ASSESSING THE SUSTAINABILITY OF ALTERNATIVE TRANSPORT INFRASTRUCTURES

Marta Bottero*
Interuniversity Department of Regional and Urban Studies and Planning (DIST)
Politecnico di Torino
Torino, ITALY
E-mail: marta.bottero@polito.it

Valentina Ferretti
Interuniversity Department of Regional and Urban Studies and Planning (DIST)
Politecnico di Torino
Torino, ITALY
E-mail: valentina.ferretti@polito.it

Silvia Pomarico
Interuniversity Department of Regional and Urban Studies and Planning (DIST)
Politecnico di Torino
Torino, ITALY
E-mail: silvia.pomarico@polito.it

ABSTRACT

This paper addresses the problem of sustainability assessment of territorial transformation through the use of the ANP. The case of a new transport infrastructure in a city located in Italy is considered in the study. The project discussed involves further development of the existing ring road in the city which will lead to a radically new multifunctional design of the urban area. In the case study, four alternatives have been identified and compared in order to select the most sustainable option. The model takes into consideration in more detail the different aspects of the decision-making process economic, environmental, social, transport and urban planning aspects) that have been organized according to the Benefits, Opportunities, Costs and Risks (BOCR) categories. In the present study a focus group was organized with actors from Public Authorities in order to discuss the general aspects of the problem. Also, several experts were questioned in order to elicit the priorities of the aspects under consideration. The application of the ANP technique, which was performed using the *Super Decisions* software, allowed the most relevant aspects of the decision-making process to be highlighted.

Keywords: Analytic Network Process; decision-making; territorial transformation; sustainability assessment; transport infrastructures.
http://dx.doi.org/10.13033/ijahp.v4i1.101

1. Introduction

Sustainable development is a multidimensional concept that includes socio-economic, ecological, technical and ethical perspectives and thus leads to issues that are simultaneously characterized by a high degree of conflict, complexity and uncertainty. When speaking about territorial planning, many objectives have to be considered in the decision-making process. These objectives range from the promotion

* Corresponding author

of cultural events to the requalification of downgraded urban areas, from the reduction of soil consumption to the optimization of environmental resource use and from the promotion of tourism to the rationalization of the mobility system. It is generally agreed that Multicriteria Analysis (Figueira *et al.*, 2005) is an adequate approach to deal with sustainability assessment of territorial transformations at both micro and macro study levels, and the use of a Multicriteria framework is an efficient tool when implementing an inter-disciplinary approach. In the context of MCA, the Analytic Network Process plays a very important role (Saaty 2005; Saaty and Vargas, 2006). This technique, which represents the generalization of the more well-known Analytic Hierarchy Process (Saaty, 1980) on dependences, is particularly suitable for dealing with complex decision-making processes which are characterized by interrelationships and feedback at stake.

among the elements This paper addresses the problem of sustainability assessment of territorial transformation through the use of the ANP. The case of a new transport infrastructure in a city located in Italy is considered in detail. The project discusses the further development of the existing city ring road which will lead to a radically new multifunctional design of the urban area.

As stated by Yin (1984), research methods based on case studies can be defined as empirical inquiries that investigate a contemporary phenomenon within its real-life context, when the boundaries between phenomenon and context are not clearly evident. In this sense, it is possible to say that case study research offers an understanding of complex issues and extends the already available knowledge about the topic. Scientists have used the case study research method for many years across a variety of disciplines; this is particularly true in the context of social sciences, where this methodology has been used to examine contemporary situations and to provide the basis for the application of ideas and extension of methods. More generally, case study methodology by investigating phenomena in their real-life context can be a very important tool in opening the "black box" of how interventions and program effectiveness are linked. This is an advantage over traditional experimental and quasi-experimental designs which may measure outcomes and some process variables, but fall short in dealing with the dynamic that is inherent in community-based collaborative initiatives (Horsch and Anderson, 1997). According to this approach, this paper aims to analyze a real case study and investigate the contribution that the ANP offers in the field of sustainability assessment and transport infrastructures.

Transport planning undeniably plays a key role in the economic growth of any region, and has long-term effects on the local community. A number of objectives must be met in order to select an optimal transport route. These objectives can be in conflict with one other, according to the opinions of the different stakeholders involved in the process. In order to support the decision-making process related to the implementation of the aforementioned project, an ANP model was developed. The reasons for using an ANP-based decision approach in the present analysis include: (i) the assessment of different transport route alternatives is a multicriteria decision-making process; (ii) there are dependencies among groups of criteria and between these and the alternatives to be analyzed, and (iii) the detailed analysis of the inter-relationships between criteria forces the Decision Makers (DMs) to reflect carefully on their project priority approach and on the decision-making problem itself. This helps DMs to gain a better understanding of the problem and to make a more reliable final decision.

2. ANP: theory overview and state of the art

The ANP (Saaty, 2005) represents a theory of relative measurement on absolute scales of both tangible and intangible criteria based on both the judgement of experts and on existing measurements and statistics needed to make a decision. The ANP represents any decision as a network and allows the structure to develop more naturally by freeing us from the burden of ordering the components in the form of a directed chain as in the AHP hierarchy.. The ANP therefore represents a better way to faithfully describe what can happen in the real world, and is gaining merit as a useful tool to help technicians make their decision processes traceable and reliable. By including dependences and feedbacks and by cycling their influence by means of the supermatrix approach, the ANP is more objective and more likely to capture what happens in the real world, thus providing effective support for the kind of decisions needed to plan for the future (Zoffer *et al.*, 2008). From a methodological point of view the ANP is based on five fundamental steps (Saaty, 2005): (i) structuring of the decision-making problem; (ii) clusters and nodes weighting by means of pairwise comparisons; (iii) supermatrices formation; (iv) elicitation of final priorities and (v) sensitivity analysis. There are two possible ways for structuring the decision-making problem: the simple network or the complex Benefits-Opportunities-Costs-Risks (BOCR) network (Saaty, 2005).

A very large and consolidated amount of literature concerning the ANP exists in different fields. Applications have been made in the sphere of waste management (Khan and Faisal, 2008; Aragonés-Beltrán *et al.,* 2010; Bottero and Ferretti, 2011), strategic policy planning (Ulutas, 2005), environmental impact assessment of territorial transformations (Bottero *et al.,* 2008; Bottero and Mondini, 2008; Liu and Lai, 2009), market and logistics (Liang and Li, 2008), economics and finance (Niemura and Saaty, 2004) and civil engineering (Neaupane and Piantanakulchai, 2006). In the transport planning field in particular, applications of ANP models exist for selecting optimal routes and for designing new corridors (Piantanakulchai, 2005; Tuzkaya and Onut, 2008). Finally, , a number of interesting works in the transport planning and territorial transformation field exist in recent studies focusing on sustainability assessment (Pèti, 2012; Bojković *et al.*, 2011; Bottero and Ferretti, 2010; Bottero and Lami, 2010; Basbas and Papanikolaou, 2009; Lombardi, 2009).

3. Application

3.1 Presentation of the case study and description of the alternatives

The purpose of the evaluation is to compare the different road infrastructure alternatives that the city is analysing in order to achieve a priority ranking of the alternative projects. In the present application, four alternatives were identified and compared in order to select the most sustainable option. More importantly, the transformation under examination refers to the so-called “undesirable facilities location problems”. In addition, the projects are currently under development and the alternatives refer to a timetable projected to the year 2030. For the aforementioned reasons, it is not possible to provide a detailed description of the alternatives. The full range of alternative options is described in Table 1. In the rest of the paper the projects under examination will be denoted as “alternative X” and “alternative Y”.

Table 1
Alternative description

Alternatives	Description
Alternative 0	This alternative represents the situation with no project.
Alternative X	The transformation refers to the implementation of a new North-South highway in the Western metropolitan area. This project will lead to a radically new multifunctional design of the city, including new residential and commercial areas and a highly innovative multilevel road project.
Alternative Y	This alternative refers to the development of the Eastern part of the city ring road in order to strengthen the existing road network. The area to be crossed by the road is characterized by agricultural land and the main concern of the project relates to the amount of land being consumed.
Alternative Z	This alternative refers to the development of both the aforementioned projects.

3.2 Construction of the BOCR network

A complex ANP model was developed in order to take into account the complexity of this decision-making problem. The use of the simple network, on the contrary, would have been largely unsuitable because the large number of elements and connections would have seriously weighed down the model. The problem has been divided into five clusters (economic aspects, environmental aspects, social aspects, transport aspects and urban planning aspects) that were organized according to the BOCR model. With reference to the alternative options previously described (section 3.1), the general objective of the analysis is to rank the alternative projects according to their overall performance. Each decision-making problem is characterized by positive and negative aspects that can emerge in different temporal phases. In this ANP model, the Benefits and Costs have been considered, respectively, as positive and negative aspects of the transformation with reference to a short time period, for which detailed previsions are available. The Opportunities and the Risks have been considered, respectively, as positive and negative aspects of the transformation over a long time period, and they are difficult to anticipate. Table 2 represents the ANP model according to the BOCR structure. There are four subnets which have different clusters and elements, always including a common cluster of alternatives. As an example, Figure 1 shows in detail the Benefits subnetwork.

Table 2
The ANP model

BOCR	Clusters	Elements	Denotation
BENEFITS	Environmental aspects	Environmental quality improvement	B1
	Economic aspects	Real estate valorization	B2
		Valorization of the local commercial system	B3
		Investment profitability (tolls and rates)	B4
	Social aspects	Services improvement for the inhabitants	B5
		Adherence to local community expectations	B6
	Urban planning aspects	Creation of a polycentric system	B7
		Significance of the project for the urban transformation	B8
	Transport aspects	**Increase in accessibility and mobility for both people and goods**	B9

Table 2 (Cont'd)
The ANP Model

OPPORTUNITIES	Economic aspects	Trade efficiency	O1
		Possible valorization of the neighboring areas	O2
	Environmental aspects	Environmental mitigation measures	O3
	Social aspects	Travelling time reduction	O4
	Transport aspects	Transport and communication means innovation	O5
	Urban planning aspects	Revitalization of the area	O6
		Improvement in the image of the town	O7
COSTS	Economic aspects	Investment costs	C1
		Operating and maintenance costs	C2
	Environmental aspects	Soil consumption	C3
		Negative impacts of the construction work	C4
		Air and acoustic pollution	C5
	Social aspects	Duration of construction work	C6
	Transport aspects	Complexity of the project	C7
		Traffic congestion due to the construction work	C8
RISKS	Economic aspects	Lean investment profitability	R1
	Environmental aspects	Visual impact	R2
		Impacts on groundwater	R3
		Effects on the ecological connections	R4
		Urban sprawl	R5
	Social aspects	Social opposition to the project	R6
		Cost of injury	R7
	Transport aspects	Inefficiency of the transport system	R8

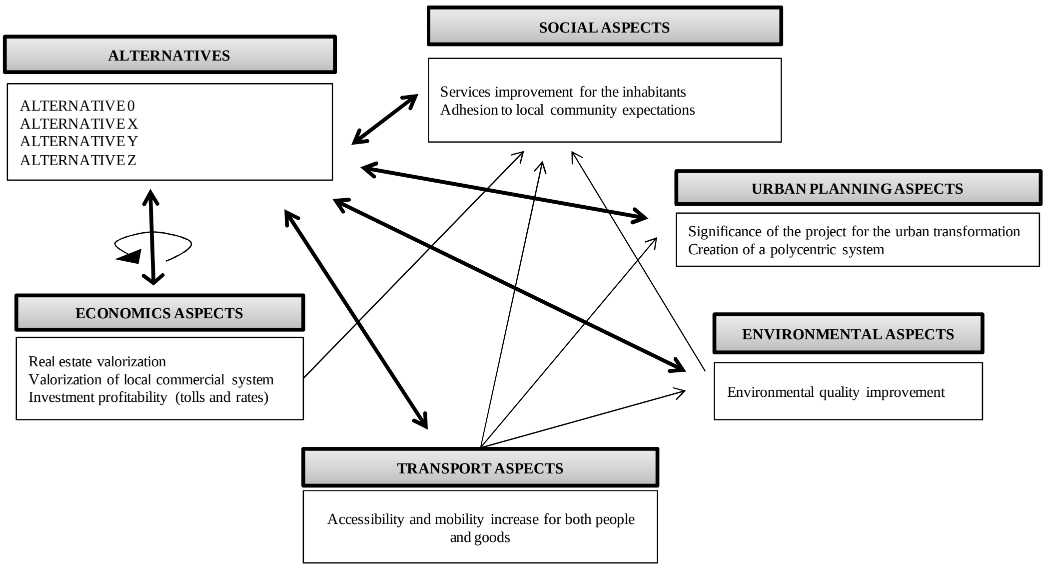

Figure 1 Benefits subnetwork

3.3 Development of the model

The next stage in the analysis according to the ANP methodology consists of 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. At the cluster level, the numerical judgments used to fill the pairwise comparison matrices were derived by a specific focus group. The focus group was made up of Decision-Makers and project coordinators from the local Public Authorities who worked together to evaluate the different aspects that characterized the problem with respect to the overall objective in order to reach a consensus decision on weights and priorities. The result of this phase is represented by the so-called cluster matrix. 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 3).

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

Table 3
Pairwise comparison matrix at the cluster level for the Benefits subnetwork

ALTERNATIVES	Environmental aspects	Economic aspects	Social aspects	Transport aspects	Urban planning aspects	**Priorities**
Environmental aspects	1	1/5	1/3	1/7	1/5	0.040
Economic aspects	5	1	3	1/3	1	0.186
Social aspects	3	1/3	1	1/5	1/4	0.078
Transport aspects	7	3	5	1	5	**0.508**
Urban planning aspects	5	1	4	1/5	1	0.188

Table 3 shows the pairwise comparison matrix and the main eingenvector which represents the priorities of the different aspects in the Benefit subnetwork with respect to the goal. This result highlights that transport 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 level determine the columns of the cluster matrix. Table 4 shows the cluster matrix for the Benefits subnetwork. The priorities of the elements that had previously been compared (Table 3) are shown.

Table 4
Cluster matrix for the Benefits subnetwork

	Alternatives	Environmental aspects	Economic aspects	Social aspects	Transport aspects	Urban planning aspects
Alternatives	0.000	0.750	0.594	1.000	0.400	1.000
Environmental aspects	0.040	0.000	0.000	0.000	0.046	0.000
Economic aspects	0.186	0.000	0.249	0.000	0.275	0.000
Social aspects	0.078	0.250	0.157	0.000	0.096	0.000
Transport aspects	0.508	0.000	0.000	0.000	0.000	0.000
Urban planning aspects	0.188	0.000	0.000	0.000	0.184	0.000

Once the clusters comparison had been conducted, it was necessary to study the problem in depth through the analysis of the elements. At the nodes level, in order to create the pairwise comparison matrices the values were derived from the judgments expressed by technical experts in the field of environmental assessment, transport infrastructures, social analysis, urban planning and economic feasibility. Each expert received a detailed questionnaire containing only questions about his own field of expertise with reference to the specific issue of the decision-making process. For example, a question submitted to a technical expert in the transport field was: *With reference to the evaluation of the priority of the considered projects, from the Benefits point of view, which alternative satisfies the objective "accessibility and mobility increase for both people and goods" more closely? And how much more?* The judgments expressed were used to fill in the related pairwise comparison matrix (Table 5).

Alternative 0	9	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	9	*Alternative X*
Alternative 0	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	*Alternative Y*
Alternative 0	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	**8**	9	*Alternative Z*
Alternative X	9	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	9	*Alternative Y*
Alternative X	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	*Alternative Z*
Alternative Y	9	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	9	*Alternative Z*

Table 5
Pairwise comparison matrix at the node level for the Benefits subnetwork

Accessibility and mobility increase for both people and goods	Alternative 0	Alternative X	Alternative Y	Alternative Z	**Priorities**
Alternative 0	1	1/7	1/3	1/8	0.045
Alternative X	7	1	5	1/3	0.307
Alternative Y	3	1/5	1	1/5	0.096
Alternative Z	8	3	5	1	0.552

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 6 represents the unweighted supermatrix, with reference to the Benefits subnetwork. The priorities of the elements that had previously been compared (Tables 5) are shown.

Table 6
Unweighted supermatrix for the Benefits sub network

		Alternatives				*Environmental aspects*	*Economic aspects*			*Social aspects*		*Transport aspects*	*Urban planning*	
		0	X	Y	Z	B1	B4	B3	B2	B6	B5	B9	B7	B8
Alternatives	0	0.000	0.000	0.000	0.000	0.056	0.033	0.036	0.041	0.122	0.061	0.045	0.042	0.066
	X	0.000	0.000	0.000	0.000	0.279	0.264	0.170	0.243	0.444	0.302	0.307	0.290	0.292
	Y	0.000	0.000	0.000	0.000	0.139	0.188	0.170	0.141	0.122	0.124	0.096	0.085	0.084
	Z	0.000	0.000	0.000	0.000	0.525	0.515	0.625	0.576	0.312	0.513	0.552	0.583	0.558
Environmental aspects	B1	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Economic aspects	B4	0.333	0.714	0.637	0.683	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	B3	0.333	0.143	0.258	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.750	0.000	0.000
	B2	0.333	0.143	0.105	0.117	0.000	0.000	1.000	0.000	0.000	0.000	0.250	0.000	0.000
Social aspects	B6	0.750	0.250	0.500	0.250	1.000	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.000
	B5	0.250	0.750	0.500	0.750	0.000	0.000	1.000	0.000	0.000	0.000	0.875	0.000	0.000
Transport aspects	B9	1.000	1.000	1.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Urban planning aspects	B7	0.500	0.833	0.750	0.875	0.000	0.000	0.000	0.000	0.000	0.000	0.833	0.000	0.000
	B8	0.500	0.167	0.250	0.125	0.000	0.000	0.000	0.000	0.000	0.000	0.167	0.000	0.000

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.

3.4 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 7). Leaving aside the alternative options, Table 7 shows the priorities of the elements of the model.

Table 7
Final priorities of the elements of the model

Benefits		**Opportunities**		**Costs**		**Risks**	
B1	0.027	**O1**	0.065	**C1**	0.068	**R1**	0.050
B2	0.040	**O2**	0.103	**C2**	0.014	**R2**	0.096
B3	0.059	**O3**	0.015	**C3**	0.025	**R3**	0.054
B4	0.052	**O4**	0.047	**C4**	0.028	**R4**	0.055
B5	0.050	**O5**	0.091	**C5**	0.016	**R5**	0.110
B6	0.019	**O6**	0.166	**C6**	0.125	**R6**	0.086
B7	0.098	**O7**	0.056	**C7**	0.115	**R7**	0.033
B8	0.020			**C8**	0.171	**R8**	0.036
B9	0.214						

The results of the complex ANP model highlight that the most important elements in the decision-making problem are: i) increase in accessibility and mobility for both people and goods (transport aspects cluster) for the Benefits subnetwork (0.214); ii) the revitalization of the area (urban planning aspects) for the Opportunities subnetwork (0.166); iii) the traffic congestion due to the construction work (transport aspects) for the Costs subnetwork (0.171); and iv) the urban sprawl (environmental aspects) for the Risks subnetwork (0.110).

3.5 Aggregation of the final results by means of the strategic criteria

In the case of the BOCR model, it is necessary to synthesize the outcome of the alternative priorities in order to obtain an overall ranking. According to the ANP technique, the analysis can make use of strategic criteria organized in an additional top layer, which can be very useful for determining the weights of the BOCR merits; these weights can be used to aggregate the priority vectors from the four subnetworks and to obtain the final list. The idea of using strategic criteria comes from the necessity of linking the global objectives of the problem to the particular decision. According to this approach, it is possible to link the global invariant strategic criteria to the alternatives in order to evaluate the importance of the BOCR elements for the decision, instead of directly comparing each component of BOCR against each other with respect to the goal.

Using strategic criteria in the model leads to a multi-layered structure with Benefits, Opportunities, Costs and Risks (BOCR) merit nodes at the top level of the network, control criteria within each of the four attached subnetworks and finally bottom level decision subnetworks which contain the alternatives that are in turn attached to the control criteria. The top level network also has an attached Ratings component for evaluating the importance of the BOCR through the use of the strategic criteria (Saaty, 2003).

The mechanism for using the strategic criteria in the model can be described as follows:

(i) definition of the strategic criteria;
(ii) weighting of the strategic criteria with respect to the goal;
(iii) determination of the BOCR weights with respect to the strategic criteria;
(iv) use of the BOCR weights in the aggregation formula for the overall synthesis of the alternative priorities.

Although the weighting of the strategic criteria with respect to the goal is made according to the pairwise comparison approach (Saaty, 1980), the determination of the BOCR weights may follow a different procedure. It is possible to rate how the highest priority alternative in the four BOCR subnetworks affects each strategic criteria by means of the rating process. This process makes use of a matrix, where the columns represent the strategic criteria and the rows represent the BOCR elements. Keeping in mind the best alternative under Benefits, Opportunities, Costs and Risks, it is necessary to rate across the row how this alternative affects each strategic criterion respectively in a beneficial, opportune, costly and risky way. For example, considering the Opportunities subnetwork, it is necessary to assess how the best alternative under Opportunities impacts the strategic criteria in a positive way. If the rating categories are High, Medium and Low, selecting High on a strategic criterion means that the alternative is really good and positive for that strategic criterion. Turning, for example, to Costs, using the same High, Medium and Low categories, it is possible to assess how much the highest priority alternative costs for each of the control criteria. Selecting High on a strategic criterion means that the highest priority alternative costs a lot for that strategic objective (Saaty, 2010).
There is a large amount of literature pertaining to the use of strategic criteria in ANP models (Saaty and Ozdemir, 2008; www.superdecision.com). In the present application, the strategic criteria reflect the general objectives which have to be pursued in territorial transformation projects, named “population well-being and quality of life”,

“optimization in the use of natural resources” and “equity in the reallocation of the economic Benefits”. Figure 2 gives a representation of the ANP model considering the use of strategic criteria while Table 8 shows how the BOCR merits were rated on the set of the aforementioned strategic criteria.

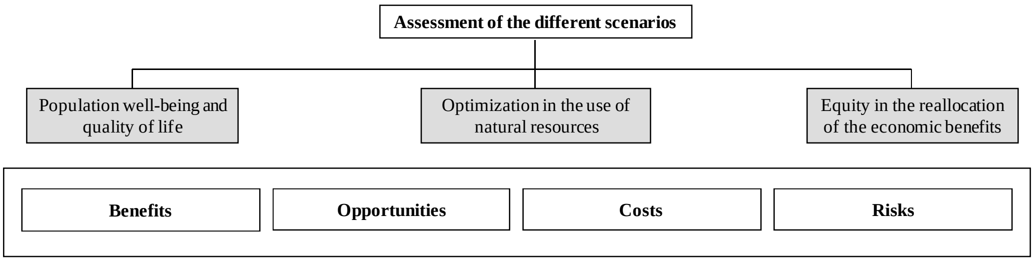

Figure 2 Representation of the complete multilayered ANP model including the use of strategic criteria for the decision problem under examination

In prioritizing the strategic criteria, the aspects related to “population well-being and quality of life” were given the highest importance (0.65 in the final priority vector), followed by the aspects related to the “equity in the reallocation of the economic benefits” (0.25), and finally by the aspects related to the “optimization in the use of natural resources” (0.10). This leads to the following priorities for the BOCR merits: 0,47 for Benefits, 0.12 for Opportunities, 0.35 for Costs and 0.06 for Risks.

Table 8
Strategic criteria and rating scale for the ANP model

BOCR	Priorities	Equity in the reallocation of the economic benefits [0,25]	Population well-being and quality of life [0,65]	Optimization in the use of natural resources [0,10]
Benefits	0.47	High	High	Medium
Opportunities	0.12	Medium	Medium	Medium
Costs	0.35	Low	High	Medium
Risks	0.06	Medium	Low	Low

The aforementioned priorities were used in order to synthesize the outcome of the alternatives for each of the BOCR subnetworks and to obtain the overall synthesis. In particular, the global formula *bB+oO-cC-rR* was applied, where *b*, *o*, *c* and *r* represent the priorities obtained by rating the BOCR with respect to the strategic criteria, and *B*, *O*, *C* and *R* represent the ideal priorities of the alternatives in the Benefits, Opportunities, Costs and Risks subnetworks, respectively (Saaty, 2005). The results of the calculations showed that “alternative Z” has the highest priority (0.54), followed by “alternative X” (0.32), then by “alternative Y” (0.08) and finally by “alternative 0” (0.05). In particular, from the Benefits point of view, the objectives related to the “equity in the reallocation of the economic benefits” and to the “population well-being and quality of life” are fulfilled very well by “alternative Z”, while it fulfils less well the objective related to the “optimization in the use of natural resources” (due to atmospheric and acoustic emissions associated with the alternative). From the Opportunities point of view, "alternative Z" fulfils the strategic objectives moderately well (the assessment is uncertain due to the long term temporal horizon). From the Costs point of view, "alternative Z" is not expensive with reference to the "equity in the reallocation of the economic benefits", but rather expensive with reference to "population well-being and quality of life" (significant impacts during the construction phase) and to the "optimization in the use of natural resources" (land consumption). Finally, from the Risks point of view, "alternative Z" is moderately risky with reference to the "equity in the reallocation of the economic benefits" (uncertain profit, possible need of public funding), but less risky in terms of "population well-being and quality of life" and "optimization in the use of natural resources". The analysis performed thus provides a transparent decision-making structure, making key considerations and values explicit and providing opportunities for stakeholders and community participation.

3.6 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.

In the present paper three 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, the analysis explored the modification of the influences of the alternatives on the criteria and of the criteria on the alternatives. Finally, in the third study, an attempt was made to verify the rank reversal of the alternatives (Saaty, 2006) 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 (Tuzkaya *et al.*, 2007). The sensitivity analysis for the four subnetworks is represented in Figure 3, 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 road infrastructure alternatives are considered it becomes clear that "alternative Z" provides more benefits compared to the other options (Fig. 3a). The sensitivity analysis shows that the Costs dimension is quite an unstable subnetwork (Figure 3b), since both the results and the rank of the alternatives are very sensitive to the changes in the weight of the costs. The ranking of the alternatives changes from "alternative Z"- "alternative X"- "alternative Y"- "alternative 0" (for 0% cost weight) to "alternative 0"- "alternative Y"- "alternative X"- "alternative Z" (for 100% cost weight). In the Opportunities subnetwork (Figures 3c) the road infrastructure alternatives are almost completely insensitive to the changes in the weight of the control criteria. Finally, the sensitivity analysis shows that the Risks dimension (Figure 3d) is the most unstable subnetwork, and five inversions in the ranking of the alternatives can be identified.

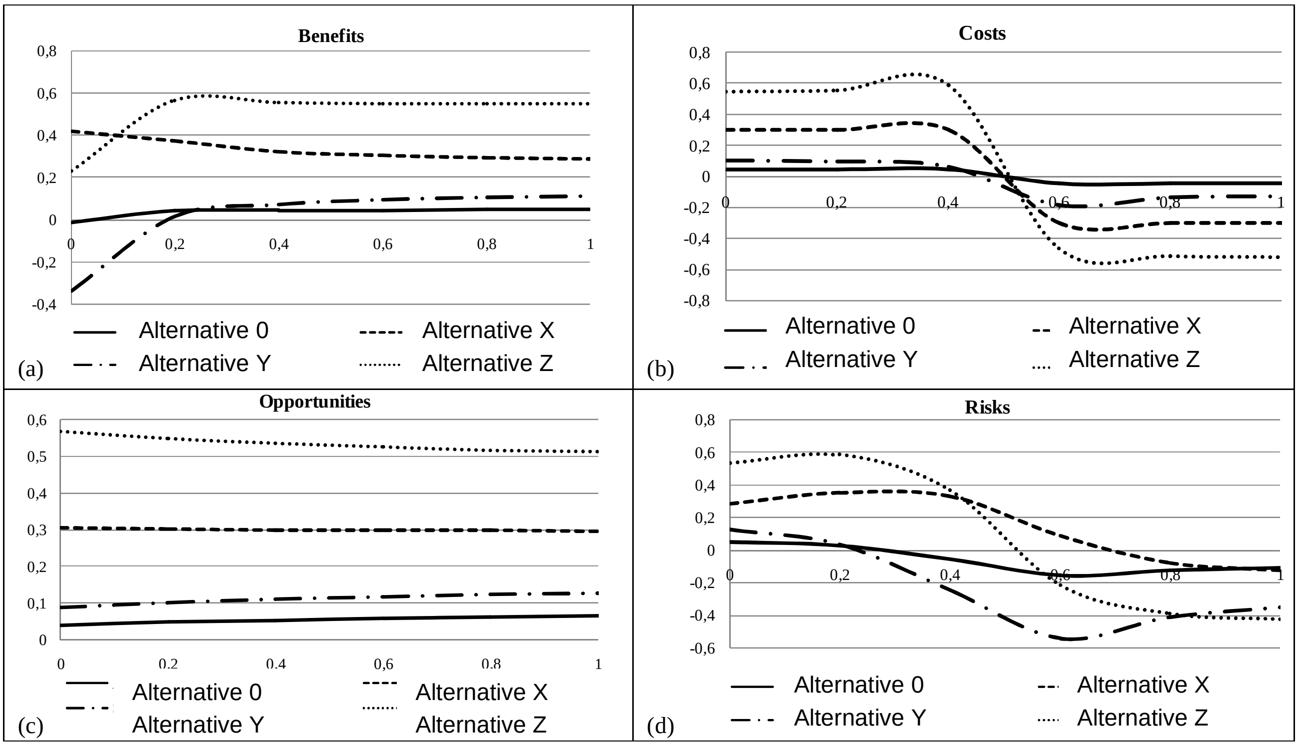

Figure 3 Sensitivity analysis for each subnetwork using the additive (reciprocal) formula

In the second sensitivity analysis, the influences between the elements and the alternatives were modified and the resulting final priority list of the alternatives was analyzed in order to see if any changes occurred. In particular, the priorities of the elements of the model resulting from the limit supermatrix were considered and, for each of the four subnetworks, the highest priority alternative and the highest priority element in each cluster were taken into account. In order to perform the analysis, the influences among the aforementioned elements were changed in the unweighted supermatrix. The original values were modified by +/- 50% in a three-step process (Aragonés-Beltràn *et al.*, 2010), resulting in several possible combinations which have generated new rankings of alternatives. Table 9 represents the results of the analysis where, for each subnetwork, the first iteration represents the original values and the corresponding final priorities of the alternatives. Instead the following iterations consider the subsequent modifications of influences and the resulting new priorities.

Table 9
Sensitivity analysis modifying influences among elements and alternatives in the unweighted supermatrix

Iteration		Unweighted supermatrix values						Limit priorities			
		B3 vs Z	**B5 vs Z**	**B7 vs Z**	**Z vs B3**	**Z vs B5**	**Z vs B7**	**0**	**X**	**Y**	**Z**
BENEFITS	1	0.1998	0.7500	0.875	0.625	0.5135	0.583	0.021	0.119	0.051	0.230
	2	0.2997	0.9999	0.9999	0.625	0.5135	0.583	0.020	0.118	0.050	0.230
	3	0.1998	0.75	0.875	0.937	0.77	0.875	0.015	0.086	0.037	0.283
	4	0.0999	0.375	0.438	0.625	0.5135	0.583	0.021	0.121	0.051	0.228
	5	0.1998	0.75	0.875	0.312	0.257	0.292	0.026	0.152	0.065	0.178
		C4 vs Z	**C1 vs Z**	**C8 vs Z**	**Z vs C4**	**Z vs C1**	**Z vs C8**	**0**	**X**	**Y**	**Z**
COSTS	1	0.163	0.833	0.5	0.568	0.658	0.497	0.021	0.132	0.053	0.233
	2	0.245	0.9999	0.75	0.568	0.658	0.497	0.021	0.137	0.052	0.237
	3	0.163	0.833	0.5	0.853	0.988	0.746	0.013	0.081	0.036	0.318
	4	0.082	0.417	0.25	0.568	0.658	0.497	0.020	0.129	0.053	0.229
	5	0.163	0.833	0.5	0.284	0.329	0.373	0.027	0.168	0.063	0.181
		O2 vs Z	**O6 vs Z**		**Z vs O2**	**Z vs O6**		**0**	**X**	**Y**	**Z**
OPPORTUNITIES	1	0.5	0.75		0.692	0.471		0.031	0.135	0.061	0.230
	2	0.75	0.9999		0.692	0.471		0.030	0.129	0.063	0.238
	3	0.5	0.75		0.9999	0.706		0.021	0.102	0.040	0.294
	4	0.25	0.375		0.692	0.471		0.033	0.142	0.059	0.220
	5	0.5	0.75		0.346	0.235		0.041	0.170	0.084	0.162
		R5 vs Z	**R6 vs Z**		**Z vs R5**	**Z vs R6**		**0**	**X**	**Y**	**Z**
RISKS	1	0.356	0.75		0.417	0.565		0.046	0.076	0.143	0.215
	2	0.535	0.9999		0.417	0.565		0.046	0.074	0.147	0.214
	3	0.356	0.75		0.625	0.848		0.040	0.056	0.120	0.262
	4	0.178	0.375		0.417	0.565		0.046	0.077	0.139	0.216
	5	0.356	0.75		0.208	0.283		0.053	0.094	0.165	0.169

For the Opportunities and Risks subnetworks, less iterations were performed: this happens in those cases where there is only one element in a cluster to be put in correlation to the highest priority alternative. As can be seen, there are no relevant changes in the new ranking of the alternatives compared to the original one.

Finally, we tried to investigate the possibility of rank reversal of the alternatives (Saaty, 2006) by developing a third sensitivity analysis. This analysis eliminated one alternative at a time from the original model, and evaluated the new results. Table 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 (Saaty *et al*., 2009), the question is not whether rank should be preserved (Tversky *et al*. 1990), but whether or not the assumption of independence applies (Saaty *et al*., 2009). According to the proposed sensitivity analysis the rank reversal of the alternatives does not occur (Table 10).

Table 10
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: 0.05 X: 0.28 Y: 0.12 Z: 0.55	Z>X>Y>0	Z	0: 0.08 X: 0.66 Y: 0.26	X>Y>0
Opportunities	0: 0.07 X: 0.30 Y: 0.13 Z: 0.50	Z>X>Y>0	Z	0: 0.11 X: 0.59 Y: 0.30	X>Y>0
Costs	0: 0.05 X: 0.30 Y: 0.12 Z: 0.53	Z>X>Y>0	Z	0: 0.09 X: 0.68 Y: 0.23	X>Y>0
Risks	0: 0.10 X: 0.16 Y: 0.30 Z: 0.45	Z>Y>X>0	Z	0: 0.15 X: 0.35 Y: 0.50	Y>X>0

The purpose of the sensitivity analysis was 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 is not only aids in selecting the best alternative, but also helps DMs to understand why one alternative is preferred over the other options (Khan and Faisal, 2008).

4. Discussion and conclusions

This paper illustrates the application of the complex ANP method to support the choice between different projects for the further development of the existing ring road of a city in Italy. The technique allows the most important elements of the decision to be highlighted through a transparent and traceable decision-making process thus facilitating deliberation. Moreover, the technique supports communication with the DMs and grants mutual understanding. The results of the analysis that was performed show that the ANP-BOCR model is suitable to represent a real world problem. In fact, the technique provides the means to perform complex trade-offs on multiple evaluation criteria, while taking the DM's preferences into account. The main drawback in the practical application of the ANP is a consequence of the complexity of the decision-making 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 writing up of the questionnaires and the comparison process should be helped by a facilitator (Aragonés-Beltrán *et al.*, 2010). However, there are still a number of opportunities for expanding the study and for validating the obtained results. First, it would be of scientific interest to assess the strategic criteria through a participatory focus group in order to move the collaborative decision processes forward. Second, the model could be combined with a Costs-Benefits Analysis in order to develop an overall assessment of the transformation project impacts (Tsamboulas and Mikroudis, 2000). In conclusion, the adopted methodology was successful in structuring the complex planning context, in communicating the stakeholders' perspectives, in improving the stakeholders' commitment and perception of being involved, in enhancing transparency in the decision-making process and thus in increasing acceptance of the proposed solutions.

REFERENCES

Aragonés-Beltrán, P., Pastor-Ferrando, J.P., Garcìa-Garcìa, F., & Pascual-Agullò, A. (2010). An Analytic Network Process approach for siting a municipal solid waste plant in the Metropolitan Area of Valencia (Spain). *Journal of Environmental Management*, *91*, 1071-1086.

Basbas, S., & Papanikolaou, A. (2009). Evaluation of a sustainable urban transport system through the use of the transecon methodology. *International Journal of Sustainable Development and Planning 4(1)*, 18-34.

Bojković, N., Macura, D., Pejčić-Tarle, & S., Bojović, N. (2011). A comparative assessment of transport-sustainability in central and Eastern European countries with a brief reference to the republic of Serbia. *International Journal of Sustainable Transportation, 5(6),* 319-344.

Bottero, M., & Ferretti, V. (2010). Integrating the Analytic Network Process (ANP) and the Driving orce-Pressure-State-Impact-Response (DPSIR) model for the sustainability assessment of territorial transformations. *Management of Environmental Quality, 21(5),* 618-644.

Bottero, M., & Ferretti, V. (2011). An Analytic Network Process-based approach for location problems: the case of a waste incinerator plant in the Province of Torino (Italy). *Journal of Multicriteria Decision Analysis*, *17*, 63–84.

Bottero, M., & Lami, I.M., (2010). Analytic Network Process and sustainable mobility: an application for the assessment of different scenarios. *Journal of Urbanism 3(3),* 275-293.

Bottero, M., Lami, I.M., & Lombardi, P. (2008). *Analytic Network Process. La valutazione di scenari di trasformazione urbana e territoriale*. Firenze: Alinea.

Bottero, M., & Mondini, G. (2008). An Appraisal of Analytic Network Process and its role in sustainability assessment in Northern Italy. *International Journal of Management of Environmental Quality,* 19(6), 642- 660.

Figueira. J., Greco, S., & Ehrgott, M. (Eds.). (2005). *Multiple Criteria Decision Analysis. State of the Art Survey.* New York: Springer.

Horsch K., Anderson C. (1997), Interview with Robert Yin. *The Evaluation Exchange, 3*(1), 4.
http://www.hfrp.org/evaluation/the- evaluation-exchange/issue-archive/methodology/interview-with-robert- k.-yin

Khan, S., & Faisal, M.N. (2008). An analytic network process model for municipal solid waste disposal options. *Waste Management, 28(9),* 1500-1508.

Liang, C., & Li, Q. (2008). Enterprise information system project selection with regard to BOCR. *International Journal of Project Management, 26(8),* 810-820.

Liu, K.F.R., & Lai, J.H. (2009). Decision-support for environmental impact assessment: a hybrid approach using fuzzy logic and fuzzy analytic network process. *Expert Systems with Applications, 36(3),* 5119-5136.

Lombardi, P. (2009). Evaluation of sustainable urban redevelopment scenarios. *Proceeding of the Institution of Civil Engineers: Urban Design and Planning, 162(4),* 179-186.

Neaupane, K.M., & Piantanakulchai, M. (2006). Analytic network process model for landslide hazard zonation. *Engineering Geology, 85,* 281-294.

Niemura, M.P., Saaty, T.L. (2004). An Analytic Network Process Model for financial-crisis forecasting. *International Journal of Forecasting, 20(4),* 573-587.

Pèti, M. (2012). A territorial understanding of sustainability in public development. *Environmental Impact Assessment Review, 32(1),* 61-73.

Piantanakulchai, M. (2005). Analytic Network Process model for highway corridor planning. *Proceedings of ISAHP 2005*. Honolulu, Hawaii.

Saaty, RW. (2003). *Decision-making in Complex Environments: The Analytic Hierarchy Process (AHP) for Decision-making and the Analytic Network Process (ANP) for Decision-making With Dependence and Feedback.* Pittsburgh, PA: RWS Publications.

Saaty, RW. (2010). *Routing BOCR against strategic criteria*. (working paper).

Saaty, T.L. (1980). *The Analytic Hierarchy Process*. New York: McGraw Hill.

Saaty, T.L. (2005). *Theory and Applications of the Analytic Network Process: Decision Making with Benefits, Opportunities, Costs, and Risks*. Pittsburgh, PA: RWS Publications.

Saaty, TL. (2006). Rank from comparisons and from ratings in the analytic hierarchy/network processes. *European Journal of Operational Research, 168,* 557–570.

Saaty, TL, Ozdemir, MS. (2008). *The Encyclicon. A Dictionary of Complex Decisions Using the Analytic Network Process*. Pittsburgh, PA: RWS Publications.

Saaty, T.L., & Vargas, L.G. (2006). *Decision Making with the Analytic Network Process*. New York: Springer.

Saaty, T., Vargas, L., Whitaker, R. (2009). Addressing with brevity criticisms of the Analytic Hierarchy Process. *International Journal of the Analytic Hierarchy Process,* 1(1), 121-134.

Tsamboulas, D., Mikroudis, G. (2000). EFET-evaluation framework of environmental impacts and costs of transport initiatives. *Transportation Research, 5*, 283-303.

Tversky, A., Slovic P., Kahneman, D. (1990). The causes of preference reversal. *The American Economic Review*, 80(1), 204-215.

Tuzkaya, G., & Onut, S. (2008). A fuzzy Analytic Network Process based approach to transportation-mode selection between Turkey and Germany: a case study. *Information Sciences, 178(15),* 3133-3146.

Tuzkaya, G., Onut, S., Tuzkaya, U.R., Gulsun, B. (2007). An Analytic Network Process approach for locating undesirable facilities: an example from Istanbul, Turkey. *Journal of Environmental Management*, 88, 970–983.

Ulutas, B.H. (2005). Determination of the appropriate energy policy for Turkey. *Energy, 30(7),* 1146-1161.

Yin, R. (1984). *Case study research: Design and methods* (1st ed.). Beverly Hills, CA: Sage Publishing.

Zoffer, J., Bahurmoz, A., Hamid, M.K., Minutolo M., & Saaty T. (2008). Synthesis of complex criteria decision making: a case towards a consensus agreement for a Middle East conflict resolution. *Group Decision Negotiation, 17,* 363-385.