
**INTERNATIONAL JOURNAL OF MULTICRITERIA DECISION MAKING**

*Inderscience Publishers*

**www.inderscience.com/ijmcdm/**

Dr. Isabella Lami
DIST, Politecnico di Torino
ITALY

November 9th, 2012

Re: Dominance-based Rough Set Approach and Analytic Network Process for assessing urban transformation scenarios (authors: Francesca Abastante, Marta Bottero, Salvatore Greco, Isabella Lami)

Dear Dr. Lami,

I am very happy to inform you that on the basis of the reviewers' recommendations, your above paper is accepted for publication in the *International Journal of Multicriteria Decision Making (IJMCDM)*, in its current form.

Your paper will appear in an forthcoming issue of the journal. As soon as the proofs of your paper are ready, you will be asked to check them for corrections, if needed.

Thank you for choosing IJMCDM as the outlet of your research.

Sincerely yours,

Prof. Constantin Zopounidis
*Editor-in-Chief*

# Dominance-based rough set approach and analytic network process for assessing urban transformation scenarios

Francesca Abastante and Marta Bottero

Department of Regional and Urban Studies and Planning (DIST),
Politecnico di Torino,
Corso Massimo D'Azeglio 42, 10123 Turin, Italy
E-mail: francesca.abastante@polito.it
E-mail: marta.bottero@polito.it

Salvatore Greco

Department of Economics and Business,
University of Catania,
C.so Italia 55, 95129 Catania, Italy
E-mail: salgreco@unict.it

Isabella M. Lami*

Department of Regional and Urban Studies and Planning (DIST),
Politecnico di Torino,
Corso Massimo D'Azeglio 42, 10123 Turin, Italy
Fax: +39-011-6450
E-mail: isabella.lami@polito.it
*Corresponding author

**Abstract**: The paper shows the contribution that two different multiple criteria decision aiding (MCDA) methods could provide in the field of strategic decisions and urban and territorial planning. In particular, the analytic network process and the dominance-based rough set approach have been considered and discussed in the work with reference to their role in supporting such decision-making processes, trying to compare the different contributions given by the two approaches in this specific domain of application.

**Keywords**: dominance-based rough set approach; DRSA; analytic network process; multiple criteria decision aiding; MCDA urban transformations; sustainable development; urban requalification; transport planning.

**Reference** to this paper should be made as follows: Abastante, F., Bottero, M., Greco, S. and Lami, I.M. (xxxx) 'Dominance-based rough set approach and analytic network process for assessing urban transformation scenarios', *Int. J. Multicriteria Decision Making*, Vol. X, No. Y, pp.000–000.

**Biographical notes:** Francesca Abastante, graduated in Architecture in 2009, is currently a PhD student at the Politecnico of Torino in Urban Planning and Real Estate Market. The scientific interests are related to the use of MCDA in urban and territorial transformations with particular reference to the decision-making processes.

Marta Bottero, PhD in Geo-Environmental Engineering, is an Assistant Professor at the Department of Regional and Urban Studies and Planning of Politecnico di Torino in Italy. Her scientific interests are related to sustainability assessment of urban and territorial transformations, with particular reference to the analysis of the environmental impacts through specific evaluation techniques.

Salvatore Greco is a Full Professor since 2001 at the Department of Economics and Business of University of Catania. His main research interests are in multicriteria decision analysis and preference modelling, particularly, with the use of rough set theory. He has been an Invited Professor at the Poznan University of Technology, at the University of Paris Dauphine and at Ecole Central Paris. He edited, together with Josè Figueira and Matthias Ehrgott, a collection of state-of-the-art surveys in multiple criteria decision analysis, published by Springer in 2005. This book became a reference book in MCDA.

Isabella M. Lami, PhD in Urban Planning and Real Estate Market, is an Assistant Professor at the Department of Regional and Urban Studies and Planning of Politecnico di Torino in Italy. The scientific interests are related to the use of MCDA in urban and territorial transformations.

## 1 Introduction

Any urban and territorial transformation has to address a double perspective: the potentialities of the region development, and the satisfaction of the users' needs. Moreover, it is necessary to face the problem under the 'sustainable development' point of view: this means to consider the full range of consequences (economic, social, physical) that could affect the territorial system and the local communities involved in the transformation. In this context, the decision-making process implies the selection among alternatives, which is made on the basis of the understanding of the possible choices and the criteria through which it is necessary to judge such choices. It is therefore important to build some tools able to describe and to measure these aspects that constitute the framework within which the decision-making process is progressively defined in a complex context. The difficulties in the process increase when the objectives are various and conflicting, when uncertainty subsists respect to the alternatives of intervention and to the criteria of evaluation and, finally, when the decisional arenas include a large amount of stakeholders.

It has been generally agreed that multiple criteria decision aiding (MCDA) can provide a very useful support in such decision problems, being used to make a comparative assessment of alternative projects or heterogeneous measures (Roy and Bouyssou, 1995; Figueira et al., 2005). These methods allow several criteria to be taken into account simultaneously in a complex situation and they are designed to help decision makers (DMs) to integrate the different options, which reflect the preferences of the involved actors, in a prospective or retrospective framework.

The paper aims at investigating the role of two different MCDA methodologies, namely analytic network process (ANP) (Saaty, 2005; Saaty and Vargas, 2006) and dominance-based rough set approach (DRSA) (Greco et al., 2001) as a support in assessing urban and territorial transformations scenarios and at comparing the different contributions given by the two approaches in this context. Those two methods have been considered because both of them are quite well known in the literature and because they show diversified characteristics. ANP is more oriented to involve the DMs in structuring the problem with respect to the complex influences of different elements of the decision problem at hand. DRSA is supporting the DMs in explaining their preferences on some well known cases such that, on these basis, one can define a clearly justified and soundly supported recommendation for the decision problem.

The plan of the paper is the following. Section 2 illustrates assessing territorial transformations. Section 3 describes the application of the two methodologies in the field of territorial transformations. Section 4 contains the main findings and the strengths and weaknesses of the two methodologies. Finally, the conclusions propose some possible implementation of the research in the field under investigation.

## 2 Assessing territorial transformations

### *2.1 Cities on the move: sustainability and participative processes*

Over the last 30 years, all the most important European urban economies have been involved in voluntary or involuntary restructuring processes. Cities are constantly changing systems, always. The novelty is not related to the fact that cities are now subject to phenomena of change but to the larger difficulties, with respect to the past, in prefiguring and governing the possible developments and their effects. The recent proposals for regeneration of brownfield sites are often connected to the creation of new transport infrastructures. The peculiar nature of the urban areas characterised by high added value thanks to their new accessibility, and the well-established profitability of the activities that are (or can be) established in the area, is an element of convergence of different (public and private) interests in terms of the different regeneration hypotheses.

The basic element for these complex urban requalification operations to take place is a highly motivated leadership. The choices adopted may vary considerably in Europe regarding the following two main aspects:

1. the attitude of the land owner, who can be extremely active in seeking public or private funds so as to minimise its financial commitment; or, on the other hand, he can be characterised by a more ‘fence sitter’ behaviour about area development phenomena
2. the sustainability of regeneration.

This second aspect has to be seen in two ways, regarding both its more environmental and territorial aspects, and its role in the decisional process. Regarding the first issue, assessing territorial transformation scenarios is normally addressed through the sustainable development paradigm identified by the Brundtland Commission (Brundtland, 1987), which has been defined as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Since the Brundtland Commission, many alternative definitions of sustainability have been proposed and different interpretations of the concept made. Whereas the Brudtland Commission presented a two-pillars model reflecting environment and development concerns, a later model has been proposed and it is based on the so-called ‘triple-bottom-line’ considering to separate development issues into environmental, social and economic factors.

Recently, in the domain of sustainability assessment, more inclusive approaches have been taken into account, which add new dimensions to the model, such as the political-institutional aspects, the cultural factors and the technological elements (Mondini, 2009). This is directly connected to the second aspect of sustainability, namely the way of building consent in this type of operations. Successful examples in Europe show how the process of consultation should start as soon as possible, so that the interested communities are faced with the problem rather than a specific solution.

In particular, public participation has gained attention in the international debate on sustainable development following the UN Conference on the Environment and Development in Rio in 1992 (UNCED, 1992). This topic has lately been broadened in the Aarhus convention on information, public participation in decision-making and access to justice in environmental matters (UNECE, 1998). It has generally been agreed that the earlier and the more intensively the public is involved in an urban planning project, the more likely the project will succeed. In this context, there is a great need for new tools, that are able to support and enhance public participation in urban and territorial planning by expanding communication between planners and citizens. Therefore, the decision making process can only be perceived as an adaptive process, where the actors involved are continuously learning. Under these conditions, decision-making is not simply a strategic action to satisfy individual actors, but a social learning process that requires the stimulation of trust, identity and solidarity within the respective society (Stagl, 2006).

### *2.2 Sizes and phases of the evaluation*

In the presence of actors who produce and manage the space in the city often with conflicting goals, and increasing resource constraints, it is evident the importance of having tools that can allow to better understand how spatial planning tasks within the complex urban dynamics. In this sense it is necessary to find evaluation approaches and tools which are able to manage this complexity at the different scales: it is possible to deal with a single building, a block inside a city, the whole urban system and so on.

Another fundamental issue to be considered is the temporal phase in which the evaluation takes place. According to the taxonomy that has been proposed by Bezzi (1998), it is possible to distinguish the following categories:

- *ex-ante* evaluation: it is used for formulating the project and for setting the main problems
- *in-itinere* evaluation: it is used for controlling the operation during its implementation in order to verify if the project is able to meet the initial objectives
- *ex-post* evaluation: it is used for a retrospective analysis of the operation, in order to define the efficiency and the effectiveness of the project.

Table 1 is a synthetic representation of the main evaluation approaches in the field of urban and territorial transformations.

Mention has to be made to the fact that the theories that are considered in the present paper are mostly used in the *ex-ante* phase, while few applications exist with reference to the *ex-post* phase.

**Table 1** Evaluation taxonomy

| | *Ex-ante* | *In-itinere* | *Ex-post* |
|---|---|---|---|
| WHY | To formulate the project | To control if the project meets the initial objectives, putting in evidence the unexpected effects | To learn from past experiences and to inform Public Authorities and population |
| WHEN | Before the preparation of the project | During the construction phase | After a reasonable period of time |
| WHAT | Strategy and tactic | Tactic with reference to the strategy | Mostly the strategy, then the tactic |
| HOW | Scenario building | Performance indicators | Surveys |
| | Experts judgements | Documents analysis | Analysis of the effects |
| | Costs-benefits analysis | Monitoring data | Econometric models |
| | Multicriteria analysis | | |

*Source:* Elaboration from Bezzi (1998)

## 3 Application of MCDA methodologies in territorial transformation decision problems

### *3.1 Why assessing urban and territorial transformations?*

Cities can be seen as collective goods, that are created and defined through both public and private investments and decisions. As a consequence, the economic value of the single parts of a city is not provided by individual gestures, but by a collective action. In other words, synergies and externalities are possible in the physical surrounding areas where individual decisions took place (Camagni, 2008).

Urban quality is a public good and under the pressure for territorial competitiveness, cities can develop specific urban policies oriented towards the production of urban quality. Nevertheless, due to the fact that urban quality is a complex public good, urban requalification projects are complex problems and *a priori* there is not the certainty that all the cities have the financial and cognitive resources for designing and affording urban requalification processes in an efficient way (Calafati, 2010).

The three ‘traditional’ phases for developing territorial transformations – i.e., land acquisition, construction works and management operations – faced enormous difficulties during the last years and the result is an unsymmetrical urban development. Procedural, organising and financial troubles had systematically slowed down the realisation process for the public city. Now, we are facing a huge change in the role of public administration and, as a consequence, in the role played by the laws. According to Micelli (2011), the accommodation takes the place of the coercion and the imposition becomes agreement.

With reference to the aforementioned observations, it is clear that financial analysis has a very important function in evaluating public and private benefits and thus in legitimating the agreement between public administration and private developers. In any case, in the opinion of the authors, it is also evident the contribution of multiple criteria decision analysis (MCDA) in such decision problems. MCDA allow a learning process for the DM to be structured and make her/him able to evaluate the full range of elements that constitute the urban and territorial quality. In the new scenario above described, a very important position is covered by the so-called Public-Private Partnerships, that allow the transformations to be implemented and require appropriate evaluation tools and methods.

These considerations led the authors to take into consideration two MCDA theories: the ANP and the DRSA. The choice of the two theories is due to several reasons. To start with, both the methodologies, in a different manner, well facilitate the communication between public and private actors: the ANP technique for the participatory way of expressing the evaluations by means of specific focus group; the DRSA method for the clarity of the language used in the formulation of the rules. The theoretical and methodological diversity led the authors to develop a sort of 'comparison' between the two methods with reference to their suitability in solving urban and territorial decision problems. Moreover, the ANP has been considered in numerous applications concerning real word problem in the domain of territorial planning; the authors themselves tested the appropriateness of the technique for facing decisions in the context of infrastructural development at the European level. In fact, the network structure of the ANP allows to take into account the interrelationships among the different elements of the decision problem. This is very important in spatial planning, where the urban and territorial quality is seen as a union of different 'landscapes' that represent parts of the city/territory as they are perceived by the people, which think about the city/territory as a whole and not as a sum of different physical elements.

DRSA presents different characteristics with respect to ANP. Its main advantage is in the nature of the input information required to the DMs and in the output information supplied to them (Slowinski et al., 2009). Indeed, using DRSA, the input information is given by some of decision examples on some alternatives well known to the DM, while the output information is a set of set of 'if…, then…' decision rules: for example, a decision rule could be:

*rule 1* "if the social aspect is very good and the economic aspect is considered at least medium, the alternative is good".

Those rules, from one side, are explicitly related to the original information: e.g., *rule 1* is saying that all the example of decisions given by the DMs with very good social aspect and at least medium economic aspect, were considered by the DMs as good. From the other side, the decision rules give understandable justifications for the decisions to be made: e.g., *rule 1* is suggesting that a new alternative very good with respect to the social aspect and at least medium with respect to the economic aspect, just for this can be considered as good. Therefore, the obtained rules, after approval by the DMs, are applied to the whole set of alternatives of the decision problems at hand. The advantages of DRSA can be well appreciated if compared with other MCDA methods which are perceived by the DM as a 'black box' because the input information (weights of criteria, tradeoffs, indifference, preference and veto thresholds and so on) is not easy to be supplied, and, moreover it is often processed in a way which is not clear for the DM, that cannot see what are the exact relations between the provided information and the final recommendation. In that context, the result of MCDA methodology has to be accepted because the analyst's authority guarantees that the result is 'right', frustrating the aspiration of the DM to find good reasons to make decision. In this perspective DRSA gives an answer to the need for a more transparent methodology in which the relation between the original information and the final recommendation is clearly shown, for this transparency DRSA can be considered as a 'glass box' (Greco et al., 2008).

## *3.2 The ANP technique*

### *3.2.1 Methodological background and state-of-the art*

The ANP (Saaty 2005; Saaty and Vargas, 2006) is a recent development of the well-known AHP (Saaty, 1980, 2000) and it 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. In order to deal with the complexity of real problems in a non-simplistic way, it is necessary to use feedback networks to arrive at the kind of decisions needed to cope with the future. The ANP enables such inter-dependences to be surveyed and measured by generalising the approach of the super-matrices introduced by the AHP, and it is gaining merit as a useful tool to help technicians make their decision processes traceable and reliable.

From the methodological point of view the ANP is based on five fundamental steps (Saaty, 2005):

1 structuring of the decision-making problem

2 clusters and nodes weighting by means of pairwise comparisons

3 supermatrices formation

4 elicitation of the final priorities

5 sensitivity analysis.

The five steps are illustrated in the following part of the paragraph.

Step 1 Development of the structure of the decision-making process.

First, the decision-making structure must be defined through the recognition of its main objective. Such an objective should later be divided into groups ('clusters'), that are made up of various elements ('nodes'), and alternatives or options.

Secondly, the relationships between the different parts of the network must be identified. Each element can be a 'source', that is, an origin of a path of influence, or a 'sink', that is, a destination of a path of influences. There are two possible structures for an ANP model, a 'simple' network and a 'complex' network:

- The 'simple' network is a free-modelling approach, which is not supported by any guide or pre-determined structure. It consists of a network which has cycles connecting its components and a loop that connects a component to itself.
- The 'complex' network or benefits, opportunities, costs, and risks (BOCR) network allows one to simplify the problem structuring by classifying issues in traditional categories of positive and negative aspects (Saaty and Ozdemir, 2008). The favourable sure concerns are called benefits, while the unfavourable ones are called costs; the uncertain concerns of a decision are the positive opportunities that the decision might create and the negative risks that it can entail. Each of these four concerns utilises a separate structure for the decision. A full BOCR is in some ways similar to a SWOT analysis (i.e., strengths, weakness, opportunities and threats), a

strategic planning tool largely used in urban and territorial analysis. It is possible to assert that while the BOCR model is expected to catch all the aspects (positive and negative) of the decision through the time (present and future), the SWOT analysis focus more on the external and internal elements of the problem (Wijnmalen, 2007).

Step 2 Pairwise comparison

As in the AHP, a series of pairwise comparisons are made to establish the relative importance of the different elements with respect to a certain component of the network. In the case of interdependencies, components with the same level are viewed as controlling components of each other. The comparisons are made with the Saaty's fundamental scale which is a nine-points ratio measurement scale used to compare any two elements, translating qualitative variables in numerical values and *vice-versa* (Table 2) (Saaty, 1980). The choice of using a pairwise comparison method is that the human mind is more confident in discerning comparing two elements respect to another. In fact, in complex decision problems, the DMs, even if experts, are often in trouble with the large amount of data they have to manage. The process of decomposition in two by two elements of the problem helps the DM to make an informed choice (Saaty, 2005).

**Table 2** The Saaty's fundamental scale: numerical ratings associated with pairwise comparison

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

The numerical judgements established at each level of the network make up pair matrices. The weighted priority vector is calculated through pairwise comparisons between the applicable elements. This vector corresponds to the main eigenvector of the comparison matrix (Saaty, 1980, 2003).

Mention has to be made to the fact that the eigenvector method yields a natural measure of consistency. Saaty (1980) defined the consistency index (*CI*) as in equation (1):

$$CI = \frac{(\lambda_{\max} - n)}{n - 1} \tag{1}$$

where $\lambda_{\max}$ is the maximum eigenvalue and $n$ is the number of factors in the judgement matrix. Accordingly, Saaty (1980) defined the consistency ratio (*CR*) as in equation (2):

$$CR = \frac{CI}{RI} \tag{2}$$

where *RI* is the consistency index of a randomly generated reciprocal matrix from Saaty's fundamental scale, with forced reciprocals. Saaty (1980) has provided average consistencies (*RI* values) of randomly generated matrixes (up to 11 × 11 size) for a sample size of 500.

The consistency ratio *CR* is a measure of how a given matrix compares to a purely random matrix in terms of the consistency index. A value of the consistency ratio $CR < 0.1$ is considered acceptable. Larger values of *CR* require the decision-maker to revise his judgements.

Step 3 Supermatrix formation.

The supermatrix elements allow a resolution to be made of the interdependencies that exist among the elements of the system. It is a portioned matrix where each sub-matrix is composed of a set of relationships between and within the levels, as represented by the DM's model (Step 1). The supermatrix obtained in this step is called the initial supermatrix and it contains all the eigenvectors that are derived from the pairwise comparison matrixes of the model. The eigenvector obtained from a cluster level comparison with respect to the control criterion is applied to the initial supermatrix as a cluster weight. This result is the weighted supermatrix.

Step 4 Final priorities.

In this step, the weighted supermatrix is raised to a limiting power, as in equation (3), in order to converge and to obtain, as stated in the Perron-Frobenius theorem, a long-term stable set of weights that represents the final priority vector.

$$\lim_{k \to \infty} W^k \tag{3}$$

In the case of the complex network, it is necessary to synthesise the outcome of the alternative priorities for each of the BOCR structures in order to obtain their overall synthesis; for this operation different aggregation formulas are available (Saaty, 2005).

Step 5 The fifth and last step consists in carrying out the sensitivity analysis on the final outcome of the model in order to test its robustness (Saaty, 2003).

A very large and consolidated amount of AHP and ANP literature exists in which it is possible to find a wide range of applications (Sipahi and Timor, 2010). With particular reference to ANP, the literature is more recent and some publications can be found in different fields. Mention can be made of works in the sphere of urban and territorial transformation projects, including waste management (Promentilla et al., 2006; Aragonés-Beltràn et al., 2010), transport infrastructures (Tuzkaya and Onut, 2008; Bottero and Lami, 2010), environmental impact assessment (Bottero et al., 2008, 2011; Bottero and Mondini, 2008; Bottero and Ferretti, 2011), civil engineering (Piantanakulchai, 2005; Neaupane and Piantanakulchai, 2006), new form of settlements (Abastante and Lami, 2012; Lami and Vitti, 2011).

**Figure 1** The ANP model for the choice of the best requalification scenario for an urban area

| **BOCR** | **Clusters** | **Elements** |
|---|---|---|
| BENEFITS | Environmental aspects | Green areas improvement |
| | Economic aspects | Real estate valorization |
| | Social aspects | Functional mix<br>Adhesion to local community expectations |
| | Urban planning aspects | Significance of the project for the urban transformation<br>Increase in connectivity<br>Revitalization of the area<br>Synergy with other urban projects |
| | Transport aspects | Accessibility increase for the Lingotto station<br>Local mobility increase<br>Creation of a polycentric system |
| OPPORTUNITIES | Economic aspects | Possible valorization of the neighborhood areas<br>Creation of new attractiveness for the area |
| | Environmental aspects | Improvement in acoustic quality<br>Improvement in air quality<br>Improvement in soil quality<br>Creation of a new urban landscape and landmark<br>Increase in biomass<br>New availability of green spaces |
| | Social aspects | Increase in social integration |
| | Transport aspects | New connection between C. Spezia and C. Sebastopoli<br>New connection between the Lingotto station and the metro |
| | Urban planning aspects | Connection between different parts of the city<br>Promotion of new forms of settlement<br>Creation of new services |
| COSTS | Environmental aspects | Negative impacts of the construction works<br>Management of the construction wastes |
| | Economic aspects | Investment costs<br>Construction time |
| | Transport aspects | Modification of the railway facilities<br>Reconstruction of the existing underground passages<br>Difficulties in serving the transport function during the construction works |
| RISKS | Economic aspects | Lean investment profitability<br>Operation and management costs |
| | Environmental aspects | Increase in water and energy consumptions<br>Negative interaction with the water network<br>Urban waste production<br>Presence of dangerous industrial activities<br>New traffic flows |
| | Social aspects | Gentrification |
| | Urban aspects | Lack of integration with the context<br>Presence of constrains and territorial index |

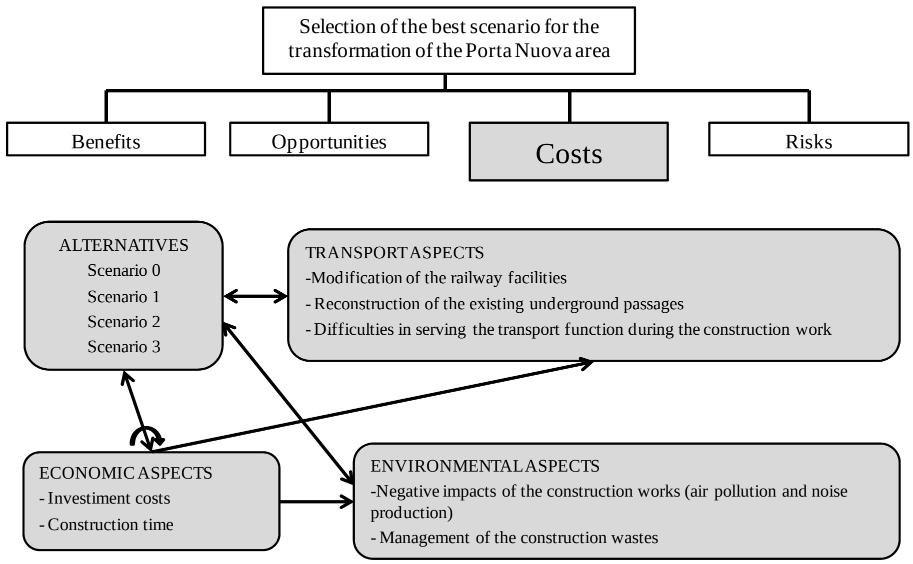
*Source:* Elaboration from Bottero, Lami and Lombardi (2008)

### *3.2.2 Example of ANP application*

With the aim of clarifying the role of the ANP technique in the domain of urban and territorial transformations, the following part of the paragraph will illustrate the main methodological steps of the analysis, considering the input data for feeding the model, the calculation process and the outcomes of the application. In order to better describe the analysis, the explanation will refer to a real ANP application concerning the choice of the best requalification scenario for an urban area in Turin, Italy (Bottero et al., 2008).

According to the ANP, the first step of the analysis is structuring the decision problem. As an example, Figure 1 shows the decision network that has been defined for the aforementioned application. In this case, the BOCR model has been used: the different elements of the decision problem have identified and grouped into clusters, that were organised in four subnetworks according to the BOCR categories. Each subnetwork includes also the alternatives (in this case four different requalification scenarios were identified) that were organised in an autonomous cluster. Figure 2 shows in details the costs subnetwork.

**Figure 2** Representation of the Costs subnetwork




*Source:* Elaboration from Bottero, Lami and Lombardi (2008)

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. In pairwise comparisons the Saaty's fundamental scale is used to compare any two elements (Saaty, 1980). The comparison and evaluation phase 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 judgements used to fill the pairwise comparison matrices normally are derived by a specific focus group made up of DMs and stakeholders which work together to evaluate the different aspects that characterised 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.

As an example, considering the aforementioned application, the questions that had to be solved by the focus group were of the type:

*With reference to the choice of the best alternative requalification scenario, which of this two aspects do you think is more costly? And to what extent?*

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

In this case, the focus group agreed in assigning more importance to the economic costs, specifying the value of 5, which in the Saaty's fundamental scale means that one decision element has more influence than the other.

Once the clusters comparison has been conducted, it is necessary to study the problem in depth through the analysis of the elements. At the nodes level, in order to fill in the pairwise comparison matrices, the values can be derived from the judgements expressed by technical expert. With reference to the Turin application, a detailed questionnaire was submitted to different experts concerning questions about only of his/her own field of expertise.

Once all the pairwise comparison matrices are compiled, all the related vectors together form the unweighted supermatrix. Finally, according to the ANP theory, the cluster matrix is applied to the initial supermatrix as a cluster weight. The result is the weighted supermatrix, which is raised to a limiting power in order to obtain the limit supermatrix, where all columns are identical and each column gives the global priority vector.

In the case of the considered application, four limit supermatrices were obtained, one for each subnetwork. Each column of the limit supermatrices obtained from the four subnetworks provides the final priority vector of all the elements being considered. Table 3 shows the priority of the elements related to the costs subnetwork.

**Table 3** Priorities of the elements belonging to the costs subnetwork

| *Clusters* | *Elements* | *Priorities* |
|---|---|---|
| Alternatives | Scenario 0 | 0.025 |
| | Scenario 1 | 0.032 |
| | Scenario 2 | 0.072 |
| | Scenario 3 | 0.304 |
| Environmental aspects | Negative impacts of the construction works | 0.019 |
| | Management of the construction wastes | 0.009 |
| Economic aspects | Investment costs | 0.097 |
| | Construction time | 0.054 |
| Transport aspects | Modification of the railway facilities | 0.114 |
| | Reconstruction of the existing underground passages | 0.100 |
| | Difficulties in serving the transport function during the construction works | 0.174 |

*Source:* Elaboration from Bottero et al. (2008)

Finally, in order to obtain the ranking of the different areas in the analysis, it was necessary to synthesise the raw priorities of the alternatives obtained from the limit supermatrices by normalising them by cluster. Table 4 shows the normalised priorities of the alternatives in each subnetwork. These priorities became the input values for the final aggregation and synthesis of the model results (Table 5).

After obtaining a ranking of the alternatives it is useful to perform a sensitivity analysis on the final outcome of the model in order to test its robustness. In the application under description the sensitivity analysis showed that the rank of the alternatives was preserved and the scenario 2 was the most stable alternative for all the experiments.

**Table 4** Final priorities of the alternative in the four subnetworks

| *Alternatives* | *Benefits* | *Opportunities* | *Costs* | *Risks* |
|---|---|---|---|---|
| Scenario 0 | 0.063 | 0.060 | 0.059 | 0.278 |
| Scenario 1 | 0.136 | 0.157 | 0.073 | 0.176 |
| Scenario 2 | 0.252 | 0.262 | 0.167 | 0.172 |
| Scenario 3 | 0.549 | 0.521 | 0.702 | 0.374 |

*Source:* Elaboration from Bottero et al. (2008)

**Table 5** Ranking of the alternative scenarios according to the different aggregation formulas

| *Alternatives* | *Aggregation formulas* | | | |
|---|---|---|---|---|
| | $B*O*1/C*1/R$ | $B+O+1/C+1/R$ | $B+(1-C)+O+(1-R)$ | $B^{1/2}*C^{-1/2}*O^{1/2}*R^{-1/2}$ |
| Scenario 0 | 4 | 4 | 4 | 4 |
| Scenario 1 | 2 | 2 | 3 | 2 |
| Scenario 2 | 1 | 3 | 1 | 1 |
| Scenario 3 | 3 | 1 | 2 | 3 |

*Source:* Elaboration from Bottero et al. (2008)

## *3.3 The DRSA theory*

### *3.3.1 Methodological approach*

The rough sets theory was introduced by Pawlak (1982, 1991) and it constitutes a tool for describing a set of objects for which inconsistent or ambiguous information are available. The rough sets philosophy is based on the assumption that with every object of a universe *U* there is associated a certain amount of information (data, knowledge, etc.) expressed by means of some attributes. The mathematical basis of the theory is the indiscernibility relation defined as $I_p$ in universe *U*: objects that have the same description (in terms of attributes) are indiscernible with reference to the available information. This relation allows a partition of the universe of objects under examination to be made. In this sense it is possible to identify blocks of indiscernible objects, called elementary sets or granules that can be used to build new knowledge.

An information system is the base on which rough set theory is applied. It may contain two classes of attributes, called condition and decision attributes, respectively, which may be utilised to transform the information system to a decision table. The decision table can then be denoted as $S = (U, C, D)$ where *C* and *D* are the condition and decision attribute sets, respectively. The decision attributes together with the indiscernibility relation are used to partition the information table into decision classes. Objects which are indiscernible from each other are defined by similar conditions and are classified into the same decision class.

According to MCDA, the information given by the DM is in the form of preference-ordered attribute domains and decision classes. Furthermore, the decisions may be inconsistent because of the limited discriminatory power of the criteria for the analysis or because of the hesitation of the DM. In order to take into account the inconsistency typical to decision problems, Greco et al., (1999, 2001, 2002) proposed an extension of the classical rough set approach (CRSA). This innovation is based on the substitution of the indiscernibility relation by a dominance relation in the rough approximation of decision classes. The CRSA, as already seen, is based on an equivalence relation, through which it is not possible to take properly into account the information related to preference ordered information; according to this theory it is not possible to identify the inconsistency due to the presence of ordered criteria among the attributes. In the DRSA, the set of decision rules induced gives a more synthetic representation of knowledge contained in the decision table because the minimal sets of rules thus obtained have a smaller number of rules and use a smaller number of conditions. The reason is the difference between the set of rules induced from a classical approach and a set of rules coming from the DRSA. In fact, the application to new objects of DRSA rules expressed in the form *"if... at least/at most..., then..."* gives better results than the application of the CRSA rules expressed in the form *"if... equal..., then…".* The separation of certain and doubtful knowledge about the DMs preferences is done by distinction of different kinds of decision rules, depending whether they are induced from lower approximations of decision classes or from the boundaries of these classes composed of inconsistent examples that do not observe the dominance principle.

There are many works about the theoretical aspects of the CRSA (Pawlak, 1982, 1991) and DRSA (Greco et al., 1999, 2001, 2008); recently a research has been developed where the use of the DRSA theory in decisions-aiding processes concerning urban and territorial projects is considered (Abastante et al., 2010; 2011a, 2011b).

### *3.3.2 Basic concepts of DRSA*

Let assume that the information system is defined by $S = (U, Q)$ wherein both $U$ and $Q$ are both finite non-empty sets, $U$ represents the universe and $Q$ represents a set of attributes. With every attribute $q \in Q$ there is an associated set $V_q$ containing the set of values of attribute $q$.

Let $\succeq_q$ be a weak preference relation on $U$ with reference to criterion $q \in C$, such that $x \succeq_q y$ means "$x$ is at least as good as y with respect to criterion $q$". Moreover, let $Cl = \{Cl_t, t \in T\}$, $T = \{1, 2, ..., n\}$ be a set of classes of $U$, such that each $x \in U$ belongs to one and only one class $Cl_t \in Cl$. We assume that for all $r, s \in T$, such that $r > s$, each element of $Cl_r$ is preferred to each element of $Cl_s$. Let us also consider the following upward and downward unions of classes, represented respectively, in equations (4) and (5):

$$Cl_t^{\geq} = \bigcup_{s \geq t} Cl_s \tag{4}$$

$$Cl_t^{\leq} = \bigcup_{s \geq t} Cl_s \tag{5}$$

It is said that $x$ dominates $y$ with respect to $P \in C$ (denotation $xD_Py$) if $x \succeq_q y$ for all $q \in P$. Since the intersection of complete preorders is a partial preorder and $\succeq_q$ is a complete preorder for each $q \in P$, $D_P$ is a partial preorder. Given $P \subseteq C$ and $x \in U$, let

$$D_P^{+}(x) = \{y \in U : yD_p x\} \tag{6}$$

$$D_P^{-}(x) = \{y \in U : xD_p x\} \tag{7}$$

represent so-called, *P-dominating set* and *P-dominated set* with respect to $x$, respectively. In the DRSA, the sets to be approximated are upward and downward unions of classes and the items used for this approximation are dominating and dominated sets.

The $P$-lower and the $P$-upper approximation of $Cl_t^{\geq}$, $t \in T$, with respect to $P \subseteq C$ (denotation $\underline{P}\left(Cl_t^{\geq}\right)$ and $\overline{P}\left(Cl_t^{\geq}\right)$, respectively, are defined as follows:

$$\overline{P}\left(Cl_t^{\geq}\right) = \left\{x \cup U : D_P^{+}(x) \subseteq Cl_t^{\geq}\right\} \tag{8}$$

$$\overline{P}\left(Cl_t^{\geq}\right) = \left\{x \cup U : D_{\overline{P}}^{-}(x) \cap Cl_t^{\geq} \neq 0\right\}. \tag{9}$$

Analogously, the P-lower and the P-upper approximation of $Cl_t^{\leq}$, $t \in T$, with respect to $P \subseteq C$ (denotation $\underline{P}\left(Cl_t^{\leq}\right)$ and $\overline{P}\left(Cl_t^{\leq}\right)$), respectively, are defined as follows:

$$\underline{P}\left(Cl_t^{\leq}\right) = \left\{x \cup U : D_{\overline{P}}^{-}(x) \subseteq Cl_t^{\leq}\right\} \tag{10}$$

$$\overline{P}\left(Cl_t^{\leq}\right) = \left\{x \in U : D_{\overline{P}}^{=}(x) \cap Cl_t^{\leq} \neq 0\right\}. \tag{11}$$

The $P$-boundaries ($P$-doubtful regions) of $Cl_t^{\geq}$ and $Cl_t^{\leq}$ are defined as:

$$Bn_p\left(Cl_t^{\geq}\right) = \underline{P}\left(Cl_t^{\geq}\right) - \overline{P}\left(Cl_t^{\geq}\right) \tag{12}$$

$$Bn_p\left(Cl_t^{\leq}\right) = \underline{P}\left(Cl_t^{\leq}\right) - \overline{P}\left(Cl_t^{\leq}\right). \tag{13}$$

Equations (18) and (19) define the quality of approximation of $Cl_t^{\geq}$ and $Cl_t^{\leq}$ for all $t \in T$ and for any $P \subseteq C$, respectively:

$$\alpha_p\left(Cl_t^{\geq}\right) = \frac{\left|\underline{P}\left(Cl_t^{\geq}\right)\right|}{\left|\overline{P}\left(Cl_t^{\geq}\right)\right|} \tag{14}$$

$$\alpha_p\left(Cl_t^{\leq}\right) = \frac{\left|\underline{P}\left(Cl_t^{\leq}\right)\right|}{\left|\overline{P}\left(Cl_t^{\leq}\right)\right|}. \tag{15}$$

Furthermore, it is possible to identify the quality of approximation of the partition $Cl$ by means of a set of criteria $P$ (denotation $\gamma_P(Cl)$); $\gamma_P(Cl)$ is a ratio that expresses the relation the between all the $P$-correctly classified objects and all the objects in the table and it is defined as follows:

$$\gamma_P(Cl) = \frac{\left|U - \left(\left(\cup_{t \in T} Bn_P\left(Cl_t^{\geq}\right)\right) \cup \left(\cup_{t \in T} Bn_P\left(Cl_t^{\leq}\right)\right)\right)\right|}{|U|} \tag{16}$$

Every minimal subset $P \subseteq C$ such that $\gamma_P(Cl) = \gamma_C(Cl)$, is called a *reduct* of $C$ with respect to $Cl$ and is denoted by $RED_{Cl}(P)$. Again, a data table may have more than one reduct. The intersection of all the reducts is known as the core, denoted by $CORE_{Cl}$.

On the basis of the approximations obtained by means of the dominance relations, it is possible to induce a generalised description of the preferential information contained in the decision table, in terms of decision rules (Slowinski et al., 2009).

### *3.3.3 Example of DRSA application*

With the aim of clarifying the role of the DRSA theory in the domain of urban and territorial transformations, the following part of this section will illustrate the main methodological steps. In order to better describe the analysis, the explanation will refer to a DRSA application to evaluate different alternatives for connecting the urban area of Turin and the suburban tourist centre of Venaria Reale (Italy), which are related to two innovative transport solutions, a tram-train system (TT) and a bus rapid transit (BRT), that have been considered (Abastante et al., 2011b). From the point of view of the connection paths, four scenarios were identified as the possible route options.

According to the theory of the DRSA, it is necessary to define the information system identifying the objects of the considered universe and the attributes. This leads to the definition of the decision table. In our case, 19 objects have been taken into account, which are related to transport connection systems in different cities. The objects are described by condition attributes (number of inhabitants, length of the line, mean distance between stations, demand of passengers and cost of the infrastructure) and by decision attributes (type of transport system: TT or BTR).

The decision table is represented in Table 6, where the symbol '?' stands for missing values.

From the decision table above described it is possible to induce a set of decision rules using DRSA theory. Each rule contains a premise formulated as a set of conditions expressed in terms of the considered attributes, a conclusion formulated as the choice of one transportation systems and a support given by the number of cities satisfying the premise and the conclusion. For each rule is given also the name of the cities supporting it. 20 decision rules have been induced for TT service and 34 decision rules have been induced for the BRT system. For example, the rule number 28 in the set of the rules for the BRT system is described as follows:

*If the number of the habitants is ≥256,000 and the distance between stations is ≤450 m and the cost is ≤290 million of euros, then the final decision is BRT, according to the experience of the cities of Eindhoven, Clermont-Ferrand and Douai.*

All the rules obtained have been considered in the four alternative scenarios identified. The DRSA gives to the DM a preference information in simple terms by means of a set of decision examples where each decision rule can be justified by decision examples supporting it. It does not give a unique indication about which transport solution is preferable for all the scenarios, actually. In order to help the DM to manage the rules, one could assume that a rule containing certain attributes is more remarkable for the DM and the experts, making that rule more meaningful than others. In this case, according to the literature and the specific DMs request, it has been decided to define the attributes related to 'cost' and 'mean distance between stations' as the most important factors that can affect the choice of the transport system in this particular application.

Similarly, one can assume that a rule with the highest number of supporting objects has to be considered more meaningful in comparison to another one with a smaller number of supporting objects. According to this specific interpretation, the results coming from the performed application show that the decision rules related to the BRT sound more interesting.

Table 7 contains the rules that have positive support in the four scenarios with reference to two transport modalities, according to the strategies previously described.

**Table 6** Decision table for the choice of the best transport connection between Turin and Venaria

| *Object* | *Condition attributes* | | | | | | *Decision attributes* |
|---|---|---|---|---|---|---|---|
| | *City* | *Number of habitants* | *Length of line (km)* | *Distance between station (meter)* | *Demand (passengers/day)* | *Cost (Million of Euros)* | *Type of system* |
| 1 | Karksruhe | 1,200,000 | 560 | 589 | 301,368 | 150 | TT |
| 2 | Kassel | 550,000 | 122 | 2,033 | ? | 100 | TT |
| 3 | Saarbrucken | 500,000 | 44 | 1,000 | 40,000 | ? | TT |
| 4 | Zwickau | 125,000 | 19.1 | 637 | 13,700 | 89 | TT |
| 5 | Chemnitz | 740,000 | 23.1 | 920 | ? | ? | TT |
| 6 | Alicante | 1,650,000 | 51 | 1,000 | ? | 500 | TT |
| 7 | Leiden | 260,000 | 50 | 1,250 | 41,100 | 400 | TT |
| 8 | Nordhausen | 50,000 | 7 | ? | 6,300 | ? | TT |
| 9 | Mulhouse | 110,000 | 37.8 | 350 | 40,000 | 340.2 | TT |
| 10 | Strasburg | 100,000 | 43.8 | 1,350 | 22,000 | 395 | TT |
| 11 | Manchester | 2,500,000 | 36.6 | 1,000 | 52,000 | 440 | TT |
| 12 | Paris | 1,175,000 | 8 | 890 | 44,000 | 52.7 | TT |
| 13 | Rotterdam | 2,000,000 | 35 | ? | 117,000 | 810 | TT |
| 14 | Sheffield | 1,273,000 | 60 | 3,500 | 3,300 | 31 | TT |
| 15 | Rouen | 400,000 | 37.6 | 725 | 35,000 | 145 | BRT |
| 16 | Eindhoven | 725,000 | 15 | 350 | ? | 100 | BRT |
| 17 | Clermont-Ferrand | 256,000 | 14 | 450 | 55,000 | 290 | BRT |
| 18 | Istanbul | 14,000,000 | 72.3 | 1,300 | 1,470,000 | 177 | BRT |
| 19 | Douai | 550,000 | 12 | 310 | 18,000 | 117 | BRT |

*Source:* Abastante et al. (2011b)

**Table 7** Final results of the DRSA application

| *Scenarios* | *Rules with positive support TT* | *Presence of the attribute ‘cost’* | *Presence of the attribute ‘mean distance between stations’* | *Number of objects supporting the rule* | *Rules with positive support BRT* | *Presence of the attribute ‘cost’* | *Presence of the attribute ‘mean distance between stations’* | *Number of objects supporting the rule* |
|---|---|---|---|---|---|---|---|---|
| 1 | Rule 7 | x | x | 2 | Rule 17 | x | ✓ | 2 |
| | | | | | Rule 28 | ✓ | ✓ | 3 |
| 2 | Rules 2 | ✓ | x | 6 | Rule 28 | ✓ | ✓ | 3 |
| | Rule 7 | x | x | 2 | Rule 30 | ✓ | ✓ | 2 |
| 3 | Rule 2 | ✓ | x | 6 | Rule 28 | ✓ | ✓ | 3 |
| | Rule 7 | x | x | 2 | Rule 30 | ✓ | ✓ | 2 |
| 4 | Rule 2 | ✓ | x | 6 | None | x | x | / |

## 4 Main findings coming from the ANP/DRSA applications

It is possible to point out some general reflections about the main characteristics of the two considered theories, the necessary data for the application, and the nature of the results. It is important to underline that the considerations here described are strongly influenced by the fact that we observe DRSA and ANP (and their potential application) only in the context of urban and territorial transformations.

With respect to the ANP, we can summarise the main characteristics as follows:

- It is a multicriteria theory able to consider not only numerical data, statistics, etc., but also preferences and feelings of the DM.
- It does not handle missing data but often it is possible 'to circumvent' the problem, resetting the structure of the decision model.
- It takes into account the views of different actors, even with heterogeneous languages. In this sense it is important to underline that ANP allows to develop the theme of participation, due to the focus groups where different actors and DMs involved can deal directly.
- The ANP may contribute to the construction and review of alternatives.
- It is based on the assumption of the decomposition of a complex problem into simpler elements, systematising the relationship among the nodes. Similarly, it uses the principle of pairwise comparison to simulate the process of the human mind (Saaty, 1980, 2005).

With specific reference to the ANP output, we can put in evidence that:

- The ANP, like other methods, offers as a final result the ranking of alternatives and, for this reason, provides a readable and immediately understandable result.
- The way in which the ANP is applied really coincides with the iterative and interactive role increasingly required to an evaluation process.
- It is possible to combine the ANP with new visualisation tool as GIS (Ferretti and Pomarico, 2011; Bottero and Ferretti, 2011), or dynamic maps created with the software 'Rhinoceros' (Lami et al., 2011) in order to enforce the communication of the results coming from the evaluation model.
- From the scientific perspective, the weakness of the method is that it is often judged as a 'black box', where the data are processed in a not intelligible way for the DM, and sometimes even for the experts.
- The translation of the qualitative judgements into quantitative ones in the Saaty's fundamental scale is not entirely clear.
- From the application point of view, the most worrying aspect is the huge number of questions to which the participants must answer.

Regarding the DRSA, the main aspects to be highlighted in this context are:

- It is a multicriteria methodology able to consider quantitative, qualitative and missing data, preferential information.

- The information come from a set of examples related to real or simulated decisions. This means that DRSA is an indirect approach preferences.
- It does not need many samples of data (so it is not a statistical technique).
- The evaluation model is structured by the expert considering the goal of the DM, the related literature, etc. The method returns a set of decision rules that allow the DM to critically interpret the problem and to interact with the decision analysts in a more conscious way. Through the rules analysis it is possible to modify and re-think the preference information. In this sense, it can be considered as the first basis for an iterative participative model (Greco et al., 2008; Abastante et al., 2010).
- The method allows inconsistent or ambiguous information to be considered and processed because, according to the DRSA theory, it is possible to manage also uncertain rules coming from the boundary region.
- It is a purely ordinal approach which does not use invasive operations on the data (e.g., average, normalisation and other calculations).
- The method can be used in the ex-post phase for the suitability of the decision rules in explaining and justifying the choices made by the DM (Abastante et al., 2011a).

With respect to the DRSA output, we can put in evidence that:

- It can be considered as a ‘glass box’ where the process to get the final rules is clearly traceable (Greco et al., 2001).
- It gives transparent feedback organised in learning oriented perspective.
- DRSA conjugates well understandable results expressed in terms of decision rules articulated in natural language, with a rigorous mathematical theory which ensures the robustness of obtained results.
- The possible weakness of the DRSA is that the decision rules are clear but sometimes it is not clear which are the indications given to the decision problem. This is because the DM is required to have an active role in the decision aiding process, such that, it is expected that in his/her sphere of autonomy, he/she uses the rules to build reasonable arguments to support the final decision.

Finally, it can be noticed that there are many ANP applications in the urban and territorial transformations context, also with stakeholders really having an active role in decision-making, while the DRSA, even if very promising, has been used only in few cases of this type and only in academic contexts. This allows to report how the authors have seen the effectiveness of the use of the ANP method so many times, at least in facilitating the participatory process of decision-making, while there are still few elements of opinion based on a real experience with DRSA technique.

It is also possible to think about the conjoint use of the two methodologies to address the same problem at different stages of decision-making process: first, it is possible to start with the representation of the problem provided by the conceptual scheme of ANP to highlight (and share) the crucial aspects of the issue and to identify possible alternative solutions. Later, it is possible to use DRSA to extrapolate a series of rules to support the DM reflecting and choosing the most appropriate solution, as well as in the communication and explanation of the decision.

## 5 Conclusions

The paper discusses the application of two multicriteria methodologies, the ANP and the DRSA, for supporting the decision making processes related to territorial transformations in the different phases of the analysis.

Both methodologies are suitable for the analysis of problems concerning environmental, urban, transport, social, economic and technical elements, where the DM has to handle heterogeneous information: qualitative and quantitative, preference-ordered or not, expressed on ordinal and cardinal scales.

Both ANP and DRSA can give a real contribution in the strategic decision phase, which often lacks in detailed information from the point of view of the considered alternatives and the elements at play.

The main strength of the ANP theory is the ability to represent the decision problem through the network structure. This representation forces the DM to reflect about the elements at stake and their reciprocal influence relationship. On the contrary, the principal weakness of ANP is related to the very complex elaboration process of the initial data; as a consequence, the relationships between the input and the output of the model are weak and very difficult to be readable. In this sense, one can say that the ANP method offers a punctual recommendation in the form of a score for each alternative of the decision problem at hand, but the process through which this recommendation is obtained is often perceived as a 'black box'.

On the other side, very often he DRSA methodology does not provide a punctual recommendation, and, rather it offers to the DM some results on the decision problem at hand aiding the DM to construct his/her preferences with the aim of permitting a maturation of a convict and well argumented decision. This is permitted by the 'glass box' nature of the DRSA methodology allowing to acquire and give back information in a very simple and understandable way (example of decisions as input and decision rules as output).

Taking into account the specific differences and the related advantages and disadvantages of the two methodologies, one can imagine to use both ANP and DRSA in the decision process, in order to exploit the positive aspects of both of them. Following this approach, the DM can gain more awareness of the elements at stake while structuring the model by the network of the ANP, and thus, thanks to this new consciousness of the decision problem at hand, the DM can better understand the results of the DRSA. Therefore, in a learning perspective, conjoint use of ANP and DRSA permits to increase the knowledge of the DM about the decision problem under examination.

Finally, given the spatial nature of the decision problems under consideration, future improvements of the work could refer to the integration of the MCDA tool with geographic information systems in order to develop a multicriteria spatial decision support system (MCSDSS) that will enable multi-purpose planning (Malczewski, 1999). In this sense, visualisation techniques are of great importance to present and communicate the results to DMs and the interest groups (Al-Kodmany, 1999; Wu et al., 2010).

## Acknowledgements

We would like to thank two anonymous referees whose remarks permitted to improve the quality of the article.

## References

Abastante, F. and Lami, I.M. (2012) 'Quality function deployment (QFD) and analytic network process (ANP): an application to analyze a cohousing intervention', *Journal of Applied Operational Research*, Vol. 4, No. 1, pp.14–27.

Abastante, F., Bottero, M., Greco, S. and Lami, I.M. (2010) 'A dominance-based rough set approach model for selecting the location for a municipal solid waste plant', Paper presented at the *72nd Meeting of the European Working Group of Multiple Criteria Decision Aiding*, 7–8 October 2010, Paris, France.

Abastante, F., Bottero, M., Greco, S. and Lami, I.M. (2011a) 'Addressing the location of undesirable facilities through the dominance based rough set approach', Paper presented at the *21st International Conference on Multiple Criteria Decision Making*, 13–17 June 2011, Jyvaskyla, Finland.

Abastante, F., Bottero, M., Greco, S. and Lami, I.M. (2011b) 'The role of analytic network process and dominance-based rough set approach in strategic decisions for territorial transformations', *Valori e Valutazioni*, Vol. 7, No. 1, pp.101–122.

Al-Kodmany, K. (1999) 'Using visualization techniques for enhancing public participation in planning and design: process, implementation, and evaluation', *Landscape and Urban Planning*, Vol. 45, No. 1, pp.37–45.

Aragonés-Beltràn, P., Pastor-Ferrando, J.P., Garcìa-Garcìa, F. and 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*, Vol. 91, No. 5, pp.1071–1086.

Bezzi, C. (1998) 'La valutazione sociale. Una mappa concettuale', in Bezzi, C. and Palombo, M. (a cura di): *Strategie di valutazione*, Gramma, Perugia.

Bottero, M. and 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*, Vol. 17, Nos. 3–4, pp.63–84.

Bottero, M. and Lami, I.M. (2010) 'Analytic network process and sustainable mobility: an application for the assessment of different scenarios', *Journal of Urbanism*, Vol. 3, No. 3, pp.275–293.

Bottero, M. and 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*, Vol. 19, No. 6, pp.642–660.

Bottero, M., Comino, S., Pomarico, S. and Rosso, M. (2011) 'Environmental analysis and territorial planning: a multicriteria – spatial decision support system for assessing the quality of a river basin', paper submitted for the discussion at the *73rd Meeting of the European Working Group of Multiple Criteria Decision Aiding*, 13–14 April 2011, Corte, France.

Bottero, M., Lami, I.M. and Lombardi, P. (2008) *Analytic Network Process. La valutazione di Scenari di Trasformazione Urbana e Territoriale*, Alinea, Firenze.

Brundtland, G. (1987) *Our Common Future*, Oxford University Press, Oxford.

Calafati, A. (2010) *Riqualificazione Urbana e Sviluppo Economico Nelle Marche*, Rapporto elaborato su incarico del Servizio Ambiente e Paesaggio della Regione Marche, available at http://www.antoniocalafati.it (accessed on 28 May 2012).

Camagni, R. (2008) 'Il finanziamento della città pubblica', in Baioni R. (Ed.): *La Costruzione Della Città Pubblica*, Alinea, Firenze.

Ferretti, V. and Pomarico, S. (2011) 'Un modello MC-SDSS per la localizzazione di un termovalorizzatore di rifiuti nella Provincia di Torino', *Valori e Valutazioni*, Vol. 6, No. 1, pp.177–194.

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

Greco, S., Matarazzo, B. and Slowinski, R. (1999) 'Rough approximation of a preference relation by dominance relations', *European Journal of Operational Research*, Vol. 117, No. 1, pp.63–83.

Greco, S., Matarazzo, B. and Slowinski, R. (2001) 'Rough rough sets theory for multicriteria decision analysis', *European Journal of Operational Research*, Vol. 129, No. 1, pp.1–47.

Greco, S., Matarazzo, B. and Slowinski, R. (2002) 'Rough approximation by dominance relations', *International Journal of Intelligent Systems*, Vol. 17, No. 2, pp.153–171.

Greco, S., Matarazzo, B. and Slowinski, R. (2008) 'Dominance-based rough set approach to interactive multiobjective optimization', in Branke, J. et al. (Eds.): *Multiobjective Optimization*, pp.21–155, Springer-Verlag Berlin Heidelberg, New York.

Lami, I.M. and Vitti, E. (2011) 'A combination of quality function deployment (QFD) and analytic network process (ANP) to evaluate urban redevelopment projects. An application to the "Belle de Mai – La Friche" of Marseille (France)', *Journal of Applied Operational Research*, Vol. 3, No. 1, pp.2–12.

Lami, I.M., Masala, E. and Pensa, S. (2011) 'Analytic network process (ANP) and visualization of spatial data: the use of dynamic maps in territorial transformation processes', in *ISAHP2011: Online Proceedings of the International Symposium on the Analytic Hierarchy Process*, available at http://204.202.238.22/isahp2011/dati/autor.html.

Malczewski, J. (1999) *GIS and Multicriteria Decision Analysis*, John Wiley and Sons, New York.

Micelli, E. (2011) *La Gestione Dei Piani Urbanistici – Perequazione, Accordi, Incentivi*, Marsilio, Venezia.

Mondini, G. (2009) 'Il progetto di sostenibilità', in Bottero, M. and Mondini, G. (a cura di): *Valutazione e Sostenibilità. Piani, Programmi, Progetti*, Celid, Torino.

Neaupane, K.M. and Piantanakulchai, M. (2006) 'Analytic network process model for landslide hazard zonation', *Engineering Geology*, Vol. 85, No. 1, pp.281–294.

Pawlak, Z. (1982) 'Rough sets', *International Journal of Information & Computer Sciences*, Vol. 11, No. 5, pp.341–356.

Pawlak, Z. (1991) *Rough Sets Theoretical Aspects of Reasoning About Data*, Dordrech, Kluwer.

Piantanakulchai, M. (2005) 'Analytic network process model for highway corridor planning', in *ISAHP2005: Online Proceeding of the International Symposium on the Analytic Hierarchy Process*, available at http:isahp2015/dati/autor.html.

Promentilla, M., Furuichi, T., Ishii, K. and Tanikawa, N. (2006) 'Evaluation of remedial countermeasures using the analytic network process', *Waste Management*, Vol. 26, No. 12, pp.1410–1421.

Roy, B. and Bouyssou, D. (1995) *Aide Multicritére à la Décision: Méthodes et Case*, Economica, Paris.

Saaty, R.W. (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*, RWS Publications, Pittsburgh.

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

Saaty, T.L. (2000) *Fundamentals of Decision-Making and Priority Theory with the Analytic Hierarchy Process*, RWS Publications, Pittsburgh.

Saaty, T.L. (2005) *Theory and Applications of the Analytic Network Process*, RWS Publications, Pittsburgh.

Saaty, T.L. and Ozdemir, S.O. (2008) *The Encyclicon: A Dictionary of Applications of Decision Making with Dependence and Feedback Based on the Analytic Network Process*, RWS Publications, Pittsburgh.

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

Sipahi, S. and Timor, M. (2010) 'The analytic hierarchy process and analytic network process: an overview of applications', *Management Decision*, Vol. 48, No. 5, pp.775–808.

Slowinski, R., Greco, S. and Matarazzo, B. (2009) 'Rough sets in decision making', *Encyclopedia of Complexity and Systems Science*, pp.7753–7787.

Stagl, S. (2006) 'Multicriteria evaluation and public participation: the case of UK energy policy', *Land Use Policy*, Vol. 23, No. 1, pp.53–62.

Tuzkaya, U. and Onut, S. (2008) 'A fuzzy analytic network process based approach to transportation-mode selection between Turkey and Germany: a case study', *Information Sciences*, Vol. 178, No. 15, pp.3133–3146.

UNCED (1992) *The Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests*, Technical report of the United Nations Conference on Environment and Development, 3–14 June 1992, Rio de Janeiro, Brasil, available from http://www.un.org/documents/ga/conf151/aconf15126-3annex3.htm (accessed on 1 January 2012).

UNECE (1998) *Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters*, Technical report of the United Nations Commission for Europe, available at http://www.unece.org/env/pp/documents/cep43e.pdf (accessed on 1 January 2012).

Wijnmalen, D.J.D. (2007) 'Analysis of benefits, opportunities, costs, and risks (BOCR) with the AHP–ANP: a critical validation', *Mathematical and Computer Modelling*, Vol. 46, Nos. 7/8, pp.892–905.

Wu, H., He, Z. and Gong, J. (2010) 'A virtual globe-based 3D visualization and interactive framework for public participation in urban planning processes', *Computers, Environment and Urban Systems*, Vol. 34, No. 4, pp.291–298.