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ORIGINAL ARTICLE

Integrating multicriteria evaluation and data visualization as a problem structuring approach to support territorial transformation projects

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Abstract Large freight or passenger transport projects are problematic and controversial because many financial, technical, environmental and social aspects need to be considered. Indeed, the interface between the transport project and territorial planning domains is generally the focus of considerable heated debates, which often develop into conflicting decision contexts characterized by a high level of complexity. This paper presents a possible response to these difficulties through an innovative approach that integrates the analytic network process and the interactive visualization tool. The approach is intended to be deployed as problem structuring method, with a view to creating a common language for the actors involved and a shared basis for generating fruitful discussions. The proposed approach was applied in the context of the German section of the Genoa–Rotterdam railway corridor within the Interreg IVB NWE Project “Code24”. The reported application shows how the combination of visualization and real-time interaction with spatial data provided effective decision support to a multinational stakeholder group. More generally, the application presented in this paper aims to demonstrate the potential

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of the approach for the selection of a transport improvement strategy within the content of territorial transformation.

Keywords MCDA · Visualisations · Transport · Territorial planning

Mathematics subject classification 90

1 Introduction

It is widely acknowledged that transport projects can increase the accessibility of an area, generally bringing economic benefits (Secchi 2013). However, they require significant financial investments (which are often absent), leave indelible marks on the territories and pose (short- and long-term) environmental and social risks (Cascetta 2009). Every alteration in this subset causes a change in the conditions of accessibility of an area. In turn, the change in accessibility brings an alteration in the attractiveness of an area, which results in a transformation of the physical and functional conditions of a territory. Finally, if the activities of an area are varied, a change in the demand of transport follows.

The controversy and the difficulties of a public transport project, whether of freight or passenger, arise because many different elements need to be considered, including technical aspects related to the capacity of the convoys, environmental aspects related to the pollutant emissions and social aspects associated with the use of transport. Indeed, the interface between the transport project and territorial planning domain is commonly the focus of considerable debates that often develop into conflicting decision contexts which are characterized by a high level of complexity. In the past, transport investments in cities were possible through debate on the basis of growth allocation and were the main means to promote economic development and revitalization of depressed areas (Marshall and Banister 2007). This topic has now been broadened to embrace new aspects, such as the growing awareness and concern about sustainability (Hickman and Banister 2014; Whitehead et al. 2006), for which a balance between social, ethical, environmental, financial and operational criteria is needed with both short- and long-term considerations (Bond et al. 2008, 2010; Hahn 2014). Moreover, the presence of many actors with different backgrounds has limited the information-sharing process (Kiker et al. 2005; Huang et al. 2011).

The above contextual characteristics exhibit many similarities with those for which problem structuring methods (PSMs) have been developed (Ackermann 2012; Rosenhead and Minger 2001; Mingers and Rosenhead 2004). PSMs are flexible mechanisms for addressing complex problems by representing the situation in a structured manner to develop innovative solutions (Mingers and Rosenhead 2004). They are particularly useful when it is necessary to address complex issues characterized by "the presence of multiple actors often with different perspectives and objectives, conflicting interests and uncertainties" (Mingers and Rosenhead

2004; Rosenhead and Mingers 2001; Rosenhead 1996). PSMs support participants' learning about their own and others' perspectives, as well as the problematic situation of concern (Checkland and Poulter 2006). The intention of PSMs is to assist people, who might initially have different perspectives on an issue, by means of clarifying and developing collective understandings and accommodations and identifying appropriate actions (Jackson and Keys 1984; Jackson 2003). To do this a PSM must (Mingers and Rosenhead 2004): (1) enable several alternative perspectives to be brought into conjunction; (2) be cognitively accessible to actors with different backgrounds; (3) develop a participative process of problem structuring; and, (4) operate iteratively permitting partial or local improvements to be identified.

The features of PSMs described above seem to be adaptable at making constructive improvements on the representation of alternative scenarios for decision problems concerning transport infrastructure. Indeed, the need for decision support tools that are able to consider all the different aspects of transport planning projects is becoming increasingly more evident. Additionally, overcoming the logic of simply applying the cost–benefit analysis approach that has been, until recently, almost the sole assessment tool within the field of transport, is also needed (Næss 2006). We argue that a PSM-based approach can provide a potentially useful response in this context. Specifically, we propose multicriteria decision analysis (MCDA) (Belton and Stewart 2002, 2010), deployed in 'facilitated modelling' mode (Franco and Montibeller 2010) and supported by appropriate visualization tools, as a potentially useful PSM-based approach in the context of territorial transformations connected to transport projects. By using MCDA together with other interactive software (e.g. ranging from Excel to Grasshopper and Rhinoceros), it becomes possible to visualize the perceived influences affecting the decision context, resulting in an increase of transparency of the model and thereby and increased understanding and confidence in the model itself.

The integration of MCDA and data visualization creates a tendency toward a shared understanding among the actors involved in the decision process (Andrienko et al. 2007; MacEachren 2004). The use of an interactive visualization tool can support the deployment of MCDA in terms of showing results, exploring alternative options and evaluating the differences in the localization of the expected positive and negative effects, all of which are conducted 'on the spot' (Franco and Montibeller 2010, 2011). In this paper, we report on the application of an innovative PSM-based approach that integrates the analytic network process (ANP) (Saaty 2005; Saaty and Vargas 2006) and the interactive visualization tool (InViTo) (Pensa 2013), in the context of the Corridor 24 railway corridor, Genoa-Rotterdam. This is part of a Interreg IVB NWE Project called Code24 which involves 17 partners from five European countries over 5 years (2010–2014) and aims to define a single shared strategy. The paper will describe how the approach was introduced into the decision context, how it informed the design and realization of the transport planning process, the definition of the alternative solutions to the decision problem, who the participants were, whose preferences were used in the analysis and finally how the criteria weights were elicited.

The remainder of the paper is organized as follows. In the next section, we introduce the approach and its components. Next, we describe its application, including the decision context, evaluation process, model structure and model results. We end the paper by offering some conclusions, highlighting the strengths and weaknesses of the proposed approach.

2 Methodological framework

2.1 ANP/InViTO approach

The literature reports a variety of problem structuring methods (PSMs) (Mingers and Rosenhead 2004; Rosenhead and Mingers 2001) including, for example, strategic options development and analysis (SODA) (Ackermann and Eden 2010), soft systems methodology (SSM) (Checkland 1981) and strategic choice approach (SCA) (Friend and Hickling 2005). In all these approaches, visual representation is fundamental to support the process. For example, SODA uses visual maps using the cognitive mapping technique (Eden 1988) to capture individual views of an issue. SODA also uses group visual maps constructed through the aggregation of individual maps, which are then used to facilitate group decision and negotiation (Bryson et al. 2004; Eden and Ackermann 2010). Similarly, SSM uses rich pictures and visual models of purposeful human activity to represent stakeholders' views about the system of interest (Checkland and Scholes 1990; Checkland and Poulter 2006). Finally, although software support is now available, SCA was originally developed using graphs and grids drawn on flip charts and stuck on free wall space, which provide an interactive decision forum for both individuals and small groups (Friend and Hickling 2005).

As in the approaches cited above, visual representation is a significant part of the ANP/InViTo approach presented here. Specifically, visual representation plays a key role in the content and process of collaboration, helping people involved to "get on the same page" (Vennix 1996) and to have a collective insight (Andersen and Richardson 1997) about the issue involved. The visual products resulting from its application include tangible two-dimensional or three-dimensional shared representations that portray salient dependences and relationships among participants' objectives, expertise, decision and actions. In addition, these representations can be modified by 'on-the-spot' input from every participant (Franco and Montibeller 2010, 2011; McKenzei and Winkelen 2011; Black and Andersen 2012). However, to facilitate the decision process, it is not sufficient to apply a good visualization tool. It is also necessary to have "good decision bones", to structure the decision problem in a simple and effective way to capture the complexity of the reality. This is to help the actors involved to 'choose in a strategic way rather than at a strategic level' (Friend and Hickling 2005). In this perspective, the role of the consultant becomes being both a process designer and a facilitator, rather than an investigator and solution provider (Eden 1990; Franco and Montibeller 2010; Omerod 2013).

To achieve this objective, multicriteria decision analysis (MCDA) approaches can be pivotal in complex decision processes. As MCDA approaches are countless, it is necessary to reflect on the most suitable method for the decision context at hand (Roy and Slowinski 2013). To structure the decision process presented in this paper, we chose to apply the analytic network process (ANP) methodology for several reasons (see "Appendix" for a description of the ANP method). First, the type of results the ANP methodology is expected to bring are numerical values assigned to each potential action. Moreover, the ANP methodology is able to produce a list of *k*-best actions to be analysed further by the people involved. Second, the original performance scale of the ANP method, the Saaty's fundamental scale of absolute numbers (Saaty 2005), has all the properties required for a correct application. Hence, there is no need to transform or codify the original scale, which could cause the rise of arbitrary transformation that could, in turn, affect the process as a whole. Third, the software tool involved (http://www.superdecisions.com) and the interaction protocol are compatible with the way of reasoning of the inquired people and with their meaning of useful results. Moreover, thanks to the sensitivity analysis (paragraph 3.4.2), the intelligibility and traceability of the impact of the preference information on the results are ensured. Finally, the ANP is a simple and understandable methodology even by those who are not experts in the decision process, and it is suitable to be applied jointly with visual representations in real time during workshops.

In summary, the research presented here focuses on the use of the analytic network process (ANP) methodology combined with the interactive visualization tool (InViTo) for the visual assessment of spatial issues (Pensa et al. 2014). InViTo is a visual method to communicate spatial information, which aims at improving the understanding of spatial data in decision-making processes through the exploration of alternative strategy options. The visual images presented in this paper are a tangible representation of dependences across disciplinary, organizational and cultural lines that all participants can modify. If an object is 'transformable', then anyone involved has the possibility to manipulate and alter the representation to show more clearly the consequences of the dependences he/she perceives (Black and Andersen 2012; Eden 1990; Franco 2013).

2.2 InViTo

InViTo is a visual method for communicating and sharing the information included in spatial databases. InViTo is conceived as planning support system (PSS) and spatial decision support system (sDSS) (Batty 2007; Geertman and Stillwell 2003, 2009; Klosterman 1997, 2012), which aim at building common mental models among different actors to enhance discussions and raising awareness on spatial issues.

It is based on Grasshopper, a free plug-in of McNeel Rhinoceros, which is a software for 3D modelling used in architectural and industrial design (Marina et al. 2012; Pensa 2012; Pensa et al. 2011, 2013a, b). By the integration of Grasshopper with tools for managing databases, InViTo offers a visual interface for showing, filtering and visually selecting data while comparing different alternative options.

Current PSS and sDSS are mainly based on GIS technologies and present a large difficulty in being applied in daily practice (te Brömmelstroet 2010; Vonk et al. 2005). First of all, it takes a long time for these systems to calculate results which hinder the interaction between data models and users; second, data models generally have low flexibility to adjust to specific needs; third, most of these support systems have limited abilities in communication.

Meanwhile, an overview of problem structuring method (PSMs) (Sect. 2.1) shows that the procedure for supporting decision-making during operational workshops should present specific features (Mingers and Rosenhead 2004), which have many common features with the elements required for PSS and sDSS. For these reasons, InViTo has been created to fulfil the specific requirements. In fact, it aims at being easily accessible to actors with different backgrounds, building a shared basis of discussion among the actors involved and being interactive to allow adjustments during decision processes. Furthermore, InViTo offers a way to represent different typologies of geo-referenced data and to combine them to visualize the "hidden connections" (Dodge 2005) among these data. It does not intend to overcome GIS tools, but aims at enhancing the communication of information included in the relationships among data. In fact, differently from the GIS tools commonly used, the parametric features of 3D modelling allow the direct and immediate changes in volumes shapes and colours, offering interactive visualizations of information.

To provide support in dealing with transport strategies, InViTo has been set to combine its visual interactive properties to the ANP methodology, so as to build 3D meshes according to the ANP model and the Saaty's scale. For each comparison between the elements, clusters or strategies, InViTo generates changes within the displayed maps on the basis of the numerical weights given by DMs during the compilation of the pairwise comparison matrices. The system provides a visual translation of numerical values into urban and territorial changes by means of an abstract and symbolic representation, which allows DMs to readily interact with spatial issues. This way, users are supported in analysing the issues discussed during the ANP process and can better understand where and how much their choices might have some consequences on the territory.

To work with the ANP methodology, the structure of InViTo follows three steps:

Step 1—data import: Data and information about the case study, such as GIS data, databases, CAD drawings, texts, images and even videos, are collected and elaborated to be included in a common framework. Data are then imported into the Grasshopper plug-into be managed on the basis of specific tasks connected to the case.

Step 2—definition of rules: Imported data are organized within a data model which links the information to the geometries. Each geometry is geo-referenced, so that it can be overlaid on a map and associated to specific transformation rules to determine the interactions among spatial objects. Transformation rules define the behaviour of geometries in relation to the ANP element to which they refer.

To integrate InViTo with the ANP methodology, geometries change according to the impact of the ANP elements on the area. The circumference of an element portrays the expected positive or negative effect, whereas the height shows the expected impact intensity, both of which depend on the values attributed by the participants using the Saaty's scale.

Step 3—output visualization: The geometric shapes and volumes located on the map are connected to rendering rules. These rules define how data are converted in visible forms in terms of shapes, volumes and colours. This procedure constructs a dynamic image which changes according to the values assigned by the users' answers of the ANP pairwise comparisons.

Following these three steps, InViTo generates dynamic maps that will change in real time according to the discussion which raises during the workshop based on the ANP set of questions.

3 Application

3.1 Context and objectives

The trans-European railway axis from the port of Rotterdam to the port of Genoa is a freight and passenger axis, which includes conventional and high-speed rail. Crossing the Netherlands, Germany, Switzerland and Italy, this European north–south transport axis has a length of 1.200 km and a catchment area of 70 million inhabitants. The European Union's objective is to double the capacity of the rail transport on the axis by 2020, to encourage a modal shift of freight by rail: the main projects which refer to this topic are the Swiss rail tunnel Loetschberg (opened in 2007), the Gotthard tunnel (expected in 2017) and the Mount Ceneri tunnel (expected in 2020). Furthermore, a secondary objective is to accelerate and develop the transport capacity of the corridor as a whole, ensuring optimal economic benefits and spatial integration.

Additionally, the EU aims to reduce the negative impacts on the environment at a local and a regional level. Therefore, the project will strengthen the position of the regional actors and the stakeholders within the railway corridor by focusing on regional aspects along the corridor area and developing strategies.

The importance of this connection is mainly viewed from the perspective of freight and passenger transport. Nevertheless, there are still many problems, as many sections of the corridor do not have adequate functioning capacity. Other problems are related to the standpoint of management, due to the presence of different transport services (freight, long distance, local traffic) and the lack of coordination and interoperability at a trans-regional level.

The EU-funded project "Code24", approved under the Strategic Initiatives Framework of the Interreg IVB NWE programme, aims at a coordinated transnational strategy to support the improvement and the development of this corridor (http://www.code-24.eu). To come to a shared strategy for the corridor, it is important to come to a common understanding about the unsolved issues that affect the different regions. This means to survey the consequences of the pending decisions with regard to the alternative strategies and interventions. To create a shared basis, a methodology based on reasoning and cooperation was chosen and a collaborative assessment method was developed and applied in several workshops (Lami 2014; Abastante et al. 2014).

This research illustrates the decision process that concerns the development of the Frankfurt-Mannheim area (Germany), in the Rhine/Neckar region. The aim of the action was to develop a shared position within the project partnership with regard to the most relevant issues affecting the future development of the corridor in the area at stake (Günther and Tosoni 2012). The issues were identified during a series of consecutive meetings held across Europe with local representatives and citizens, carried out in 2010 by researchers of the Eidgenössische Technische Hochschule (ETH) of Zürich. The above-mentioned meetings have highlighted some useful key points to design intervention strategies that can bring the greatest benefit to the region.

The five main problems identified for this decision process were:

1. Differences in the assumed strategies by the cities of Frankfurt and Mannheim often conflict due to territorial contexts, with geographical, social, economic and cultural specificities.
2. The transport system proved particularly sensitive to problems of consensus building.
3. Environmental issues, in particular, noise pollution caused by the passage of train and tracks.
4. The plurality of the participants during the process, all with differing aims and resources.
5. A lack of homogeneous information between the subjects involved.

In this context, the objectives of the evaluation methodology were: (1) to structure the decision problem as a learning and debating opportunity for DMs; (2) to stimulate a participatory process (including different kind of actors as local authorities, rail transport companies, municipalities, regional administrations, representatives of the citizens and experts in territorial and transport planning); (3) to produce a clearly designed procedure that will lead to clearly defined results.

The assessment procedure was organized in two phases: a workshop, structured by the ANP/InViTo framework (Sects. 2.1, 2.2); a collaborative assessment (namely a structured discussion) coordinated by the researchers of the ETH of Zürich.

3.2 Process of the evaluation

Although the workshop itself lasted 1 day and a half, the preparation process started 8 months earlier (Table 1). In fact, the evaluation models (and the evaluation method used to structure the problem and the decision process) are subject to a validation process that involves four steps: conceptual, logical, experimental and operational validation (Landry et al. 1983). The aim of the validation process is to verify whether the key issues have been appropriately considered (Tsoukiàs 2007). The first part of the evaluation process took place in the experimental validation step. This was divided in turn into two pilot tests: an internal test with experts in decision processes and a further test with real actors, experts and researchers. The experimental validation consists in testing the model using experimental data and examples to show if it is able to provide the expected results, before applying it in a real decision context (Ostanello 1997).

The pilot test with real actors, experts and researchers was very useful to improve the structure of the workshop itself from different points of view: the order of questions to stimulate the discussion after the obtained answers; the way to

Table 1 The mains steps of the evaluation process

Time	Activity	Actors involved (no.)	Model and criteria	Weight elicitation
July 2011	Internal pre-test about the INVITO methodology (at ETH ValueLab) on the case study concerning Bellinzona (CH)	12 (mostly experts)	Created by MCDA experts and visualization experts	Arithmetic average
September–November 2011	First definition of the alternative strategies and construction of the ANP-BOCR model for the specific case study of Frankfurt–Mannheim area		Created by MCDA, visualization experts and planners	
December 2011	Pilot test on the case study of Frankfurt–Mannheim area with a small number of real actors (representatives of the public administrations) and some observers (at ETH ValueLab)	16 (partly experts)	MCDA experts and planners created the first version, then discussed it with the steering group	"Majority method"
January 2012	Redefinition (by several strategic actors) of the alternative strategies as the representatives of the two cities mentioned and the Verband Region Rhein-Neckar (meeting held in Germany)	6 (experts)	Created by MCDA experts, visualization experts and planners, according to the opinions of the steering group	
February 2012	Construction of an ANP-BC model and definition of new maps		MCDA/visualization experts and planners created the model according to the opinions of the steering group	
February 2012	Online questionnaire (in German and English)	10		The questionnaire form was partly filled out individually online, with the support of an explanation dossier
Beginning March 2012	Aggregation of the weights and identification of the key questions			Geometric average and "majority method", to compare the possible differences
19–20 March 2012	Workshop with real DMs and citizen representatives (at ETH ValueLab)	10 (experts)		The questionnaire form was partly filled out with the guidance of an MCDA expert in the workshop and partly at home. The elicitation of the weight was done according to the "Majority method"

aggregate the weights given by the actors; the role of the consultant/facilitator (Omerod 2013).

The online submission of the questions that arise from the ANP model is an unconventional use of this methodology, but can bring many advantages: (1) it allows starting the plenary discussion during the workshop interfacing with informed actors; (2) it reduces the problems arising from the process of social influence (Asch 1955; Forsyth 2009) as every actor has the ability to answer the questions autonomously without being influenced by other participants. However, this aspect could also be viewed as a weakness: as without his peers an actor may not be sufficiently informed about the facts at stake and could therefore answer the question at random.

The response rate of each participant who received the survey was theoretically 100 %; however

- in most of the questions, three actors gave "no answer": this could mean that the question was unclear or redundant and therefore unnecessary;
- in several questions, the actors gave weight 1: this could be interpreted either as the respondents judged the two aspects of the problem equally important, or it being an elegant way to give "no answer" or the question was too complex which made it difficult to choose an adequate weight.

An example of such a question is given in Fig. 1, where participants were asked to give a weight using the Saaty's scale (Table 12, "Appendix") to the comparison between two different strategies in relation to a question on the operational costs. The diagram shows that most of the actors gave the weight 1 (i.e. the two aspects are equally important), two actors gave the weight 3 for the first strategy (i.e. Strategy 1 is moderately more important than Strategy 3) and one actor gave the weight 3 for the other strategy (i.e. Strategy 3 is moderately more important than Strategy 1). As a result, the answer to this question was not satisfactory, and therefore it was re-proposed to all the actors during the workshop.

After collecting all the responses from the online questionnaire, the weights were aggregated. In the literature many methods have been proposed to approach the aggregation. The most widely used methods are the geometric average (GA) and the arithmetic average (AA). The literature (Aczèl and Saaty 1983; Aczèl and Roberts

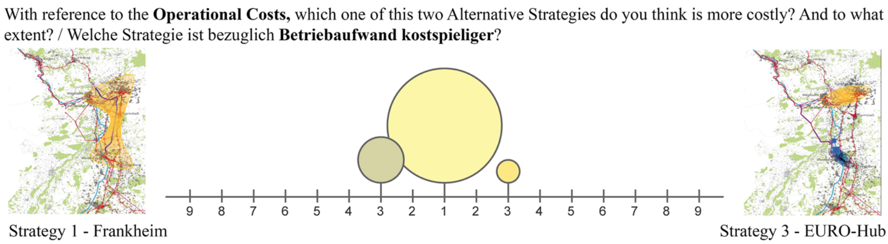


Fig. 1 Diagram showing the results of the online survey in relation to the question on operational cost. Values are given using the Saaty's scale

1988) indicates the GA as the "evolution" of the AA, but this does not mean that one is better than the other. It depends on the context of application. For example, if you were asked to determine the class average of students' test scores, you would use an AA because each test score is an independent event. On the contrary, if you were asked to calculate the annual investment return of your savings, you would use the GA because the numbers are not independent of each other (i.e. if you lose money during 1 year, you have that much less capital to generate returns during the following years and vice versa) (Mitchel 2004). Moreover, since the GA gives a null global score even if only one criterion is null, it risks excessive flattening of the values instead of capturing the differences between the elements of the decision in the final stage.

After considering both methods, we decided to apply the AA on the basis of majority, since the answers given in the online questioners are independent events. This means that we gave the preference to the node that had the highest number of votes and then among these weights we determined the AA.

We can call this last approach a "majority" method, because it bears similarities to political elections, where the party that obtains the highest number of votes wins.

The online questionnaire allowed the selection of ten key questions to be discussed during the workshop (instead of the 100 questions included in the questionnaire). The questions enabled to stimulate the discussion by maintaining short interaction time between the participants, which heightened attention spans.

The criteria to choose the crucial questions were: (1) the dispersion of responses, i.e. a substantial balance between values above and below the weight 1; (2) the high number of responses with weight 1 (on the Saaty's scale), which led us to think that rather than a real balance between the two aspects in comparison it was difficult to find a very dominant element; (3) the presence of strongly opposing weights attributed to the compared nodes; (4) the importance of the question (i.e. cluster comparison).

During the workshop the results of the online questionnaire were anonymously presented and the ten key questions were discussed. Each participant was asked to give a weight and to explain his/her opinion; he/she was free to relate to the answer given online. The facilitator of the workshop tried to reach a common weight when possible. If it was not the case, the weights were aggregated according to the majority method.

Mention has to be made of the fact that a series of workshops concerning this specific region continued even after the experience described in this article: the meetings were held in German, with the support of the ETH researchers, with the aim to discuss and deepen the transformation scenarios.

3.3 Structuring of the model

Three alternative development strategies were developed by the researchers of ETH to be compared through the use of the ANP/InViTo methodological framework and by a structured discussion. It is important to underline that the three strategies proposed are extreme simplifications of possible integrated development perspectives and their intent is to be both, revealing and provocative (Table 2).

Table 2 Alternative development strategies

Alternative strategies	Description
Strategy 1 Frankheim	High-speed connection between Frankfurt and Mannheim. This alternative strategy aims at promoting the coordination and cooperation between the two areas
Strategy 2 Net-Region	Development of the existing lines. This alternative strategy provides transport rationalization
Strategy 3 EURO-Hub	Construction of a new line for freight transport. This alternative strategy provides the implementation of the logistics hubs

Source: Günther and Tosoni (2012)

A complex ANP model was developed to take into account the complexity of the decision problem. The problem was divided into two clusters (namely, economic/transport aspects and environmental/urban planning aspects) which were organized according to an ANP-BC model (benefits–costs model).

It should be noticed that in this case the benefits–costs model is a particular typology of structuring the decision problem within the ANP methodology, as described in the "Appendix" of the present paper. The ANP-BC model is not related to the cost–benefit analysis, which is a well-known technique that is used for the economic evaluation of projects and investments (European Commission 2008). In fact, the ANP-BC model refers to a multicriteria approach for addressing the decision problem under examination, while the cost–benefit analysis is a monetary-based approach for supporting decision-making processes.

Each cluster was divided, in turn, into elements (or nodes) representing the specific aspects of a decision problem being examined.

Attention needs to be drawn to the fact that in this case the benefits represent favourable concerns which have to be maximized, while the costs are negative factors affecting the decision problem and they have to be minimized. In the ANP-BC model, considered in the present application, the benefits and the concerns of cost utilize a simple separate network structure for the evaluation.

To help the actors involved to understand the spatial consequences of their choices, each ANP question was supported by displaying the corresponding map which symbolically localizes the expected effects. Therefore, a map of estimated consequences was built for each ANP element according to the expertise of the researchers in the fields of transport, economics, environment and spatial planning.

Tables 3 and 4 resume the clusters, elements and the maps of an examined decision problem. To better read the results (Fig. 2; Table 8), an acronym is associated to each element of the decision network. The acronyms are listed in the third column of Tables 3 and 4.

It is important to underline that the visual representation provided by the illustrated maps is an approximation of the effects on a territory to identify large areas in which DMs' choices might relapse. Therefore, maps do not have to identify the actual localization of an event but, rather, provide an indication of where an

Table 3 Maps used to represent the elements of benefits subnetwork

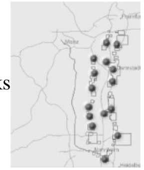
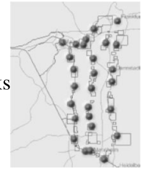
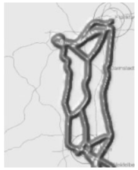
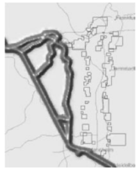
Clusters	Elements	Acronym	Maps		
			Strategy 1	Strategy 2	Strategy 3
Economic and transport aspects	Increase in level of attractiveness due to the improvement in speed/frequency/capacity of passenger transport connections	PaT	Frankfurt and Mannheim 	Railway stations along passenger tracks 	Railway stations along passenger tracks 
	Increase in level of attractiveness due to the improvement in speed/frequency/capacity of freight transport connections	FT	Freight transport railway tracks 	Freight transport railway tracks 	Freight transport railway and high-capacity tracks 

Table 3 continued

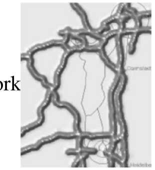
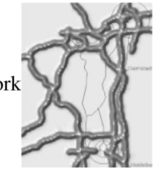
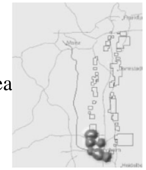
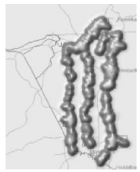
Clusters	Elements	Acronym	Maps		
			Strategy 1	Strategy 2	Strategy 3
Environmental and urban planning aspects	Reduction in pollution due to the displacement on railway lines of a portion of road traffic	PT	Motorway network 	Motorway network 	Motorway network 
	Optimization in soil consumption (widespread urbanization is limited)	SC	Frankfurt and Mannheim 	Brownfield on Mannheim area 	Brownfield on Mannheim area 
	Increase in level of services for the local population	SE	Frankfurt and Mannheim 	Settlements along passenger tracks 	Settlements along passenger tracks 

Table 4 Maps used to represent the elements of costs subnetwork

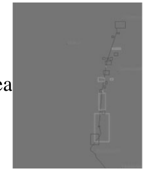
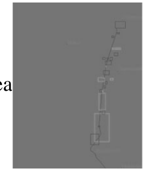
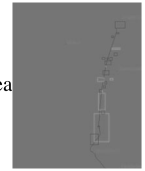
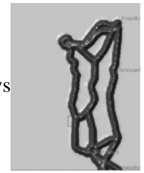
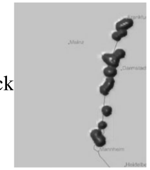
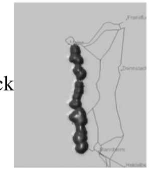
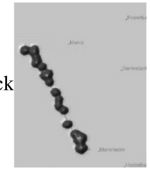
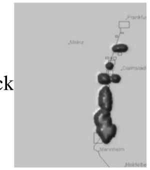
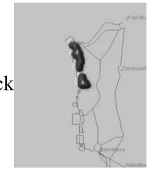
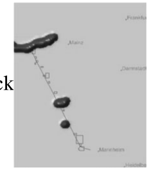
Clusters	Elements	Acronym	Maps		
			Strategy 1	Strategy 2	Strategy 3
Economic and transport aspects	Missing financial resources and construction costs (initial investments, reclamation costs)	FR	Constant over the area 	Constant over the area 	Constant over the area 
	Operational cost	OC	High-speed railway 	Existing railways 	High-capacity railway 

Table 4 continued

Clusters	Elements	Acronym	Maps		
			Strategy 1	Strategy 2	Strategy 3
Environmental and urban planning aspects	Negative impact (noise, vibrations and visual impact) due to the passage of trains	NI	Settlements along high-speed track 	Settlements along freight track 	Settlements along high-capacity track 
	Destruction of protected areas between Frankfurt and Mannheim and in the Mannheim region.	DP	Green areas along high-speed track 	Green areas along freight track 	Green areas along high-capacity track 

effect is expected. This should support DMs to build their own reasoning for long-term strategies, by offering an intuitive answer to their spatial queries.

For example, the benefit maps show the increase in level of attractiveness due to the improvement in speed/frequency/capacity of passenger transport connections (PaT) on three different maps, one for each strategy. In fact, positive effects due to PaT are expected in different areas, which can be summarized as follows:

- for Strategy 1, benefits are mostly expected in the urban areas of Frankfurt and Mannheim, because the access points to the high-speed line are located only in these two main cities. The catchment areas of the two access points are considered to cover a radial buffer area in which public local transport can allow easy accessibility to the high-speed facilities;
- for Strategy 2, benefits are attended around the rail stations along the regional transport lines; catchment areas are smaller, mainly due to a lower number of residents;
- finally, Strategy 3 presents almost the same conditions of Strategy 2, but it will also present benefits around the railway stations along the line between Mannheim and Mainz.

In the same way, the cost maps show where the negative effects are expected in the area.

3.4 Results of the application

3.4.1 Costs and benefits subnetwork

According to the ANP methodology described in "Appendix", the second step consists of pairwise comparisons, to establish the relative importance of the different elements, with respect to a certain component of the network. The comparison and evaluation phase is divided into two distinct levels: the cluster level, which is more strategic, and the element level, which is more specific and detailed. In the present application, as described in Sect. 3.2, several workshops and focus groups were organized to fill in the pairwise comparison matrixes of the evaluation model.

With reference to the cluster level, we can see an example of question that has been asked to the focus group. Let us consider the cluster of the alternatives as the parent node in the benefit subnetwork; the question that was discussed with the experts was of the type:

"With reference to the choice of the best alternative development strategy for the Rein/Mein-Rhine/Neckar region, which one of these two aspects do you think is more beneficial? And to what extent?"

Economic and transport aspects	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Environmental and urban planning aspects

Table 5 Pairwise comparison matrix at the cluster level for the benefits subnetwork

	Economic and transport A	Environmental and urban planning A	Priority vector
Economic and transport A	1	3	0.75
Environmental and urban planning A	1/3	1	0.25

Table 6 Cluster matrix of the benefit subnetwork

	Alternative strategies	Economic and transport A	Environmental and urban planning A
Alternative strategies	**0.00**	1.00	1.00
Economic and transport A	**0.75**	0.00	0.00
Environmental and urban planning A	**0.25**	0.00	0.00

Bold values indicate the priorities of the elements compared in Table 5

Let us assume that the calculation of the average between the responses expressed in the workshop was 3, meaning that economic and transport aspects are moderately more important than environmental and urban planning aspects in the decision problem under investigation (see "Appendix" for a detailed explanation of the numerical values of the 1–9 scale used in the questionnaire). This judgement was used to fill in the related pairwise comparison matrix (Table 5).

Table 5 shows the pairwise comparison matrix and the main eigenvector which represents the priorities of the different aspects in the Benefit subnetwork with respect to the goal. This result puts in evidence that from the benefits point of view, the economic aspects and transport are the most important ones (0.75 in the priorities list). According to the ANP methodology, the final priority vectors that result from the comparison matrices at the cluster level determine the columns of the cluster matrix. Table 6 shows the cluster matrix for the benefits subnetwork. The priorities of the elements that had been previously compared (Table 5) are shown.

Once the clusters comparison has been conducted, it is necessary to study the problem in depth through the analysis of the elements. As for the cluster level, at the element level the values used for filling in the pairwise comparison matrices were derived from the judgements expressed in the focus groups. With the aim of better clarifying the explanation, an example of the question is shown:

With reference to the evaluation of the priority of the considered projects, from the benefits point of view, which alternative pursues more the objective "increase of level of services for the population"? And how much more?

Alternative 1	9	8	7	6	5	4	3	2	1	2	3	4	5	**6**	7	8	9	Alternative 2
Alternative 1	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Alternative 3
Alternative 2	**9**	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3

Bold values indicate the expressed judgements

Table 7 Pairwise comparison matrix at the node level for the benefit sub network

	Alternative 1	Alternative 2	Alternative 3	Priority vector
Alternative 1	1	1/6	3	0.16
Alternative 2	6	1	9	0.77
Alternative 3	1/3	1/9	1	0.07

Table 8 Unweighted supermatrix of the benefit subnetwork

	Alternative strategies			Econ. and transp.		Env. and urban planning		
	1	2	3	FT	PaT	SE	SC	PT
Alternative strategies								
1	0.00	0.00	0.00	0.20	0.20	*0.16*	0.24	0.11
2	0.00	0.00	0.00	0.06	0.74	*0.77*	0.67	0.33
3	0.00	0.00	0.00	0.74	0.06	*0.07*	0.09	0.57
Econ. and transp.								
FT	0.18	0.25	0.78	0.00	0.00	0.00	0.00	0.00
PaT	0.82	0.75	0.22	0.00	0.00	0.00	0.00	0.00
Env. and urban planning								
SE	0.17	0.20	0.12	0.00	0.00	0.00	0.00	0.00
SC	0.52	0.09	0.54	0.00	0.00	0.00	0.00	0.00
PT	0.31	0.71	0.33	0.00	0.00	0.00	0.00	0.00

The expressed judgements were used to fill in the related pairwise comparison matrix (Table 7).

The result of Table 7 highlights that from the point of view of the increase of the level of services, alternative 2 strongly exceeds the other options (0.77 in the priority vector), followed by alternative 1 (0.16 in the priority vector) and finally alternative 3 (0.07 in the priority vector).

Once all the pairwise comparison matrices were compiled, all the related vectors together formed the unweighted supermatrix. In this case, two supermatrices were obtained, one for each subnetwork. Table 8 represents the unweighted supermatrix, with reference to the benefit subnetwork. The priorities of the elements that had previously been compared (Table 7) are shown.

The application of the cluster matrix to the initial supermatrix as a cluster weight provides the weighted supermatrix, which is raised to a limiting power to obtain the limit supermatrix, where all columns are identical and each column gives the global priority vector.

In this case, two limit supermatrices were calculated, one for each subnetwork using the formula (1):

$$\lim_{k \to \infty} W^k. \tag{1}$$

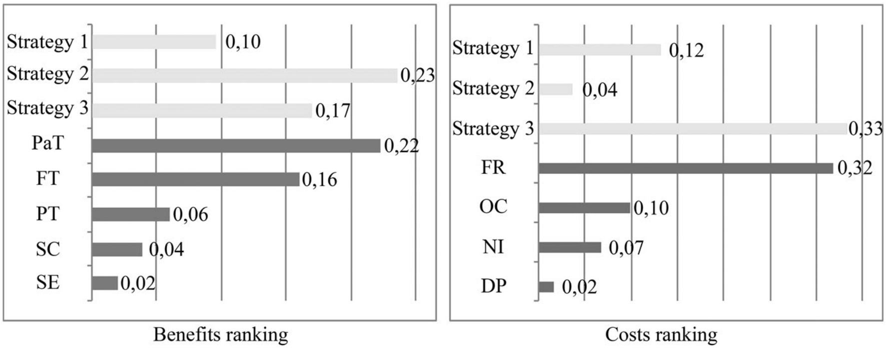


Fig. 2 Final priorities of the benefits and costs subnetworks

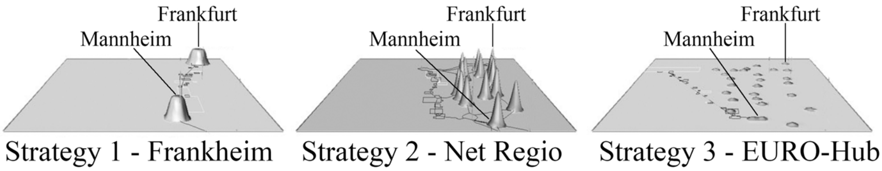


Fig. 3 Partial map showing the contribution of the element "attractiveness due to passenger transport connection—PaT" under the benefits subnetwork

According to this formula, the weighted supermatrix W is raised to a limiting power to converge and to get, as stated in the Perron–Frobenius theorem, a long-term stable set of weights that represents the final priority vector.

The final priority vectors obtained by the limit supermatrices are shown in Fig. 2 using the histogram representation. Leaving aside the priorities of the alternative strategies (identified by a light-grey bar in the graphs of Fig. 2), it is possible to observe that with reference to the benefit subnetwork, the most important element is represented by the attractiveness due to passenger transport connection—PaT (0.22 in the priority vector), while considering the cost subnetwork the most important element concerns the problem of missing financial resources—FR (0.32 in the priority vector).

Running parallel to the development of the ANP model, the numerical results provided by the evaluation model were considered and implemented into the thematic maps. For instance, Fig. 3 provides the partial maps related to the most important beneficial elements: attractiveness due to passengers transport connection (PaT).

The maps highlight that Strategy 2 has higher peaks in comparison to the other strategies, which implies that actors consider Strategy 2 as the option with more benefits. Although, Strategy 1 has lower peaks, it has larger catchment areas concentrated on the urban areas of Frankfurt and Mannheim; subsequently, actors were asked to reason about spatial issues on land use and decide between concentrated or diffuse development. Furthermore, with reference to passenger

Table 9 Final priorities of the alternatives under the benefits and the costs subnetworks

Alternative strategies	Benefits subnetwork	Costs subnetwork
Strategy 1	0.20	0.26
Strategy 2	0.46	0.08
Strategy 3	0.34	0.66

Table 10 Final ranking of the alternative strategies according to the different formulas

	Additive (negative) *B*–*C*	Additive (probabilistic) $B + (1 - C)$	Multiplicative $B \times (1/C)$
Strategy 1	0.0091	0.2788	0.0943
Strategy 2	0.7564	0.5215	0.8393
Strategy 3	−0.2345	0.1997	0.0664

transport, Strategy 3 has the lowest results, which is perceptible due to the absence of peaks.

The normalization of the strategies' priorities on the cluster of the alternatives provides the priority vector of the three considered options (Table 7). To illustrate, let us consider the priority of Strategy 1 under the benefits subnetwork resulting from Fig. 2 (0.10). To normalize this score on the cluster of the alternatives, it is necessary to develop the following calculation: 0.10/(0.10 + 0.23 + 0.17) = 0.2. As a result, the final priority of Strategy 1 in the benefits subnetwork is 0.2 as reported in Table 9. Following a very similar procedure, it is possible to obtain the final priorities of the alternatives for the two subnetworks.

Again in this case, the results of the ANP application were aggregated into the partial thematic maps considering the numerical results of the evaluation model. Therefore, benefits and costs were integrated into two maps, which define not only the localization of positive and negative effects, but also their intensity.

Following the ANP methodology, in the case of the complex network structure, it is necessary to synthesize the outcomes of the alternative priorities for each of the considered subnetworks (Table 9) to obtain an overall synthesis. Different aggregation formulas are available and the chosen formula depends on the final desired use of the results (see "Appendix" for a description of the ANP method). According to Saaty (2003), if the objective of the evaluation is to rank alternative options and to choose the highest priority alternative, all the aggregation formulas are applicable. Table 10 shows the final ranking of the alternative strategies according to the three formulas suggested by the methodology.

As is noticeable from Table 10, all the available formulas converge in considering Strategy 2 as the best performing of the scenarios, followed by Strategy 3 and finally Strategy 1.

The results of ANP analysis are also visible in the map comparison (Fig. 4). To visualize costs and benefits, InViTo has been set to generate two distinct meshes which can also be overlapped to compare each other. To improve the understanding

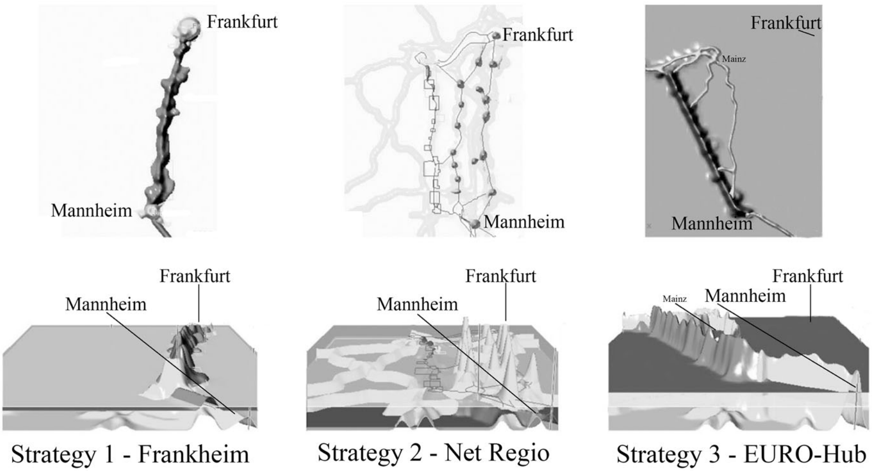


Fig. 4 Overlapping of the total amount of costs (in *dark grey*) and benefits (in *light grey*)

of these visualizations, the 3D peaks are intersected by a slicing plane (the black horizontal plane), which can be vertically moved to cut lower values away from the visualization. This plane is at the same height from all perspectives and provides a visual method for comparing the heights of the peaks in the different scenarios. It also works, simultaneously, as a visual cursor, which selects the areas with the highest values and allows participants to intuitively understand which scenario presents higher benefits or costs.

3.4.2 Sensitivity analysis

After obtaining a ranking of the alternative strategies, a sensitivity analysis based on an automatic process was performed on the final outcome of the model to test its robustness. The sensitivity analysis is concerned with a "what if" kind of question to see whether the final answer is stable when the inputs, either judgements or priorities, are changed. As a matter of fact, it is of special interest to see whether these changes modify the order of the alternatives.

In the present application, two different sensitivity analyses were carried out to study the robustness of the model with respect to the components and interdependencies of the network.

In the first analysis the stability of the solution was studied with regard to the control criteria priorities (benefits and costs).

In the second, the work attempted to verify the rank reversal of the alternatives by eliminating one alternative at a time from each subnetwork of the model and from the whole network, which was followed by studying the resulting final ranking and searching for potential changes.

With reference to the first analysis, while measuring the sensitivity of the alternatives to the BC weights, an additive formulation is used, since the meaningful changes could not be obtained by a multiplicative formula.

The sensitivity analysis for the two subnetworks is represented in Fig. 5, where the *x* axis represents the changes in the weights of the control criteria, while the *y* axis represents the changes in the weights of the alternatives.

When the relationships between the benefits dimension and the alternative strategies are considered (Fig. 5), it becomes clear that Strategy 2 provides more benefits compared to the other options; in fact, regardless of the benefits criterion Strategy 2 was always preferred over Strategies 1 and 3. As far as the Strategies 1 and 3 are concerned, it is possible to highlight that an inversion of the priorities occurs: in this case, when the weight of the benefits is lesser than 0,7, Strategy 1 is preferred over Strategy 3, whereas when the weight is greater than 0,7, Strategy 3 becomes more preferable to Strategy 1. It is interesting to notice that when the weight of the benefits is 1, the priority list of the alternative strategies is the same resulting from the calculation of the benefits subnetwork (Table 9) while when the weight of the benefit is 0, the priority list of the alternative strategies is the same as resulting from the calculation of the costs subnetwork (Table 9).

In contrast, the sensitivity analysis of the costs dimension (Fig. 5) shows that also in this case, Strategy 2 is most suitable as it has fewer costs compared to the other strategies. Also here, an inversion of priorities occurs in Strategies 1 and 3: however, in this case, when the weight of the costs is lesser than 0.3, Strategy 3 is preferred, although when the weight is greater than 0.3, Strategy 1 becomes the more favourable strategy. Following the aforementioned reasoning, it is interesting to note that when the weight of the costs is 1, the priority list of the alternatives is the same as that resulting from the calculation of the costs subnetwork (Table 9). However, when the weight of the costs is 0, the priority list of the alternatives is the same as that resulting from the calculation of the benefits subnetwork (Table 11).

To test the robustness of the model with respect to the rank reversal of the alternatives (Saaty 2005), the present study proposes a second sensitivity analysis

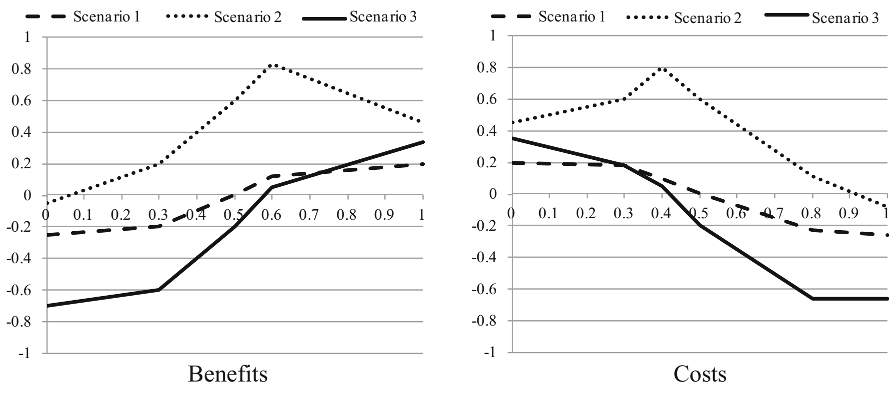


Fig. 5 Sensitivity analysis for the benefits and costs subnetworks

consisting in the elimination of one alternative at a time from the original model and in the evaluation of the new results. Table 11 illustrates the original ranking of the alternatives and the results arising from the elimination of the highest priority alternative. As it is possible to see from Table 9 that the rank is preserved, with a small exception for the benefits subnetwork where the two alternatives rank very similarly; it is thus possible to conclude that the final result of the model is stable.

4 Discussion and conclusions

The approach presented here involved the integration of a multicriteria evaluation approach and a visualization tool intended to support the evaluation of complex decision alternatives, while considering the different aspects of the decision problem from the perspective of a wide range of stakeholders. In this context, the role of the approach as a problem structuring method was "to provide a representation of a problematic situation in order to enable effective multicriteria analysis" (Belton and Stewart 2010).

The approach proved to be cognitively accessible and useful in generating discussion among the participating actors. The 3D visualization tools, in particular, enabled the actors to become active subjects instead of passive objects (Qiu and Fan 2013). The visual representation of the expected impacts, which could be modified by the input of each participant, was perceived as beneficial for understanding what the consequences of a decision could be pertaining to land and population. Moreover, it allowed the aggregation of several alternative perspectives and provided, when required, support for changing viewpoints as evidenced by the participants' feedback collected via post-workshop questionnaires and group discussions.

To summarize, the main strengths of the ANP/InViTo approach can be listed as follows: (1) it facilitated the effective involvement of actors with very different expertise to build trust and understanding between culturally diverse parties; (2) it increased analytic capacity for performing complex trade-offs on multiple

Table 11 Sensitivity analysis with respect to the rank reversal of the alternatives

Networks	Priority of the alternatives	Original ranking	Eliminated alternative	New priorities	New ranking
Benefits	1: 0.19 2: 0.47 3: 0.34	2 > 3 > 1	2	1: 0.52 3: 0.48	1 ≈ 3
Costs	1: 0.26 2: 0.08 3: 0.67	3 > 1 > 2	3	1: 0.80 2: 0.20	1 > 2
BC	1: 0.28 2: 0.52 3: 0.20	2 > 1 > 3	2	1: 0:65 3: 0.35	1 > 3

evaluation criteria, taking into account the preferences of those involved; (3) it enabled the possibility of focussing on the most important elements of the decision problem through a transparent and traceable decision process; (4) it provided the opportunity to compare and contrast several alternatives; (5) it offered the possibility of improving the analysis by structuring the decision process in phases.

Despite its potential, improvements are needed to consider the ANP/InVITo integrated approach as a proper problem structuring methodology. Three main areas of future research are proposed. First, the ANP requires a complex elaboration process of the initial data, which makes the relationship between the input and the output very difficult to read and this aspect needs improvement. Second, the ANP offers a precise result for each alternative of the decision problem at hand, but the process through which this result is obtained is often perceived as a "black box". Research efforts that can help to increase transparency are therefore needed. Finally, in contrast with the well-known 2D visual representations used by most PSMs (i.e. cognitive maps, rich pictures, decision graphs), the 3D spatial visualization provided by InViTo represents a novel development that may require some time to be properly understood and embraced by the users. More research to explore the conditions under which understanding and use of 3D visualization can be improved is thus needed. Research designs that include testing the approach tool in different territorial contexts would help to implement this proposed agenda.

Appendix: Analytic network process

The analytic hierarchy process—or AHP (Saaty 1980—and its more generalized evolution, i.e. the analytic network process—or ANP (Saaty 2005; Saaty and Vargas 2006)—are currently used in territorial decision problem.

The analytic network process (ANP) is a multicriteria methodology able to consider a wide range of quantitative and qualitative criteria, according to a complex model (Saaty 2001, 2005). It is particularly suitable for the complex decision problem like the one presented in this paper. The ANP allows and addresses the making of the decisions in the light of their links to other decisions. It structures the decision problem into a network and uses a system of pairwise comparisons to measure the weights of the structure components and to rank the alternatives. The ANP model consists of control hierarchies, clusters and elements, as well as interrelations between elements, because it is able to connect clusters and elements in any manner to obtain priority scales from the distribution of the influence between the elements and clusters. The structure of the model is characterized by continuous feedback between the elements and the clusters, capturing the complexity of the reality (Saaty and Vargas 2006).

In this sense, the ANP assists the people involved to design a possible course of action(s). It also further allows comparison of what consequences there might be in the light of some action. The application process of the ANP can be summarized into four main phases:

Step 1—structuring the decision problem and model construction: The first step consists in developing the structure of the decision-making process. This involves defining its main objective and identifying groups or “clusters” constituted by various elements (“nodes”) that influence the decision, and alternatives or options from which to choose. In particular, the elements (or nodes) represent the fundamental aspects of the system under examination.

There are two types of models that can be developed within the ANP methodology, a “simple” network, and a “complex” network:

- The “simple” network is a free-modelling approach, which is not supported by any guide or pre-determined structure. It consists of a network, which has cycles connecting its components and a loop that connects a component to itself.
- The “complex” network or BOCR (benefits, opportunities, costs, risks) network allows one to simplify and structure the problem by classifying issues in traditional categories of positive and negative aspects. The favourable concerns are called benefits, while the unfavourable ones are called costs; the uncertain concerns of a decision are the positive opportunities that the decision might create and the negative risks that it can entail (Bottero et al. 2011). Each of these four concerns utilizes a separate structure for the decision. A full BOCR is in some ways similar to a SWOT analysis: it is possible to assert that while the BOCR model is expected to catch all the aspects (positive and negative) of the decision through time (present and future), the SWOT analysis focuses more on the external and internal elements of the problem. A particular kind of complex model is the “strategic” network model which is structured as a BOCR model, but a further level of analysis is added to better catch the strategic elements of a particular problem (Saaty 2005; Saaty and Ozdemir 2005).

After having chosen which structure is more suitable in the decisional context, whether the simple or the complex BOCR one, the relationships between the different elements of the network must be identified. All the elements in the network can be related in different ways, since the network can incorporate feedback and complex inter-relationships within and between clusters, thus providing a more accurate modelling of complex settings.

Step 2—compilation of pairwise comparison matrices: A series of pairwise comparisons are made to establish the relative importance of the different elements with respect to a certain component of the network. In the case of interdependencies, components with the same level are viewed as controlling components of each other. The comparisons are made with the Saaty’s fundamental scale of absolute numbers (Saaty 2005).

In particular, each single element is evaluated using a pairwise comparison. The comparisons are made on a nine-point scale, the so-called “fundamental scale of Saaty”, which translates verbal reviews in numerical ratings. The Saaty’s fundamental scale is represented in Table 12.

The numerical judgements established at each level of the network make up pair matrices. The weighted priority vector is calculated through pairwise comparisons between the applicable elements. This vector corresponds to the main eigenvector of the comparison matrix (Saaty 1980, 2005).

Table 12 Saaty's fundamental scale

Value	Definition	Explanation
1	Equally important	Two decision elements equally influence the parent decision element
3	Moderately more important	One decision element is moderately more influential than the other
5	Much more important	One decision element has more influence than the other
7	Very much more important	One decision element has significantly more influence over the other
9	Extremely more important	The difference between influences of the two decision elements is extremely significant
2, 4, 6, 8	Intermediate judgement values	Judgement values between equally, moderately, much, very much and extremely

Step 3—construction of supermatrices: A supermatrix represents, in the case of the ANP, the relationships that exist within the network model and the relative assigned weights. It is an array containing all the priority vectors that are extracted from individual pairwise comparison matrices compiled during the previous steps of analysis.

The supermatrix elements allow for a resolution of interdependencies that exist among the elements of the system. It is a portioned matrix where each sub-matrix is composed of a set of relationships between and within the levels as represented by the decision-maker's model (Step I). The general form of the supermatrix is described in Fig. 6 where CN denotes the *N*th cluster, *eNn* denotes the *n*th element in the *N*th cluster and *Wij* is a block matrix consisting of priority weight vectors (w) of the influence of the elements in the *i*th cluster with respect to the *j*th cluster. If the *i*th cluster has no influence to the *i*th cluster itself (a case of inner dependence), *Wij* becomes zero. The supermatrix obtained in this step is called the initial supermatrix.

Firstly, the supermatrix plays a fundamental role in the analysis because it allows us to understand certain relationships of influence determined during the development of the network. Secondly, the supermatrix is crucial also because, being composed of different eigenvectors, it provides numerical data about the priorities of elements forming part of the decision system. During the development of the ANP methodology, three different supermatrices are extracted:

- The unweighed supermatrix (or initial supermatrix), which contains all the eigenvectors that are derived from the pairwise comparison matrixes of the model.
- The weighted supermatrix, which is a stochastic supermatrix obtained by multiplying the values in the unweighed supermatrix by the weight of each cluster. In this way, it is possible to consider the priority level assigned to each cluster.
- The limit supermatrix, which is the final matrix of the analysis obtained by raising to a limiting power the weighted supermatrix to converge and to obtain a long-term stable set of weights that represents the final priority vector.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">C_1</td><td colspan="4">C_2</td><td rowspan="2">....</td><td colspan="4">C_N</td></tr>
<tr><td>e_{11}</td><td>e_{12}</td><td>…</td><td>e_{1n1}</td><td>e_{21}</td><td>e_{22}</td><td>…</td><td>e_{2n2}</td><td>e_{N1}</td><td>e_{N2}</td><td>…</td><td>e_{NnN}</td></tr>
<tr><td rowspan="4">C_1</td><td>e_{11}</td><td colspan="4" rowspan="4">W_{11}</td><td colspan="4" rowspan="4">W_{12}</td><td rowspan="4">…</td><td colspan="4" rowspan="4">W_{1N}</td></tr>
<tr><td>e_{12}</td></tr>
<tr><td>…</td></tr>
<tr><td>e_{1n1}</td></tr>
<tr><td rowspan="4">C_2</td><td>e_{21}</td><td colspan="4" rowspan="4">W_{21}</td><td colspan="4" rowspan="4">W_{22}</td><td rowspan="4">…</td><td colspan="4" rowspan="4">W_{2N}</td></tr>
<tr><td>e_{22}</td></tr>
<tr><td></td></tr>
<tr><td>e_{2n2}</td></tr>
<tr><td></td><td></td><td colspan="4">…</td><td colspan="4">…</td><td>…</td><td colspan="4">…</td></tr>
<tr><td rowspan="4">C_N</td><td>e_{N1}</td><td colspan="4" rowspan="4">W_{N1}</td><td colspan="4" rowspan="4">W_{N2}</td><td rowspan="4">…</td><td colspan="4" rowspan="4">W_{NN}</td></tr>
<tr><td>e_{N2}</td></tr>
<tr><td></td></tr>
<tr><td>e_{NnN}</td></tr>
</table>

Fig. 6 General structure of the supermatrix

Step 4—final priorities :In the case of a complex network, it is necessary to synthesize the outcome of the alternative priorities for each of the BOCR structures to obtain their overall synthesis (Saaty 2005). Saaty suggests three different formulas to synthesize the results: the additive negative formula ($B + C - O - R$), the additive probabilistic formula (B + O + 1/C + 1/R) and the additive multiplicative formula ($B \times O \times 1/C \times 1/R$).

Step 5—sensitivity analysis: The last step consists in carrying out the sensitivity analysis on the final outcome of the model to test its robustness.

The sensitivity analysis is concerned with a "what if" question to discern whether the final answer is stable when the inputs, whether judgements or priorities, are changed. It is of particular interest to see if these changes modify the order of the alternatives.

As far as ANP applications are considered, the literature is quite recent and some publications can be found in strategic policy planning (Lee and Kozar 2006; Ulutas 2005), market and logistics (Agarwal et al. 2006), economics and finance (Niemura and Saaty 2004), civil engineering (Neaupane and Piantanakulchai 2006; Piantanakulchai 2005), manufacturing systems (Das and Chakraborty 2011; Milani et al. 2013), territorial and environmental assessment (Lami and Abastante 2014, Abastante and Lami 2013; Aragonés-Beltrán et al. 2010a, b; Bottero et al. 2011; Promentilla et al. 2006; Tuzkaya and Onut 2008) and transport issues (Lami 2014, Abastante and Lami 2012; Bottero and Lami 2010; Masala 2012a, b; Pensa et al. 2013a, b).

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