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TITIM GIS-tool: A GIS-based decision support system for measuring the territorial impact of transport infrastructures

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ABSTRACT

To achieve sustainability in the area of transport we need to view the decision-making process as a whole and consider all the most important socio-economic and environmental aspects involved. Improvements in transport infrastructures have a positive impact on regional development and significant repercussions on the economy, as well as affecting a large number of ecological processes.

This article presents a DSS to assess the territorial effects of new linear transport infrastructures based on the use of GIS. The TITIM – Transport Infrastructure Territorial Impact Measurement – GIS tool allows these effects to be calculated by evaluating the improvement in accessibility, loss of landscape connectivity, and the impact on other local territorial variables such as landscape quality, biodiversity and land-use quality. The TITIM GIS tool assesses these variables automatically, simply by entering the required inputs, and thus avoiding the manual reiteration and execution of these multiple processes. TITIM allows researchers to use their own GIS databases as inputs, in contrast with other tools that use official or predefined maps.

The TITIM GIS-tool is tested by application to six HSR projects in the Spanish Strategic Transport and Infrastructure Plan 2005–2020 (PEIT). The tool creates all 65 possible combinations of these projects, which will be the real test scenarios. For each one, the tool calculates the accessibility improvement, the landscape connectivity loss, and the impact on the landscape, biodiversity and land-use quality. The results reveal which of the HSR projects causes the greatest benefit to the transport system, any potential synergies that exist, and help define a priority for implementing the infrastructures in the plan.

1. Introduction

Determining the effects of a planned linear transport infrastructure (road and railway) is a highly complex task. There are a large number of environmental and socio-economic aspects involved, and a consensus has yet to be reached as to how to assess both the positive and negative impacts.

Transport infrastructures are a vital social and economic resource, and provide access to today's economic and social opportunities (Richardson, 2005). Investment in the construction and maintenance of transport infrastructures is vast, and its repercussions can be seen throughout all areas of society (Hilden, Furman, & Kaljonen, 2004; Short & Kopp, 2005). This is why correct planning of transport systems is essential (Hilden et al., 2004).

The increased use of transport systems has gone hand-in-hand with a growing awareness of their impacts (Hine, 1998), creating a need for sustainable and integrated development (European commission, 1998; US department of transportation, 2000). To attain sustainability in the area of transport it is necessary to have an overall view of the decision-making process; in other words, all the aspects involved – transport planning, land use and the environment – must be considered in conjunction rather than viewed in isolation. For Hull (2005) the great challenge is to succeed in integrating these principles into decisions on transport and land use.

This challenge requires tools that can identify and assess the environmental, social and economic aspects of their decisions (Abaza & Baranzini, 2002; Boulanger & Bréchet, 2005). A further requirement is to be able to identify which criteria need to be assessed, the importance of each one and how they can be integrated; this is a highly challenging task (Boulanger & Bréchet, 2005). To facilitate this process, the European Parliament passed Directive 2001/42/EC on the assessment of the effects of certain

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plans and programmes on the environment. Strategic Environmental Assessment (SEA)[1] is the ideal tool for complying with this Directive, as it includes social and economic aspects alongside environmental concerns. The SEA must be applied flexibly, but its application must identify sustainability targets, criteria and indicators; identify and compare alternatives and impacts (scoping); and assess these impacts (Arce & Gullón, 2000; Retief, 2007; Thérivel & Partidario, 1996).

It is far from simple to identify the most important aspects requiring consideration. Scientists and planners broadly agree on a number of options: from the socio-economic point of view, the improvement in accessibility to goods and services has a positive impact on regional development (Ozbay, Ozmen-Ertekin, & Berechman, 2003; Vickerman, Spiekermann, & Wegener, 1999). In various planning documents at the European or national scale – the European Spatial Development Perspective (ESDP) (European commission, 1999), the recommendations for the development of trans-European transport networks (TEN-T) (European commission, 2005) and the Strategic Infrastructures and Transport Plan 2005–2020 (Ministerio de Fomento, 2005) – the term "accessibility" is cited as a priority objective, and is considered an instrument for achieving economic and social cohesion targets. Likewise, several studies (Geurs & van Wee, 2004; Gutiérrez, Monzón, & Piñero, 1998; Halden, 2003; Monzón, Ortega, & López, 2013; Ortega, López, & Monzón, 2012; Talen & Anselin, 1996 among others) defend the need to exploit the potential of accessibility indicators as a support tool in infrastructure planning tasks aimed at efficiency and territorial cohesion.

Regarding territorial environmental aspects, linear transport infrastructures divide ecosystems, thus leading to a loss of habitats and increased fragmentation (McGarigal, Romme, Crist, & Roworth, 2001; Reed, Johnson-Barnard, & Baker, 1996). Habitat fragmentation can be seen as a loss of connectivity (Serrano, Sanz, Puig, & Pons, 2002) between habitats, which hinders the displacements of organisms, energy flows and migratory and dispersive movements between different patches (Taylor, Fahrig, Henein, & Merriam, 1993; Tischendorf & Fahrig, 2001).

In addition to this loss of connectivity, transport infrastructures have a considerable impact on the territory due to the occupation of the space by part of the infrastructure itself, and to their use (traffic); these are common to all types of linear infrastructures (Geneletti, 2006). The occupation of territory by a new infrastructure brings a decline in the natural values found in it. It is worth highlighting particularly the loss of natural land uses or land with high productivity, the loss of individuals and the resulting loss of biodiversity (Bottero, Comino, Duriavig, Ferretti, & Pomarico, 2013), and the deterioration of the visual landscape (Zube, Sell, & Taylor, 1982).

After establishing the criteria for assessing the effects of infrastructure plans, the next step is to find a tool capable of handling the large volume of quantitative and qualitative geographic data required. The complex interrelationships among the variables (environmental, social and economic) involved in the planning process makes it difficult to reach an objective decision. According to Witlox (2005), the large quantity of data and the complexity of these relationships mean that planners are unable to resolve correctly the problem in hand and must use computers and Information Technology (IT) programmes capable of analysing all the information. The IT tools that have proved to be capable of carrying out this work are GIS, as they are able to handle two types of information: spatial data and the quantitative and/or quantitative information associated with them. The possibility of making calculations with greater accuracy and objectivity renders this best possible tool for the processes of territorial planning and assessing the impacts caused by transport infrastructures (Sikder, 2009).

There are a number of GIS-based methodologies for solving transport problems. Transport planning is usually related to network analysis. The best route calculations, best activity location, demand models and accessibility calculations are all based on GIS network analysis. Ortega, Mancebo, and Otero (2011) provide a complete description of the GIS process for calculating accessibility indicators at the planning level; Karou and Hull (2014) model the accessibility impacts of changes in public transport provisions; Novak and Sullivan (2014) evaluate accessibility to emergency services via a road network using a link-focused approach; Sadeghi-Niaraki, Varshosaz, Kim, and Jung (2011) study relevant and related variables affecting each road segment during network analysis in order to develop an appropriate impedance model in route planning. Other widely studied aspects concern the environmental impacts of transportation. Demirel, Sertel, Kaya, and Seker (2008) estimate vehicle emissions and determine the impact of traffic on urban air quality using GIS capabilities. García-Montero, López, Monzón, and Otero (2010) develop a methodology to estimate the potential overall impact of an infrastructure plan on biodiversity and global warming for a whole country. Several methodological approaches map areas of transport sensitivity to establish the necessary protection measures (Enei, Münier, Ricci, & Fuglsang, 2012). Other studies seek to optimise the choice of corridors, usually based on spatial multi-criteria analysis, as in De Luca, Dell'Acqua, and Lamberti (2012) for high speed railway (HRS) lines, or Effat and Hassan (2013) for highway routes, considering environmental impacts, social and economical components and cost/geometric factors.

However most of these methodologies are complex and require a long calculation time. They can be improved by decision support systems (DSS), which are capable of storing, handling and processing large quantities of data; they include mathematical models; and they enable the incorporation of multi-attribute decision-making methods. There are DSS for estimating emissions, such as STEEDS (Brand, Mattarelli, Moon, & Wolfler Calvo, 2002), which assess energy and environmental impacts (emissions, pollutants, global warming potential...); or more recently HERA (Sobrino, Monzon, & Hernandez, 2014), which assess and compare the energy and carbon footprint of different highways and traffic-flow scenarios. In the optimisation of infrastructure routes or location models, DSS evaluate several possibilities for proposed routes. Kim, Wunneburger, Neuman, and Young (2014) evaluate different HSR routes, considering both suitability and cost (construction and land acquisition) aspects; SABILOC (Fernandes, Captivo, & Clímaco, 2014) facilitates the problem of location by considering environmental impacts; and Krichen, Faiz, Tlili, and Tej (2014) propose a tool for solving the problem of vehicle routing by means of loading and distance requirements. On the topic of environmental impact assessment, Herrero-Jiménez (2012) identifies environmental impacts based on graphic overlapping between project and environmental factors. However, in contrast with the vast number of GIS methodologies, there are only a limited number of real GIS-based DSS in transport planning.

Most of these DSS compare alternatives or policy options (Brand et al., 2002; Kim et al., 2014; Sobrino et al., 2014). Some focus on developing complete MCA modules (Coutinho-Rodrigues, Simão, & Antunes, 2011), while others calculate complex indicators, generally emissions-related (Arampatzis, Kiranoudis, Scaloubacas, & Assimacopoulos, 2004; Brand et al., 2002; Sobrino et al., 2014). However, except in certain cases such as SABILOC (Fernandes et al., 2014), they do not tend to involve very complex GIS calculation methodologies. Specifically, there are no DSS that allow both

[1] Sadler and Verheem (1996) define Strategic Environmental Assessment (SEA) as "a systematic process for evaluating the environmental consequences of proposed policy, plan or programme initiatives in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision making".