AN APPLICATION OF THE ANALYTIC NETWORK PROCESS FOR ASSESSING THE SUSTAINABILITY OF DIFFERENT TRANSPORT INFRASTRUCTURES

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ABSTRACT

The paper addresses the problem of sustainability assessment of territorial transformations making use of the ANP. Particularly, the case of a new transport infrastructure in a city located in Northern Italy has been considered in the work. The project refers to the implementation of the ring road of the city which will lead to a radically new multifunctional design of the urban area. In the application, four alternative scenarios have been identified and compared in order to select the most sustainable one. In more details, the model takes into consideration the different aspects of the decision problem (namely, economic aspects, environmental aspects, social aspects, transport aspects 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 has been organized with actors coming from Public Authorities in order to discuss the general aspects of the problem. Moreover, different questionnaires have been submitted to several experts in order to elicitate the priorities of the elements being considered. The application of the ANP technique, which has been performed through the software *Super Decisions*, allows the most important elements of the decision problem to be highlighted.

Keywords: Analytic Network Process; decision-making; territorial transformations; sustainability assessment; transport infrastructures.

1. Introduction

Sustainable development is a multidimensional concept that includes socio-economic, ecological, technical and ethical perspectives and thus leads to issues that are characterized simultaneously 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: aims that range from the promotion of cultural

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events to the requalification of downgraded urban areas, from the reduction of soil consumption to the optimization of environmental resources' use, from the promotion of tourism to the rationalization of the mobility system. It has been generally agreed that Multicriteria Analysis (MCA, Figueira *et al.*, 2005) is an adequate approach that can deal with sustainability assessment of territorial transformations at both micro and macro study levels and the use of a Multicriteria framework is a very useful tool to implement an inter-disciplinary approach.

In the context of MCA, a very important role is played by the Analytic Network Process (ANP, Saaty 2005; Saaty and Vargas, 2006). This technique, which represents the generalization of the more well known Analytic Hierarchy Process (AHP, Saaty, 1980) to dependences, is particularly suitable for dealing with complex decision problems which are characterized by interrelationships and feedbacks among the elements at stake.

The paper addresses the problem of sustainability assessment of territorial transformations making use of the ANP. Particularly, the case of a new transport infrastructure in a city located in Northern Italy has been considered in the work. The project refers to the implementation of the city ring road which will lead to a radically new multifunctional design of the urban area.

It can be stated that transport planning plays an undeniably key role in the economic growth of any region and it has long-term effects on the local community. The selection of the optimal transport route includes different objectives to be satisfied, which can be in conflict with one other, according to the opinion 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 has been developed. The reasons for using an ANP-based decision approach in the present analysis are: (i) the assessment of different transport route alternatives is a multicriteria decision problem; (ii) there are dependencies among groups of criteria and between these and the alternatives under evaluation to be analyzed, (iii) the detailed analysis of the inter-relationships between criteria forces the Decision Makers (DMs) to carefully reflect 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.

After the introduction, the paper is organized as follows: section 2 briefly summarizes the ANP method; section 3 presents the application that has been performed, considering the structuring of the decision problem, the development of the model and the final priorities of the elements; section 4 discusses the main findings of the work and the conclusions that have been drown from the study.

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. By freeing us from the burden of ordering the components in the form of a directed chain as in the AHP hierarchy, the ANP represents any decision as a network and allows the structure to develop more naturally. The ANP represents therefore a better way to describe faithfully 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 cope with the future (Zoffer *et al.*, 2008).

From the 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 the final priorities and (v) sensitivity analysis. Mention should be made to the fact that there are two possible ways for structuring the decision 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. Mention can be made of applications 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). With specific reference to the field of transport planning, applications of ANP models exist for selecting optimal routes and for designing new corridors (Piantanakulchai, 2005; Tuzkaya and Onut, 2008).

3. Application

3.1 Presentation of the study case and description of the alternatives

The objective of the evaluation refers to the comparison of different road infrastructure scenarios that the city under analysis is planning to undergo in order to achieve a priority ranking of the alternative projects. In the present application, four alternative scenarios have been identified and compared in order to select the most sustainable one. Mention should be made to the fact that the transformation under examination refers to the so-called "undesirable facilities location problems"; moreover, the projects are currently under development. For the aforementioned reasons, it is not possible to provide a detailed description of the alternatives, neither it is possible to show the final results of the application mentioning the ranking of the considered options. 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 "scenario X" and "scenario Y". It can be noticed that they are named scenario since they all refer to a long time horizon identified by the year 2030.

Table 1. Alternative scenarios description.

Scenarios	Description
Absence of intervention	This scenario represents the situation without any project.
Scenario 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.
Scenario Y	This scenario implies 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 use and the main concern of the project relates to the amount of land being consumed.
Scenario X + Scenario Y	This scenario refers to the development of both the aforementioned projects.

3.2 Construction of the BOCR network

A complex ANP model has been developed in order to take into account the complexity of the decision problem. The use of the simple network, on the contrary, would be very unsuitable because the high number of the elements and connections would extremely weigh down the model.

In particular, the problem has been divided into five clusters (namely, economic aspects, environmental aspects, social aspects, transport aspects and urban planning aspects) that have been 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 scenarios according to their overall performance. Each decision problem is characterized by positive and negative aspects that can emerge in different temporal phases. In this ANP model, the benefits and the 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 in the long time period, for which it is difficult to make any prevision. Table 2 represents the ANP model according to the BOCR structure. The network is made up of four subnets with different clusters and elements, as well as the common cluster of the alternatives. As an example, Figure 1 shows in details the Benefits subnework.

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
		Adhesion 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	Accessibility and mobility increase for both people and goods	B9
OPPORTUNITIES	Economic aspects	Trade efficiency	O1
		Possible valorization of the neighbouring 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 works	C4
		Air and acoustic pollution	C5
	Social aspects	Duration of construction works	C6
	Transport aspects	Complexity of the project	C7
		Traffic congestion due to the construction works	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

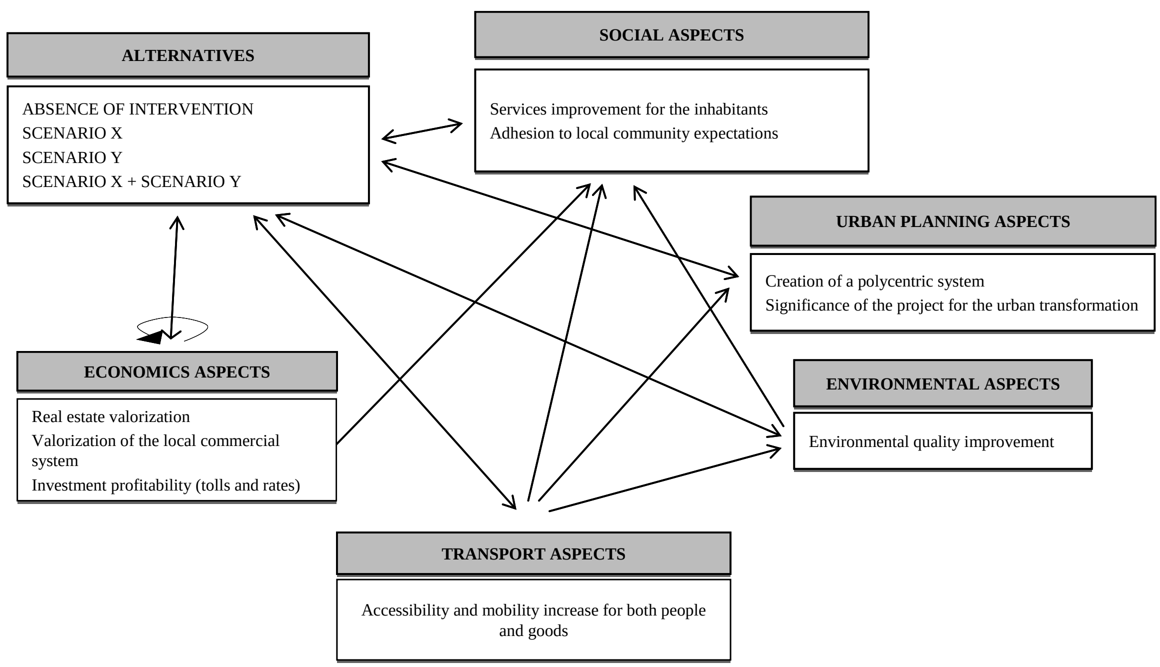

Figure 1. Benefits subnetwork.

3.3 Development of the model

With reference to the ANP methodology, the following step of the analysis 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, according to the ANP methodology, is divided into two distinct levels: the cluster one, which is more strategic, and the node one, 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 stakeholders coming form the Public Authority and they worked together to evaluate the different aspects that characterized the problem with respect to the overall objective. The result of this phase is represented by the so-called cluster matrix.
In order to fill in the pairwise comparison matrices at the node level, the values were derived from the questionnaires answered by technical experts. Each expert answered those questions concerning his own field of expertise. Once all the pairwise comparison matrices were compiled, all the related vectors together formed the unweighted supermatrix. Finally, according to the ANP methodology, the cluster matrix was applied to the unweighted supermatrix as a cluster weight. The result was the weighted supermatrix, which was raised to a limiting power 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 3). For the reasons recalled in section 3.1, Table 3 only shows the priorities of the elements of the model, leaving aside the alternative options.

Table 3. 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 problem are: i) accessibility and mobility increase 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 works (transport aspects) for the costs subnetwork (0,171); iv) the urban sprawl (environmental aspects) for the risks subnetwork (0,110).

4. Discussion and conclusions

The paper illustrates the application of the complex ANP method to support the choice among different projects for the implementation of the ring road of a city in Northern Italy. The technique allows the most important elements of the decision problem to be highlighted through a transparent and traceable decision-making process thus facilitating deliberation; moreover, the technique supports communication

with the DMs and grants a mutual understanding. The results of the performed analysis show that the ANP- BOCR model is suitable to represents a real world problem: the technique in fact provides the means of performing 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 problem that has to be analyzed. To this end, the ANP prescribes a high number of comparisons that occasionally become too complex to understand for DMs who are not familiar with the method. Hence, a great deal of attention should be devoted to the elaboration of the questionnaires and the comparison process must 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 weight the BOCR merits by means of the use of strategic criteria through multidisciplinary focus groups in order to move collaborative decision processes forward. Secondly, sensitivity analysis could be performed on the results with the aim of assessing the robustness of the model with respect to the components and interdependencies of the network. In this sense, different approaches are available. It could be possible to test the stability of the final ranking with regards to the control criteria (BOCR) priorities, to explore the modification of the influences of the alternatives on the elements and viceversa and, finally, to verify the rank reversal of the alternatives.
In conclusion, the adopted methodology has been 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 process and thus in increasing acceptance.

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