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An Integrated Approach for Supporting the Evaluation of Transport Scenarios: The Area of Bellinzona (CH)

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Abstract

Multiple Criteria Decision Analysis (MCDA) is a widely-used tool to support decision processes when a choice between different options is needed. This approach is particularly useful in situation characterized by an inter-connected range of environmental, social and economic issues. Moreover the presence of many actors with different backgrounds and knowledge constitutes a further

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level of complexity due to the difficulty in interpreting and reading outputs. The present application is one response to tackle these difficulties. It is an innovative approach integrating Analytic Network Process (ANP) and Interactive Visualization Tool (InViTo) which creates a common language among the actors involved and a shared basis for generating discussion. The methodological framework is applied to a Swiss section of the transport corridor Genoa—Rotterdam, within the Interreg IVB NWE Project "Code24" in order to demonstrate the potential of the joint use of the two tools mentioned for the selection of a suitable strategy for transport improvement within territorial transformation.

11.1 Introduction

The recent evolution of the decision making process related to the implementation of European corridors has stimulated a broad debate not only on the integration of transport and land use, but also on the need for new tools to support the decisions made in that specific field.

The underlying assumption is that there is no pre-established appropriate strategy. The open issue is how the new infrastructure corridors will benefit from their operational and technological autonomy and how, conversely, they have to interact with local history and specificity in order to positively affect every regional area as a whole. Every regional and urban node must be interpreted in relation to different levels of complementarity and polycentric integration: it is the transition from a society of places to a society of flows that requires the consideration of multiple levels of relationship, scale and intensity [35].

The need for decision support tools, which are able to simultaneously consider different aspects of transport planning, is becoming increasingly evident.

In this complex context, it has been generally agreed that Multiple Criteria Decision Analysis (MCDA) can provide a very useful support. MCDA has been used to make comparative assessments of alternative projects or heterogeneous measures [9, 25]. These methods allow several criteria to be taken into account simultaneously in a complex situation. They are designed to help Decision Makers (DMs) to integrate the different options, which reflect the opinions of the actors involved, in a prospective or retrospective framework.

Although MCDA is widely used to support decision making/aiding processes, difficulties in reading output data can often limit the process of data and knowledge sharing. One important difficulty is the diversity of the DM's backgrounds. This research approaches the integration between MCDA and data visualization in order to create a shared basis among the actors involved in the decision process [4, 14, 15]. The use of an interactive visualization tool can support MCDA in showing results, exploring alternative options and evaluating the differences in the localization of the expected positive and negative effects. Therefore, a methodological framework involving Analytic Network Process (ANP) [29, 31] and the Interactive Visualization Tool (InViTo) has been studied and applied [20, 35].

This chapter presents an application to a Swiss section of the Corridor 24, part of a Genoa-Rotterdam, Interreg IVB NWE Project, called "Code24". The Code24 Project aims at identifying a shared spatial and infrastructural development strategy for the regions connected through this infrastructure of strategic European importance. In order to come to a shared strategy for the corridor, it is important to come to a common understanding about the unsolved issues affecting the different regions. This means, first of all, to survey the consequences of the pending decisions regarding alternative strategies and interventions. In order to achieve this result an assessment procedure has been developed in the project's framework to accompany the discussion in the areas where priorities and development strategies are not yet clear and need to be set. The assessment procedure has been applied in several international workshops organized along the Corridor, in order to jointly review with local actors and stakeholders in the different areas.

The aim of the application of the assessment procedures illustrated herein concerns the classification of three development scenarios regarding the area of Bellinzona. After the introduction, the chapter is organized as follows: Sect. 11.2 illustrates the methodological framework; Sect. 11.3 describes the structure of the ANP/InViTo model and shows the results of the application; finally, Sect. 11.4 concludes the chapter by highlighting the strengths and weaknesses of the proposed joint methodological framework.

11.2 Methodological Framework

11.2.1 The Analytic Network Process

The Analytic Network Process (ANP) is a multi-criteria methodology which is able to consider a wide range of quantitative and qualitative criteria, according to a complex model [27, 28]. 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 in order 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 cluster and it is able to capture the complexity of the reality [30].

The application process of the ANP can be summarized in four main phases:

Step 1: *Structuring the decision problem and model construction.*
There are two types of models that can be developed within the ANP methodology: the complex network model and the simple structured model [28, 32].

Step 2: *Compilation of pairwise comparison matrices.*

Having constructed the decision model and having established relations between the elements, it is possible to proceed with the pairwise comparisons between the elements. The evaluation takes place in two levels: that of the clusters and that of the nodes. In pairwise comparisons, a ratio scale of 1–9, that is Saaty's fundamental scale, is used to compare any two elements where value 1 indicates that the two elements are equally important and value 9 indicates that the difference between the two decision elements is extremely significant. The assigned ratings are placed in a matrix of pairwise comparisons [26]. The main eigenvector of each pairwise comparison matrix represents the synthesis of the numerical judgements established at each level of the network [26].

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. Firstly, the supermatrix plays a fundamental role in the analysis because it allows an understanding of certain relationships of influence determined during the development of the network. Secondly, the supermatrix is crucial because, being composed by different eigenvectors, it provides numerical data about the priorities of elements forming part of the decision system [5]. 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 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 in order to converge and to obtain a long-term stable set of weights that represents the final priority vector.

Step 4: *Elicitation of the final priorities and sensitivity analysis.*

In the case of the complex network structure, it is necessary to synthesize the outcome of the alternative priorities for each of the different subnetworks in order to obtain their overall synthesis through the application of different aggregation formulas [30]. The last step consists in carrying out the sensitivity analysis on the final outcome of the model in order to test its robustness.

The literature is quite recent and some publications can be found in strategic policy planning [40], market and logistics [3], economics and finance [17] and in civil engineering [18, 23], in territorial, transport and environmental assessment [1, 2, 5–7, 13, 24, 38].

11.2.2 Visual Maps

In spatial planning, visualisation refers to the exploration of spatial data, which is a discipline known as geovisualisation. Dynamic maps and georeferenced charts are the visual methods which are becoming ever more effective for communicating such information, offering real time responses to users' queries and showing data, data clusters and relations among data. By using geovisualisation tools, spatial decision processes can significantly benefit from informing the actors involved, enhancing discussions and creating awareness of choices to be taken.

Geo-visualization is a branch of cartographic science and is defined as a technique for the exploration of spatial and spatio-temporal data through the use of interactive tools [4]. Literature on geovisualization provides different examples of three-dimensional models coming from GIS data [16]. These representations are mainly based on generative modelling [41], which results in the automatic production of three-dimensional volumes directly from databases, model libraries or through the extrusion of specific database attributes. Many tools provide these types of spatial data visualization such as "Community Viz" (Orton Family Foundation and Placeways, LLC) and "Metroquest" (Envision Sustainability Tools Inc.), but use it primarily for project presentation, instead of data exploration during the planning process. There is a lack of systems able to integrate the generation of 3D volumes and tools which make use of parametric functions.

To address these issues, a new approach to decision making has been developed, which could provide an effective framework for the construction of discussion and knowledge. This research resulted in the Interactive Visualisation Tool (InViTo), a visual method for managing spatial data in real time (see Chap. 10).

InViTo aims at combining the elements of spatial problems with their corresponding geographical effects by using dynamic maps which change according to DMs' choices. To achieve this task, InViTo organizes data and the relationships between them in a visual interface, which allow DMs to analyse and explore spatial objects in real-time. InViTo is a tool conceived as a Planning Support System (PSS) and Spatial Decision Support System (SDSS) for aiding the actors involved in sharing information and raising awareness of spatial issues at different scales [11, 12, 19, 21, 22];

In order to combine the ANP and the Invito methodologies, each BOCR element is associated with a map, which receives a weight by the actors involved in the evaluation process. The model of visualization built in InViTo sums up all the selected maps in a singular 3D mesh. This new geometry defines the intensity of the positive or negative effects on the area by means of peaks, whose heights depend on the values of the weights given by the actors and on the chosen scenario. Secondly, users can interact with the 3D model. The visualization system allows the values of the weight to be input in real time and, at the same time, it displays the changes which occur on the relative maps in real time so that the different decisions made by the actors can be readily visualized and, then, compared.

Thanks to this ability to interact with users' proposals, the visualization of data offers a methodology for explaining the relationships of cause and effect occurring between actors' decisions and spatial configuration. In fact, these maps are used to help the actors involved in understanding two main issues:

1. The correlation between their decision and territory.
2. How the assignment of a value to the weight between the different elements can vary the result.

11.3 Presentation of the Case and Illustration of the Alternatives

There are two agreements between Switzerland and the European Union (EU) which allow the cross-border land transport with no limitations despite the fact that Switzerland is not one of the Countries party to the EU (CEE/Switzerland, 1992 and Switzerland/CE 1999). Furthermore Switzerland has the obligation to transfer goods from border to border and from road to rail (Constitution art. 36/84 Alpenquerender Transitverkehr initiative 1994/99; delocalization ACT 1999).

For these reasons Switzerland would fit into the nascent European rail network in the best possible way.

To reach this objective, significant projects have been developed in Switzerland under the name "AlpTransit projects" (NEAT) (Fig. 11.1).

The key elements of the NEAT are the Gotthard Tunnel and the Löschtberg Tunnel together with the construction of new access roads. A fundamental project inserted in the NEAT system is the axis that connects Zurich (Switzerland) and Milan (Italy) and more specifically the Gotthard–Lugano portion for which the locations of stations and railway tracks have not yet been decided [11].

Economic and technical agreements between the countries involved (i.e. Germany, Switzerland and Italy) are needed in order to continue the planning of the railway layout. In fact, this has led to considerable delays of several important projects in the north–south axis: the Gotthard Tunnel is expected by 2016/2017 while the Zimmerberg Tunnel, the Hirzler Tunnel and some fundamental roads have been indefinitely postponed. In 2010 a new plan called "STEP" identified new priorities until 2025 considering the completion for the works in progress but at the same time limiting the financial resources destined for new infrastructures. STEP was developed in response to the demand for transport, which is higher on the east–west axis but lower on the north–south axis due to the on-going process of depopulation.

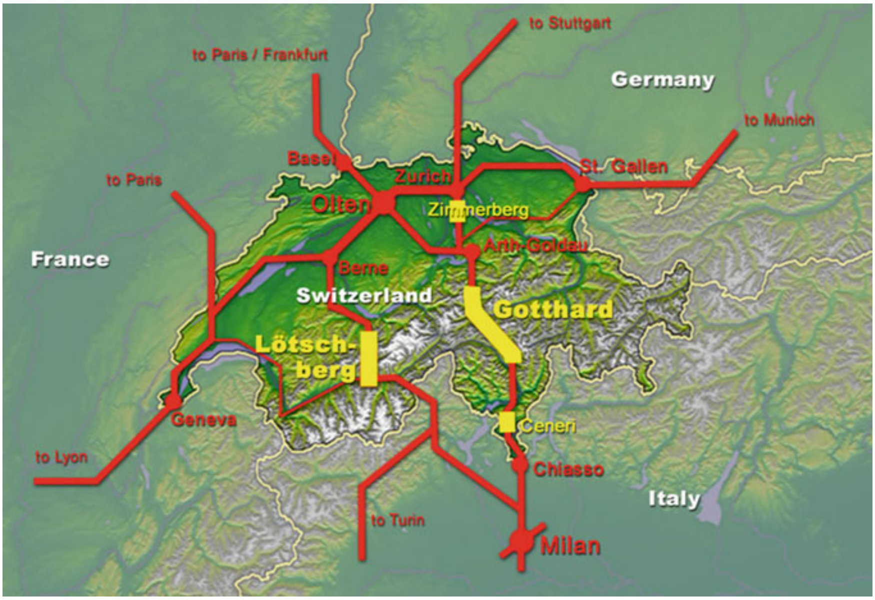


Fig. 11.1 The AlpTransit project (*Source* ETH Zurich IRL for INTERREG IVB NWE project CODE24, 2011)

Therefore the north–south axis is a crucial project that may improve or worsen the transport services depending on the operating conditions.

Spatial and territorial development is influenced by the expansion and the construction of railway infrastructure in terms of accessibility and presence of services to the population. These can enhance the attraction of an area from an economic, logistic, industrial and tourist point of view. Changes in accessibility conditions inevitably bring advantages and disadvantages to the regions affected. Therefore, accessibility is a crucial point for the territorial development on this spatial axis. Reducing travel time between Zurich and Milan means creating new daily commuter movements. This would cause major positive changes in the spatial and functional structure of the territories and in the way of living and working for residential people.

In this complex panorama, the territory of Bellinzona is in a particular situation: it will be the only site along the corridor track that will see a reduction in the travel time, starting from 2020.

Improving the accessibility of the area will open up new opportunities for a better use of brownfield sites around the train stations. Thus, the brownfield sites are strategic areas for the future development of Bellinzona. Furthermore, they constitute another challenge to the construction of the NEAT system: exploiting the potentiality of the new railway line while repositioning the workforce of the machine workshops. The attraction of a mobile workforce and of advanced

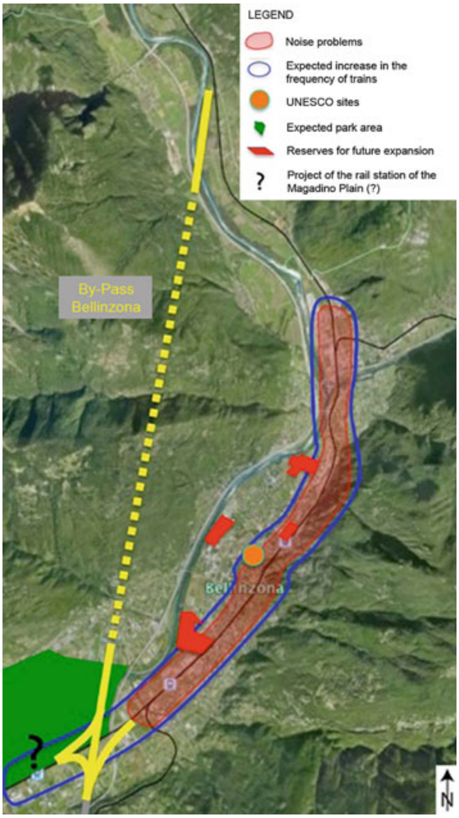


Fig. 11.2 The Bellinzona area (*Source* ETH Zurich IRL for INTERREG IVB NWE project CODE24, 2011)

services in addition to the presence of specialized labour are fundamental for the economic success of this area.

The railway by-pass of the Bellinzona area is another issue that could affect the territory. The by-pass should convey the freight and transit traffic into a tunnel located in the west side of the settlement. It constitutes a strategic project that should solve the problems related to the noise pollution that affect the area. The risks are that the tunnel might also be used for fast passenger connections, causing a downgrade of Bellinzona into a regional railway node without solving the noise issues (Fig. 11.2).

Moreover, a further difficulty is constituted by the Magadino Plain. This is a flat connection area between Bellinzona and Locarno and it is the principal topic of discussion of the Ticino planning area. The Magadino Plain is an environmentally protected area where strict building constraints have been established in order to protect the environmental balance. Despite the willingness of the planners to preserve this natural area, the landscape has inevitably been affected by the real estate market (i.e. large shopping centres and luxury villas on the slopes of the surrounding mountains). The new infrastructural projects will reduce travel time

Table 11.1 Alternative development strategies

Alternatives	Description
Scenario 1	The scenario involves the creation of a rail bypass which is destined both for passengers and freight. It implies the construction of a new rail tunnel as well as a new station in the Magadino area
Scenario 2	The scenario concerns a series of works aiming at improving the existing rail line, in order to increase the transport capacity. Some mitigations of acoustic impact will be provided within this scenario
Scenario 3	The scenario considers the construction of a rail bypass which will be exclusively destined to freight transport

and will offer new opportunities of growth but it will also bring new development pressure to the Magadino Plain.

The Italian authorities are sponsoring the construction of a costly new freight corridor for the railway line of Novara (Italy) which will cross the Magadino Plain. This would bring important advantages for the Italian freight transport but it would produce devastating effects for the Magadino Plain.

Three alternative development strategies have been designed in order to sum up the current debate on the decision process for the Bellinzona area (Table 11.1).

11.4 Structuring of the Decision Problem

11.4.1 Definition of the BOCR Model

A complex ANP model has been developed in order to identify the best alternative development strategy for the area of Bellinzona. According to the literature [28], the decision problem has been divided into four clusters (namely environmental aspects, urban aspects, transport aspects and economic aspects) in turn divided into elements. Clusters and elements were organized according to a BOCR model (i.e. Benefits, Costs, Opportunities and Risk). In this model, Benefits and Costs have been considered, respectively as positive and negative aspects of the transformation at the present time, while Opportunities and Risks have been considered as positive and negative aspects of the transformation in future scenarios. Figure 11.3 shows the complete network of the model.

The choice of applying a complex BOCR network is related to the complex nature of the examined decision problem. In fact, it allows a high number of aspects occurring in different time periods to be taken into account. Table 11.2 represents the decision network of the problem.

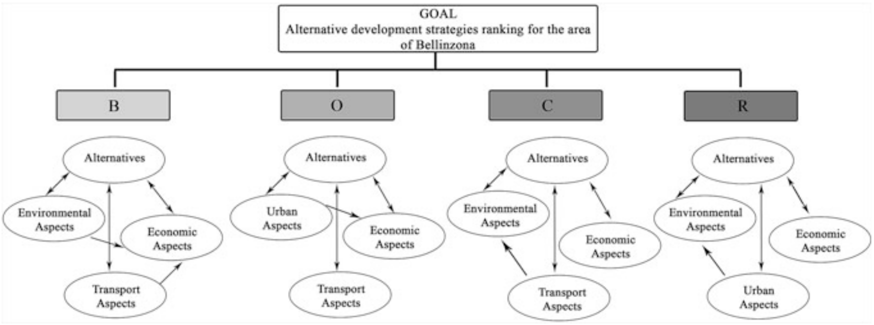


Fig. 11.3 BOCR model

11.4.2 Construction of the Partial Maps

Since the ANP technique works by assigning weights to the relationships occurring among elements, clusters and subnets, InViTo has been set up in order to generate spatial forms depending on weighted relationships among the 3D model components. Therefore, the same ANP organization of relationships and weights has been reproduced to generate the 3D model. In this sense, each element considered by the BOCR model has been associated onto a spatial map which symbolically localises its effect on the area (see Table 11.3). For example, the map of Benefits visualising the increase of accessibility uses a buffer area around the railway stations, because this is the area expected to receive the most effects related to railway accessibility. Nevertheless, not all the elements have a spatial consequence which can be positioned in a specific place. For example, the positive effects regarding the expected increase of the attractiveness to the area (CT, Table 11.3), or the possible extensions of the implementation time derived from the conflicts among the local population, (IT, Table 11.3) are both elements which have no defined boundaries and can be difficult to draft on a map only with difficulty. Furthermore, they have a diffuse consequence on the whole region considered. Therefore, their visualization has been designed as a constant value covering the whole area. On the contrary, the elements with a localized effect on defined areas have been closely associated onto maps which represent diversified values depending on the localization of their effect. Such elements include the environmental and transport aspects which generally have a recognizable area of impact.

The peculiarity of these maps is represented by the possibilities given by the interaction with them. The actors involved in the process are able to see the changes that their evaluations produce, as well as, being able to locate the elements under discussion. In this way, decision-makers are assisted in confirming or changing their point of view.

Table 11.2 Cluster and nodes of the BOCR model

Clusters	Elements		Description
Benefits			
Economic aspects	Valorization of the real estate market	RE	Valorisation of the real estate market in the area related to the improved accessibility
	Valorization of touristic local system	TL	Valorisation of the touristic local system in the area related to the improved accessibility
Environmental aspects	Conservation of protected area of Magadino	PA	Landscape protection and enhancement of territorial peculiarities of the area of Magadino
	Reduction in acoustic emission	RA	Reduction in acustic emission due to the use of compensation measures as acoustic barriers along the railway lines
Transport aspects	Increase in accessibility	IA	Increased accessibility due to the development of transport connections
	Increase in capacity of freight transport	CF	Optimization and development of freight transport connections
Opportunities			
Economic aspects	Creation of employments	CE	Creation of new employments directly related to the transport improvement
Transport aspects	Increase in connections between Ticino and Lombardy region	DT	Increase in transport connections between the Ticino area and the Lombardy region
Urban aspects	Creation of new urban centrality	UC	Creation of new urban centralities in the areas affected by the transformation
	Development of the Ticino area and of its attractiveness	CT	Increased attractiveness due to the development of transport connections
Costs			
Economic aspects	Acquisition/expropriation of areas for the insertion of the new railway line	AE	Economic costs related to the acquisition/expropriation of areas for the insertion of the new railway line
	Costs of investments	CI	Economic costs of the needed interventions

(continued)

Table 11.2 (continued)

Clusters	Elements		Description
Environmental aspects	Negative impact of the building site (noise + vibrations)	BS	Negative impact (noise and vibrations) due to the passage of trains
Transport aspects	Traffic congestion	TG	Traffic congestion due to realization/according works of the infrastructure
Risks			
Economic aspects	Lack of demand in the real estate market	LD	Lack of demand in the real estate market due to the presence of new infrastructures
	Possible extensions of implementation time	IT	Possible extensions of implementation time due to the conflicts arising with the local population
Environmental aspects	Hydro geological risk	HG	Hydro geological risk of the needed interventions
	Loss of biodiversity in the park	BP	Loss of biodiversity in the park due to the passage of trains in a protected area
Urban aspects	Dispersion settlement	DS	Risk of dispersion settlement due to the passage of trains
	Negative pressures on UNESCO sites	NP	Negative pressures on UNESCO sites due to the passage of trains in a protected area

Table 11.3 Structure of the ANP model with related maps

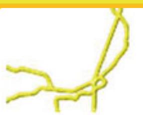
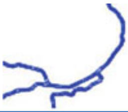
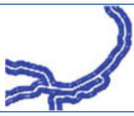
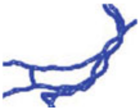
CLUSTERS	*ELEMENTS*	*MAPS and DESCRIPTION*	
Benefits			
Economic	RE		Railway Stations Buffer
	TL		Constant
Environm.	PA		Protected Area of Magadino
	RA		Railway Network Buffer
Transport	IA		Railway Stations Buffer
	CF		Railway Network
Opportunities			
Economic	CE		Railway Network
Transport	DT		Railway Stations
Urban	UC		Railway Stations Buffer
	CT		Constant

Table 11.3 (continued)

Costs			
Economic	AE		Railway Network Buffer
	CI		Constant
Environm.	BS		Railway Network
Transport	TG		Road Network

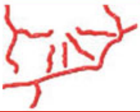
Risks			
Economic	LD		Railway Stations Buffer
	IT		Constant
Environm.	HG		Inland Waterways Network
	BP		Protected Area of Magadino
Urban	DS		Protected Area of Magadino
	NP		UNESCO Sites

Table 11.4 Pairwise comparison matrix at the cluster level for the benefits subnetwork

Alternatives	Economic aspects	Environmental aspects	Transport aspects	Priorities
Economic aspects	1	1/7	1/5	*0.075*
Environmental aspects	7	1	2	*0.592*
Transport aspects	5	1/2	1	*0.333*

11.5 Weighting and Aggregation

According to the ANP methodology described in Sect. 11.2, once the model has been structured it is necessary to develop the pairwise comparisons in order 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 node level, which is more specific and detailed. In the present application, the numerical judgments used to fill the pairwise comparison matrices were derived by a specific focus group. The focus group included different experts in the fields of transport infrastructures, environmental assessment, urban planning, economic evaluation and social sciences. The focus group had the dual purpose of helping to structure the decision problem taking into account the feedback and suggestions coming from the experts, and to compile the pairwise comparison matrices in order to come to a coherent result. Every expert was first asked to write down their individual judgments for each question. The given judgments were then illustrated and discussed in the focus group until a shared weight was achieved.

In the presented application all the calculations have been implemented using the Superdecisions software (www.superdecisions.com).

Questions such as "*Which aspects will lead to the greatest benefits associated with the transformation project? And to what extent*?" were solved by the focus group considering the cluster of the alternatives as a parent node in the Benefits subnetwork.

The judgments expressed were used to create the related pairwise comparison matrix (Table 11.4).

Economic aspects	9	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	9	Environmental aspects
Economic aspects	9	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	9	Transport aspects
Environmental aspects	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Transport aspects

Table 11.4 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 highlights that environmental aspects are the most important from the Benefits point of view. According to ANP methodology, the final priority vectors that result from the comparison matrices at the cluster

Table 11.5 Cluster matrix for the benefits subnetwork

	Alternatives	Economic aspects	Environmental aspects	Transport aspects
Alternatives	0.000	1.000	0.500	0.500
Economic aspects	*0.075*	0.000	0.500	0.500
Environmental aspects	*0.592*	0.000	0.000	0.000
Transport aspects	*0.333*	0.000	0.000	0.000

level determine the columns of the cluster matrix. Table 11.5 shows the cluster matrix for the Benefits subnetwork. The priorities of the elements that had previously been compared (Table 11.4) are shown.

Once the clusters comparison had been conducted, it was necessary to study the problem in depth through the analysis of the elements. As an example, a question submitted to the focus group was: *With reference to the evaluation of the priority of the considered projects, from the Benefits point of view, which alternative satisfies the objective "reduction in acoustic emissions" more closely? And how much more?* The judgments expressed were used to fill in the related pairwise comparison matrix (Table 11.6).

Scenario 0	9	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Scenario 1
Scenario 0	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Scenario 1
Scenario 1	9	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	9	Scenario 2

Once the pairwise comparison matrices had been compiled, all of the related vectors together formed the unweighted supermatrix. In this case, four supermatrices were obtained, one for each subnetwork. Table 11.7 represents the unweighted supermatrix, with reference to the Benefits subnetwork. The priorities of the elements that had previously been compared (Table 11.6) are shown.

Finally, according to the ANP methodology, the cluster matrix was applied to the initial supermatrix as a cluster weight. The result was the weighted supermatrix, which was raised to a limiting power in order to obtain the limit supermatrix, where all columns were identical and each column gave the global priority vector. In this case, four limit supermatrices were obtained, one for each subnetwork.

11.5.1 Final Results

Each column of the limit supermatrices obtained from the four subnetworks provides the final priority vector of all the elements being considered (Table 11.8).

The results of the complex ANP model highlight that the most important elements in the decision-making problem are: (1) reduction in acoustic emissions

Table 11.6 Pairwise comparison matrix at the node level for the benefits subnetwork

Reduction in acoustic emissions	Scenario 0	Scenario 1	Scenario 2	Priorities
Scenario 0	1	7	3	*0.649*
Scenario 1	1/7	1	5	*0.072*
Scenario 2	1/3	1/5	1	*0.367*

Table 11.7 Unweighted supermatrix for the benefits subnetwork

		Alternatives			Economic aspects		Environmental aspects		Transport aspects	
		0	1	2	RE	TL	PA	RA	IA	CF
Alternatives	0	0.000	0.000	0.000	0.105	0.063	0.051	*0.649*	0.122	0.114
	1	0.000	0.000	0.000	0.258	0.265	0.582	*0.072*	0.074	0.072
	2	0.000	0.000	0.000	0.637	0.672	0.367	*0.279*	0.804	0.814
Economic aspects	RE	0.250	0.500	0.750	0.000	0.000	0.000	1.000	0.875	0.000
	TL	0.750	0.500	0.250	0.000	0.000	0.000	0.000	0.125	0.000
Environmental aspects	PA	0.010	0.900	0.250	0.000	0.000	0.000	0.000	0.000	0.000
	RA	0.900	0.100	0.750	0.000	0.000	0.000	0.000	0.000	0.000
Transport aspects	IA	0.500	0.875	0.010	0.000	0.000	0.000	0.000	0.000	0.000
	CF	0.500	0.125	0.900	0.000	0.000	0.000	0.000	0.000	0.000

(environmental aspects cluster) for the Benefits subnetwork (0.163); (2) the development of the Ticino area and of its attractiveness (transports aspects cluster) for the Opportunities subnetwork (0.364); (3) the costs of the investment (economic aspects cluster) for the Costs subnetwork (0.232); and (4) the dispersion settlement (urban planning aspects cluster) for the Risks subnetwork (0.102).

11.5.2 Priorities of the Alternative Scenarios

The normalization of the priorities of the scenarios on the cluster of the alternatives provides the priority vector of the three considered options (Table 11.9).

Following the ANP theory, 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 11.9) in order to obtain an overall synthesis. Different aggregation formulas are available and the chosen formula depends on the final desired use of the results. If the purpose is to peak the best alternative, any of the different formulas will do [28]. Table 11.10 shows the final ranking of the alternative sites according to three formulas.

As is possible to notice from Table 11.10, all the available formulas converge in considering the scenario 2 as the best performing scenarios, followed by scenario 1 and finally scenario 0.

11.5.3 Final Decision Maps

Once the ANP questionnaire has been compiled and weights assigned to each element and cluster, the modeling system sums up all the weights and produces a three-dimensional visualization, based upon the scores given by the participants. The representation that follows is a deformation of the territory that generates a three-dimensional diagram, one for each scenario.

To obtain better comprehension on the comparison of scenarios, a slicing plane has been added to the visualization of 3D maps. This plane can be vertically moved so to work as a cursor which cuts-off the areas with lower values, i.e. those areas with less quantities of expected consequences due to the choices of actors. In this way, the slicing plane allows data to be visually selected and scenarios to be compared each other. The areas with more benefits or opportunities can be highlighted as the more preferable, while the areas with more costs and risks can be identified to better analyze the negative effects.

In the subnet of Benefits (Fig. 11.4), the system provided very different results for the three scenarios, localizing the positive effects in diverse areas. Scenario 0 shows an improvement along the rail tracks due to the reduction of noise pollution, while scenario 1 concentrates the benefits all over the Magadino protected area, which would remain outside of the zone involved in the transformation of the infrastructural system. Only scenario 2 allows a wider spread of benefits, distributing the positive effects both along the railway lines and on the park protected area, thus generating the best solution relative to this subnet. It is interesting to notice that the results of the Benefits visual map are aligned with the outcomes provided by the ANP model (Table 11.9). In fact, according to ANP priorities, the scenario 2 is the most beneficial (0.661 in the priority vector) and this finding is confirmed by the visual representation of Fig. 11.4.

Regarding the Opportunities associated with the three scenarios (Fig. 11.5), the highest peaks are in scenario 0. Those peaks are centred on the railway stations, which is the singular map associated with the “increase in connections between the Ticino and Lombardy regions”. This means that the main contribution comes from the predominant importance given to the improvement of connections between the Swiss region of Ticino and the Italian one of Lombardy, identifying it as the most important element among the opinions of actors involved. The results of this evaluation strongly influences the choice of scenario 0 because it proposes a high speed connection all over the considered area. At the same time, the maps show the prevalence of scenario 0 also in the creation of new urban centralities and new job opportunities directly related to the transport improvement. It is important to underline that the results performed by the ANP, showing that the highest number

Table 11.8 Final priorities of the elements of the model

BOCR	Clusters	Elements	Limit priorities
Benefits	Alternatives	0	0.086
		1	0.110
		2	0.249
	Economic aspects	RE	0.125
		TL	0.017
	Environmental aspects	PA	0.101
		RA	0.163
	Transport aspects	IA	0.055
		CF	0.094
Opportunities	Alternatives	0	0.379
		1	0.063
		2	0.054
	Economic aspects	CE	0.100
	Transport aspects	DT	0.364
	Urban aspects	UC	0.028
		CT	0.012
Costs	Alternatives	0	0.213
		1	0.191
		2	0.084
	Economic aspects	AE	0.163
		CI	0.232
	Environmental aspects	BS	0.062
	Transport aspects	TG	0.055
Risks	Alternatives	0	0.324
		1	0.084
		2	0.066
	Economic aspects	LD	0.205
		IT	0.099
	Environmental aspects	HG	0.023
		BP	0.060
	Urban aspects	DS	0.102
		NP	0.037

Table 11.9 Final priorities of the alternatives under the BOCR subnetworks

Alternatives	B	O	C	R
Scenario 0	0.194	0.763	0.438	0.682
Scenario 1	0.245	0.128	0.389	0.178
Scenario 2	0.661	0.109	0.173	0.140

Table 11.10 Final ranking of the alternatives according to the different formulas

	Additive (negative) $B-C$	Additive (probabilistic) $B + (1 - C)$	Multiplicative $B \times (1/C)$
Scenario 0	−0.376	0.251	0.142
Scenario 1	−0.310	0.273	0.319
Scenario 2	0.313	0.476	0.776

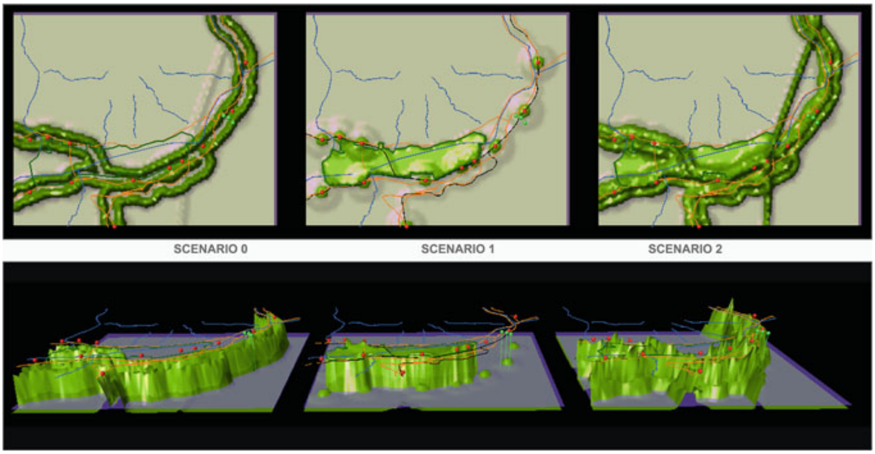


Fig. 11.4 Visualisation of Benefits' subnet by means of 3D diagrams: a comparison among three scenarios

of opportunities is provided in scenario 0, (Table 11.9) are reflected in the maps. The analysis of Costs (Fig. 11.6) shows that scenarios 0 and 2 would be strongly characterized by costs disseminated all over the area because of the large investment required for the construction of an underground bypass. On the contrary, the costs of scenario 1 would be highly concentrated along the railway line mainly as a result of expropriation. However, the most acceptable results in terms of costs are provided by scenario 2 as emerged by the ANP method (Table 11.9).

Finally, analyzing the results related to the risk subnet (Fig. 11.7), the scenario with the lowest risks is number 1. The reason of this outcome is identified in the

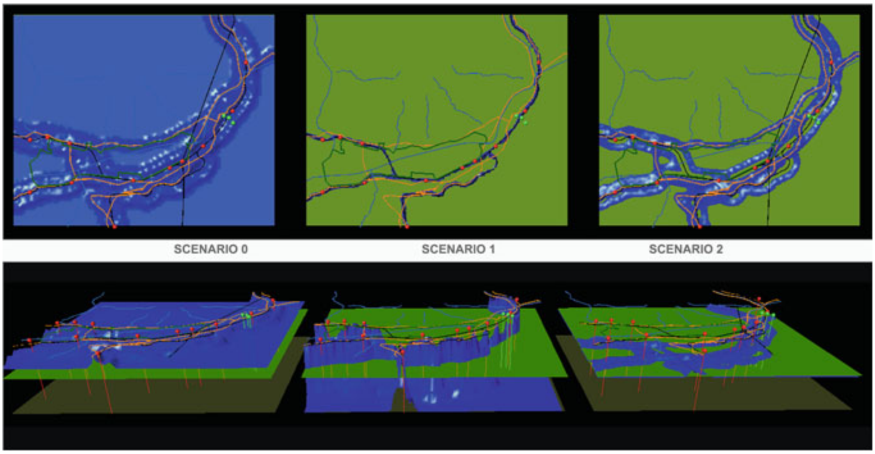


Fig. 11.5 Visualization of opportunities' subnet

possible rebound in the housing market due to the development of the railway network. Differently, scenario 0 and 2 present many hydro-geological risks, represented by the inland waterways network. Scenario 2, in fact, is expected to be threatened by the possible extension of the implementation time due to the conflicts arising with the local population. Furthermore, a significant impact to the park area of Magadino occurs in scenario 0 due to the creation of the station in addition to the rail tunnel, while scenario 2 highlights the risk associated with general economic aspects that causes urban sprawling on the whole area in line with the results in Table 11.9.

11.6 Sensitivity Analysis

In order to test the model's robustness, a sensitivity analysis was performed after obtaining a ranking of the alternatives. A sensitivity analysis is concerned with the "what if" kinds of questions to see if the final answer is stable when the inputs, whether judgments 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.

The purpose of the sensitivity analysis is to create an explanatory process by which the Decision Makers achieve a deeper understanding of the structure of the problem. It is helpful to the analyst to learn how the various decision elements interact in order to determine the most preferred alternative and to determine which elements are important sources of disagreement among DMs and interest groups. Thus the ANP not only aids in selecting the best alternative, but also helps DMs to understand why one alternative is preferable to the other options [10].

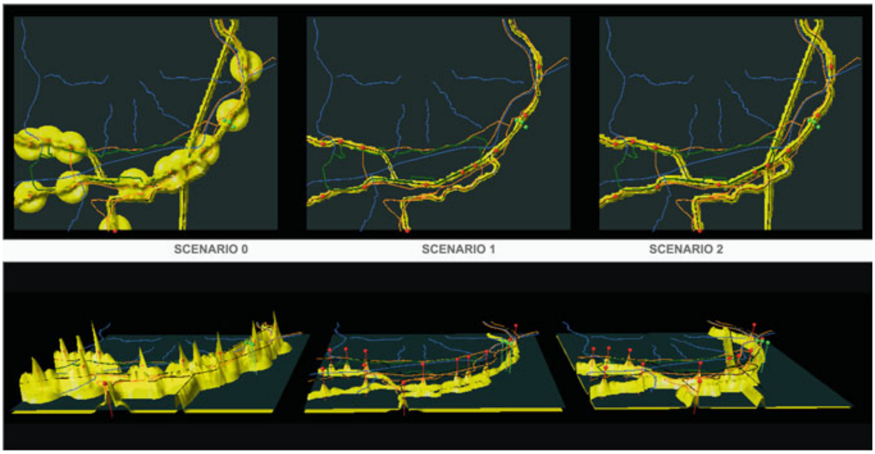


Fig. 11.6 Visualization of costs' subnet

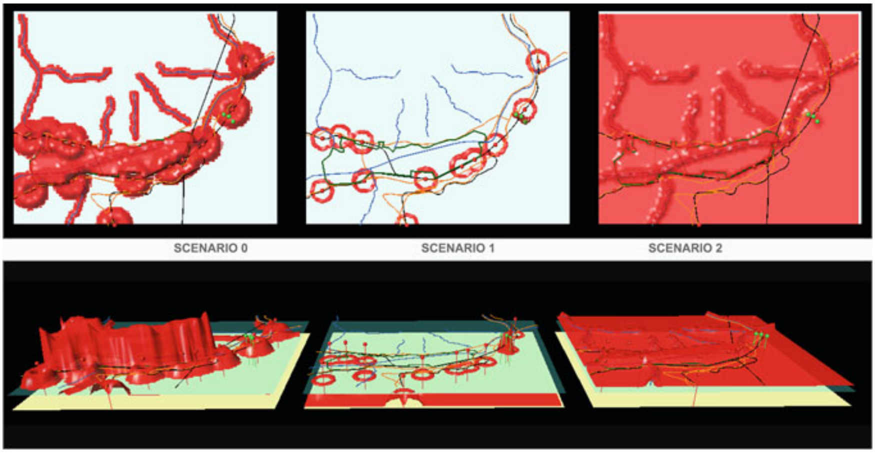


Fig. 11.7 Visualisation of risks' subnet: comparison among scenarios

In the present chapter two different sensitivity analyses were undertaken in order 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 (BOCR) priorities. In the second, an attempt was made to verify the rank reversal of the alternatives [30] by eliminating one alternative at a time from each subnetwork of the model and thus studying the resulting final ranking, searching for potential changes.

In the first study, while measuring the sensitivity of the alternatives to the BOCR weights, an additive formulation was used, since the meaningful changes could not be obtained by a multiplicative formulation [37]. The sensitivity analysis for the four subnetworks is represented in Fig. 11.8a–d where the x axis represents the changes in the weights of the control criteria and the y axis represents the changes in the weights of the alternatives.

When the relationships between the Benefits dimension and the alternatives are considered it becomes clear that "scenario 2" provides more benefits compared to the other options (Fig. 11.8a). The sensitivity analysis shows that the Opportunities dimension is the most unstable subnetwork (Fig. 11.8b), since both the results and the ranking of the alternatives are very sensitive to the changes in the weight of the opportunities. The ranking of the alternatives changes from "scenario 2"–"scenario 1"–"scenario 0" (for 0 % opportunities weight) to "scenario 0"–"scenario 1"–"scenario 2" (for 100 % opportunities weight). In the Costs subnetwork (Fig. 11.8c) the alternatives are almost completely insensitive to the changes in the weight of the control criteria. Finally, the sensitivity analysis shows that the Risks dimension (Fig. 11.8d) is quite an unstable subnetwork, and one inversion in the ranking of the alternatives can be identified.

In the second sensitivity analysis, we tried to investigate the possibility of rank reversal of the alternatives [29]. This analysis eliminated one alternative at a time from the original model, and evaluated the new results. Table 11.10 thus illustrates, for each subnetwork of the model, the original ranking of the alternatives and the results arising from the elimination of the highest priority alternative. Acknowledging that rank can and should reverse under general conditions that have been recognized such as introducing copies or near copies of alternatives and criteria [33], the question is not whether rank should be preserved [39], but whether or not the assumption of independence applies [33]. As it is possible to see from Table 11.11, the rank is preserved, with a small exception for the risks subnetwork where the two alternatives rank very similarly; it is thus possible to conclude that the final result of the model is stable.

11.7 Conclusions

This chapter illustrates the application of a complex ANP method to support the decision process regarding the different projects of the railway in the Bellinzona area. At the same time, this article presents a new approach to the integration of the modelling system for the spatial visualization of the ANP.

The ANP methodology is able to take into consideration both tangible and intangible criteria and considers the relationships between these in a systematic manner. This is particularly important for assessing the processes of urban and territorial transformation, as the case presented here.

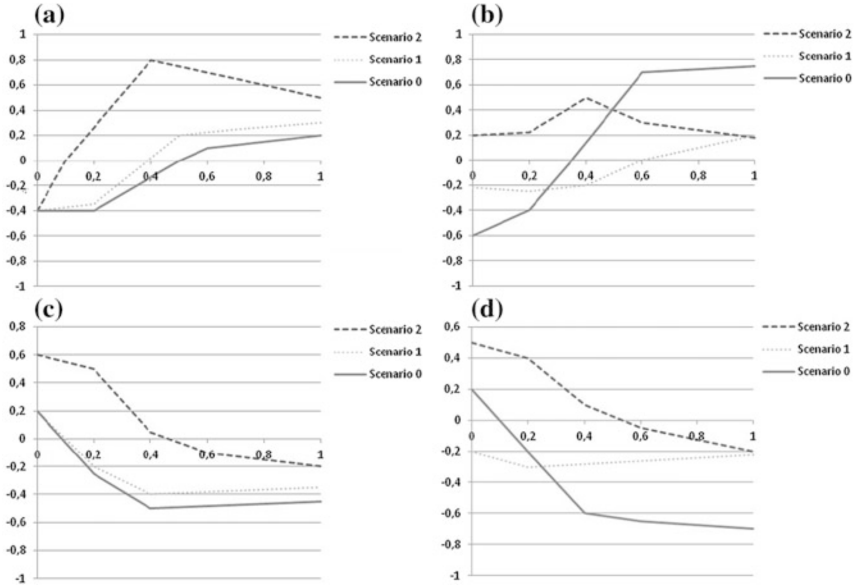


Fig. 11.8 Sensitivity analysis for each subnetwork using the additive (negative) formula

The ANP allows the most important elements of the decision to be highlighted through a transparent and traceable process, thus facilitating deliberation.

A weakness of this methodology could refer to the assignment of weights to clusters and nodes. In fact, this procedure could create misunderstandings due to a lack of ability of non-expert users to understand their meaning. The use of ANP to study alternative planning solutions in real decision arenas helped identify areas for potential improvement [11] in this sense: a more visual grammar can generate a common basis for sharing information and allowing discussions. Therefore, the indexes, weights and rankings from ANP must be an object of discussion as well as their results. Furthermore, the large quantity of data to manage during the decision process has highlighted the necessity to filter items in order to better identify and isolate core features.

The results of the analysis performed show that the ANP-BOCR model is suitable to represent a real world problem. The technique provides the means to perform complex trade-offs on multiple evaluation criteria, while taking the DMs preferences into account. The main drawback in the practical application of the ANP is a consequence of the complexity of the decision issue being analysed. For example, the ANP prescribes a large number of comparisons that occasionally become too complex for DMs to understand if they are not familiar with the method. Hence, a great deal of attention should be devoted to the wording of the questionnaires and the comparison process should be helped by a facilitator (Aragonés-Beltrán et al. 2010). The evaluation process has been supported by the use of interactive visualisations, which were effective in the creation of a common

Table 11.11 Sensitivity analysis with respect to the rank reversal of the alternatives

Subnetwork	Priority of the alternatives	Original ranking	Eliminated alternative	New priorities	New ranking
Benefits	0: 0.194	2 > 1 > 0	2	0: 0.347 1: 0.653	1 > 0
	1: 0.245				
	2. 0.661				
Opportunities	0: 0.763	0 > 1 > 2	0	1: 0.573 2: 0.427	1 > 2
	1: 0.128				
	2. 0.109				
Costs	0: 0.438	0 > 1 > 2	0	1: 0.660 2: 0.339	1 > 2
	1: 0.389				
	2. 0.173				
Risks	0: 0.682	0 > 1 > 2	0	1: 0.494 2: 0.506	2 ≈ 1
	1: 0.178				
	2. 0.140				
BOCR	0: 0.251	2 > 1 > 0	2	0: 0.444 1: 0.556	1 > 0
	1: 0.273				
	2. 0.476				

mental model among the actors involved. Furthermore, the use of visual communication provided the basis for the sharing of information and the creation of individual awareness and enhanced the discussion between the parties.

However, there are still a number of opportunities for expanding the study and for validating the results obtained. First, it would be of scientific interest to weight the BOCR categories by implementing the evaluation model by means of the strategic criteria [31]. Second, the model could be combined with a Costs-Benefits Analysis in order to develop an overall assessment of the transformation project impacts [36].

In conclusion, the methodology adopted was successful in structuring the complex planning context, communicating the stakeholders' perspectives, improving the stakeholders' commitment and their perception of being involved, enhancing transparency in the decision-making process and thus increasing the acceptance of the proposed solutions.

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