the proposed approach. One of the main conclusions obtained is that results are strongly influenced by the formulation of the accessibility indicator chosen for the analysis.

The location indicator may be very useful for policy evaluation at national or supranational levels, as it does not include a gravitational component in its formulation; therefore the relevance of long distance/strategic links is not underestimated. The potential indicator is more suited for studies with an economic orientation, although special attention has to be given to the treatment of the self-potential, which may exacerbate agglomeration effects, mainly in large cities. Results obtained with the network efficiency indicator highlight the influence of the performance of transport system, reducing the effects derived from the geographical position.

Hence, the selection of the most appropriate indicator depends on the approach of the study. If the analysis is more focused on the economic implications of equity effects, one should choose an indicator with an economic foundation, such as the potential indicator. If our interest is more inclined towards an equalisation of the transport network quality, we should choose a more infrastructure-oriented indicator, such as the network efficiency indicator.

The analysis carried out in this paper constitutes an example of a planning exercise that should be carried out when large scale transportation investments, such as a National Transport Master Plan, are to be designed. The potential of GIS representational features and the ability of accessibility indicators should be fully exploited in order to derive consistent and commonly agreed procedures to deal with the efficiency/equity conflict in assessment methodologies. This constitutes a topic for further research.

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