ANALYTIC NETWORK PROCESS (ANP) AND VISUALIZATION OF SPATIAL DATA: THE USE OF DYNAMIC MAPS IN TERRITORIAL TRANSFORMATION PROCESSES

Isabella M. Lami
Department of Housing and City
Politecnico di Torino
Torino, ITALY
E-mail: isabella.lami@polito.it

Elena Masala
Department of Technology Communication and Society
Università degli Studi Guglielmo Marconi
Roma, ITALY
E-mail: elena.masala@polito.it

Stefano Pensa
Department of Architectural and Industrial Design,
Politecnico di Torino,
Torino, ITALY
E-mail: stefano.pensa@polito.it

ABSTRACT

Multiple Criteria Decision Analysis (MCDA) is generally used to support planning and decision making processes, but the sharing of information is often limited by two main factors. First, many users have difficulty reading output data, especially tables, matrixes or databases. Second, the presence of many actors introduces different disciplines, knowledge, interests and languages. This paper shows the contribution that the visualization of spatial data can give to the Analytic Network Process (ANP) (Saaty, 2005; 2001; Saaty, Vargas, 2006). This study aims to use visualization techniques to create a common grammar among actors involved, and a shared basis for generating discussion. To do this we have implemented on-going research on a modelling system which is able to visualize various kinds of data in real time. This modelling system works on generative and parametric features applied to datasets, and is based on McNeel's "Rhinoceros" software and its free plug-in "Grasshopper". The starting point of the work described here is an application on a German section of Corridor 24, Genoa-Rotterdam, part of an Interreg IVB NEW Project, called "Code24". The goal of this ANP application is to rank three scenarios of improvement of the "Betuwe" railway line connecting Oberhausen to the Dutch borders. The research resulted in an academic internal application which allowed us to improve the system for use in real-world focus groups which included the main stakeholders of these territorial transformation projects.

Keywords: Geo-visualization, Analytic Network Process, Dynamic Maps, Parametric and Generative Modelling
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1. Introduction

The use of ANP to study alternative planning solutions in real decision-making arenas highlighted areas for potential improvement. First, the assignment of weights to clusters and nodes requested by ANP could create misunderstandings due to a lack of ability of non-expert users to comprehend their meaning. Second, a more visual grammar can generate a common basis for sharing information and allowing discussions. Therefore, the indexes, weights and rankings from ANP must be an object of discussion as well as their results. They are not part of a black box, (Latour, 1987) but also need to be assessed by the decision-makers (DM). Third, the large quantity of data to manage during the decision-making process has highlighted the necessity to filter items in order to better identify and isolate core features.

In the last twenty years many authors have studied new methodologies for improving the readability of multi-criteria analysis through integration with GIS (Geographic Information System) technologies (Malczewski, 2006). In 1988 Diamond and Wright addressed this topic which opened an international debate that transcends various disciplines. In particular, this research refers to the integration of MCDA with tools for the visualization of spatial data, such as GIS data and CAD drawings.

The visualization of spatial data, also known as geo-visualization, is a branch of cartographic science and is defined as a technique for the exploration of spatial and spatio-temporal data through the use of interactive tools (Andrienko et al, 2007). In its research agenda for 2011-2015, the Commission on Geovisualization of ICA (International Cartographic Association) recommends the use of interactive tools to improve knowledge discovery (http://geoanalytics.net/ica/). In the international landscape, interaction between user and model is a common goal, but only a few studies come close to obtaining a result able to combine data exploration, multicriteria analysis and geovisualization. One example of a paper that accomplished this goal is the "GeoViz Toolkit" (http://www.geovista.psu.edu/geoviztoolkit/index.html) proposed by the Geovista Center of Pennsylvania State University. It offers a useful system for analyzing and mining data on the basis of their geographical position, but it works only on flat maps. Meanwhile, literature on geovisualization provides different examples of three-dimensional models coming from GIS data. These representations are mainly based on generative modelling (Van den Brink, *et al.,* 2007), which results in the automatic production of three-dimensional volumes directly from databases, model libraries or through the extrusion of specific database attributes. Many tools provide these types of spatial data visualization such as "Community Viz" (Orton Family Foundation and Placeways, LLC) and "Metroquest" (Envision Sustainability Tools Inc.), but use it primarily for project presentation, instead of data exploration during the planning process. There is a lack of systems able to integrate the generation of 3D volumes and tools which make use of parametric functions.

To address these issues, a new study has begun to implement on-going research on a modelling system which visualizes various kinds of data in real time. Information and Communication Technologies (ICT) can provide a large number of tools of different typologies which offer the possibility to visualize numerous data and relate them to specific features. Since most of these tools are underused, existing software has been investigated in order to find those best fitted to multidisciplinary processes, and no new tools have been created.

This modelling system is based on McNeel's "Rhinoceros" software and its plug-in "Grasshopper", and works by applying generative and parametric features to datasets. Although this plug-in has been created to support industrial production and generative architectures, this research aims to use it as a support to decision making processes on large areas. In particular, the Grasshopper plug-in offers new opportunities in planning. It implements generative and parametric functions, which allows the system to work in real time, relating shapes with behavioural formulas, and supporting large Microsoft Excel databases. Additionally it can be implemented with plug-ins and scripts in Visual Basic language, which are available for free on the Web.

2. Combining ANP with geo-visualization

In order to successfully merge the ANP technique and three-dimensional model technology, three key issues needed to be solved:

- The translation of qualitative information into spatial form;
- The building of a framework of weighted relations among the spatial items which represent the nodes, clusters and subnets of ANP structure;
- The interaction between the model and its users.

During planning processes, many aspects of decision-making are referred to specific areas and have a well-defined spatial form and localization. These elements and their influence on land can easily be represented in a three-dimensional model. For example, a new road or a residential zone or the geometric features included in GIS data can be characterized in a three-dimensional model. On the other hand, economic or social issues do not have this direct connection with spatial form, and still need to be represented coherently.

To tackle this problem, geo-visualization offers many techniques (Tufte, 2001) which make use of symbolic features applied to spatial areas. In this instance, geo-visualization is used to support MCDA, by building an intuitive language that can enhance the cognitive process of the actors involved (MacEachren, *et al*., 2004). Data knowledge process is then implemented by two key factors: the localization of information, which defines the spatial position of data; and the cause-effect relationship that results between the actor's decisions and the spatial forms that mutate in real-time, in accordance with the changing intent of the decision makers.

ANP works on weights assigned to relations among nodes, clusters and subnets, therefore, this modelling system must be implemented in order to generate spatial forms on the basis of weighted relations among different components. For this reason, the same framework of relations and weights among ANP elements has been reproduced to set up the 3D model. One map is created for every ANP node, where the node is represented by a symbolic mode of visualization. Mathematical formulas, which can be complex, can be applied to visualize spatial behaviours since not all factors have a direct form of representation. In this way the influence of an element on the form of space can be determined with specific equations derived from different fields. Each map changes according to the weights assigned to its relation with the other nodes, clusters and scenarios. This structure of relations is very complex, but allows the visualization of the spatial effect of each node. Furthermore, the modelling system can provide a map for each level of ANP structure, allowing them to overlap and be compared.

In this system, users can interact with the model, which can visually update its form on the basis of DM's input. If during a focus group, weights and/or mathematical formulas of spatial behaviours are changed, the system will update its outputs in real time, offering an important tool for explaining the cause-effect relationships between decisions and their spatial results.

3. Application to the study case

3.1 Presentation of the case

ANP and geovisualization tools have been used to study a German section of Corridor 24, Genoa-Rotterdam. The connectivity of the German railway system between the German city of Oberhausen and the Dutch border in the Ruhr Region needs to be upgraded. In the framework of Corridor 24 development, the changes in the transport system across the border of the Netherlands and Germany imply a new spatial configuration for the areas of Northwest Germany. Therefore, the case study analyzes various possibilities for upgrading the connectivity in this area. The entire spatial dimension is very large, so the study analysis will be conducted by proposing identical scenarios for smaller areas related to focus groups. This paper shows the application of ANP and geovisualization tools beginning with a study of the area of Wesel, in which four partners of the "Code24 project" were involved: SiTI - Politecnico di Torino (Italy), ETH of Zurich (CH), University of Duisburg-Essen (D) and Universiteit of Utrecht (NL). Three alternatives have been considered in applying ANP (Table 1).

Table 1
Alternatives for improving the rail line in the Ruhr Region

Alternatives	*Characteristics*
Scenario 0	Improvement of existing "Betuwe" railway line: No new railway is created; railway signalling is increased in order to augment the number of trains.
Scenario 1	Addition of a third track in the German stretch of Betuwe railway line, which runs through many towns, making noise barriers for the passage of high speed traffic and the elimination of many grade crossings.
Scenario 2	Freight transport abandons railway passage through Venlo, and uses the Betuwe railway line to Wesel, where an existing but unused by-pass has to be restored in order to connect Wesel with both its port on the Rhine and Oberhausen through the countryside.

3.2 Structure of network

According to the literature review and problem analysis (Saaty, 2005; Bottero *et al*, 2008), the decision problem has been divided into four clusters (environmental aspects, economic aspects, transport aspects and urban planning aspects) that have been organized according to the Benefits, Opportunities, Costs, Risks (BOCR) model.

To obtain spatial visualizations of BOCR, a model was built using Grasshopper based on drawings, databases and GIS data such as infrastructures, built areas and geographical features. The model creates relationships among all the elements in order to reproduce the ANP structure as a “flow chart”. It determines the rules of the parametric model, and assigns spatial behaviour to each node. This presents many questions that need to be answered drawing from the knowledge of experts from several fields. In this test case, we do not aim to obtain a fully functional model, but to investigate how the merging of ANP with this modelling system can effectively support participative and collaborative processes. Therefore, even if the modelling system can make use of complex mathematical formulas, the initial phase of research will only employ simple rules given by the symbolic representation of phenomena, as indicated by an internal survey (Table 2).

To simplify this test case, a symbolic map, acting on a 50m x 50m grid, has been assigned to each node of ANP framework. Nodes with an identified spatial behaviour generate an influence depending on distance, while "non-spatial" nodes (such as most of the economic nodes) produce constant maps which cover the whole area. This test case makes use of two kinds of maps: a bi-dimensional one in which colour gradient is the indicator of the weight and importance of each node, and a 3D visualization one based on the extrusion of symbolic maps. ANP inquiries place the weight of a node’s importance on a numerical scale. Each map changes according to the weights assigned to its relation with other nodes, clusters and scenarios. The resulting representation is a deformation of land, acting in real time that creates a 3D diagram which expresses the weights assigned to each node. In order to increase the number of ways for communicating information, other visualizations that combine 3D models with, for example, colour and buffer areas, are also possible.

Table 2
Clusters and nodes and symbolic modes of visualization used in the test case

BOCR	*Cluster*	*Elements*	*Map*
Benefits	*Environment*	Reduction in traffic emissions in urban areas	Linear buffer along main roads
	Economic	Improving the economic role of the Region	Constant value
		New employment due to the improvement of transport	Constant value
	Transport	Increase in frequency of connection	Radial buffer on railway stations
		Creation of a freight hub, by intersecting rail, road and river transport, connected to Wesel port	Land use
		Increase in the capacity of freight transport	Linear buffer along main roads and railways
Opportunities	*Economic*	Possible creation of new jobs indirectly related to the improvement of the regional transport system	Constant value
		Increase in trade	Constant value
	Transport	Possible river connections to Berlin for freight transport	Linear buffer along main waterways and radial buffer centred on port
		Increase in the capacity of the transport of people	Radial buffer on railway stations
	Urban planning	Promotion of new forms of settlement along the enhanced track	Linear buffer along railways
		Elimination of grade crossings	Radial buffer on grade crossings
Costs	*Economic*	Investment costs	Constant value
		Acquisition/expropriation of areas for the insertion of new track	Linear buffer along railways
	Environment	Noise and vibration impacts	Linear buffer along railways and main roads
	Urban planning	Visual impact of trains	Linear buffer along railways
		Possible creation of large barriers in landscape	Linear buffer along railways
Risks	*Economic*	Possible extensions of implementation time due to conflicts arising with the local population	Constant value
		Decrease in property values	Linear buffer along railways
	Environment	Soil consumption/Land consumption	Linear buffer along railways

3.3 Resulting visualizations

For this first application, visualizations have been used to show the ANP results referring to subnets and scenarios. The BOCR model allowed users to visualize the behaviours and tendencies for each scenario. In particular, it proves to be effective when used with a slicing plane which eliminates the lowest values and displays output with more potential. The visualization of each subnet describes the effects on space, and highlights the characteristics of each scenario. Figure 1 shows the Benefits network.

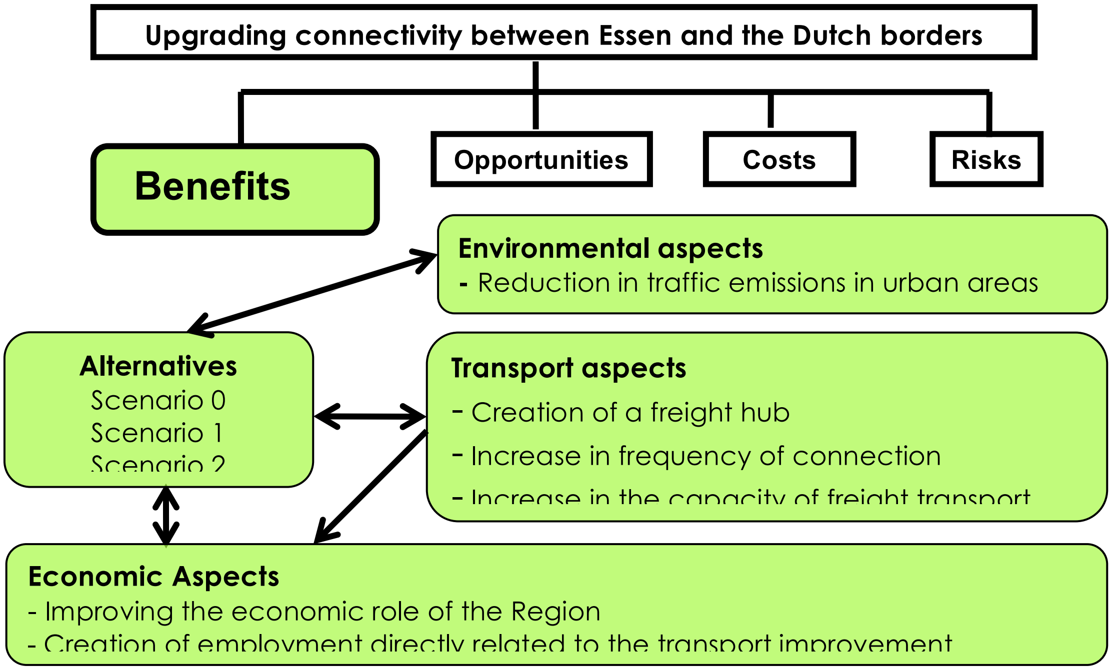

Figure 1 Benefits Network

According to the ANP methodology, after having structured the decision network, the second step of the analysis consists in filling in the pairwise comparison matrices for each subnet. It is important to highlight that there are two levels of pairwise comparisons in the ANP: the cluster level, which is more strategic, and the node level, which is more specialized. In pairwise comparisons, a ratio scale of 1-9, that is the Saaty's fundamental scale, is used to compare any two elements. The main eigenvector of each pairwise comparison matrix represents the synthesis of the numerical judgements established at each level of the network (Saaty, 1980).

Considering the pairwise comparison at the cluster level, the following questions were generated: *With respect to the choice of alternatives (i.e. the three options to upgrade the connectivity between Essen and the Dutch border)*, in your opinion, what aspect is more important, and how much more?"

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

From the cluster level comparison in subnet Benefits, it is possible to derive the cluster matrix (Table 3). In the case under examination, economic aspects are given the highest importance (0,740), followed by the transport aspects (0,166) and finally by the environmental aspects (0,094).

Table 3
Cluster matrix

	Alternatives	Economic Aspects	Environmental Aspects	Transport Aspects
Alternatives	0,000	0,500	1,000	1,000
Economic Aspects	0,740	0,000	0,000	0,000
Environmental Aspects	0,094	1,000	0,000	0,000
Transport Aspects	0,166	0,500	0,000	0,000

Once the clusters comparison has been conducted, it is necessary to study the problem in depth through the analysis of the elements. Considering the pairwise comparison at the node level, the following questions were generated: "*With reference to Scenario 2 (freight transports leave the railway passing by Venlo and use the Betuwe rail line until Wesel, where an existing but unused by-pass has to be restored in order to connect Wesel with both its port on Rhein and Oberhausen through the countryside),* in your opinion, what transport aspect is more important and how much more?

Creation of a freight hub	9	8	7	**6**	5	4	3	2	1	2	3	4	5	6	7	8	9	Increase in frequency of connections
Creation of a freight hub	9	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Increase in capacity of freight transport
Increase in frequency of connections	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Increase in capacity of freight transport

The weight assigned shows that the most appreciated characteristic of Scenario 2 is the creation of a freight hub, by intersecting rail, road and river transport, connected to Wesel port. This score is consistent with the current trends which highlight intermodal transport. The increase in capacity of freight transport is considered more important, however slightly, than the frequency.

The totality of the eigenvectors, which are derived from the pairwise comparison matrixes of the model elements, forms the unweighted supermatrix. The cluster matrix is then applied to the unweighted supermatrix as a cluster weight and the result is the weighted supermatrix (Table 4).

Table 4
Weighted supermatrix (Benefits)

		Alternatives			*Economic Aspects*		*Environmental Aspects*	*Transport Aspects*	
		Option 0	*Option 1*	*Option 2*	*Employment*	*Economic Role*	*Traffic emission reduction*	*Freight hub*	*Connections frequency*
Alternatives	*Option 0*	0,000	0,000	0,000	0,055	0,055	0,072	0,077	0,200
	Option 1	0,000	0,000	0,000	0,290	0,154	0,279	0,231	0,200
	Option 2	0,000	0,000	0,000	0,655	0,290	0,650	0,692	0,600
Economic Aspects	*Employment*	0,123	0,185	0,123	0,000	0,000	0,000	0,000	0,000
	Economic Role	0,616	0,555	0,616	0,000	0,000	0,000	0,000	0,000
Environmental Aspects	*Traffic emission reduction*	0,094	0,094	0,094	0,000	0,000	0,000	0,000	0,000
Transport Aspects	*Freight hub*	0,011	0,015	0,124	0,000	0,000	0,000	0,000	0,000
	Connections frequency	0,078	0,076	0,018	0,000	0,000	0,000	0,000	0,000

Figure 2 shows the Benefits subnet visualisation, according to the weighted matrix. The heavy weight of the economic cluster, represented by constant values, is visible in the large difference which occurs in the level height among scenarios. Scenario 1 is more useful in improving people mobility: the maps of stations, which symbolize the increase in frequency of connection, and maps of the road network, which represent the reduction of traffic emissions, are the weightiest. On the other hand, Scenario 2 shows its propensity to trade and economic development due to the importance of the creation of a logistic hub.

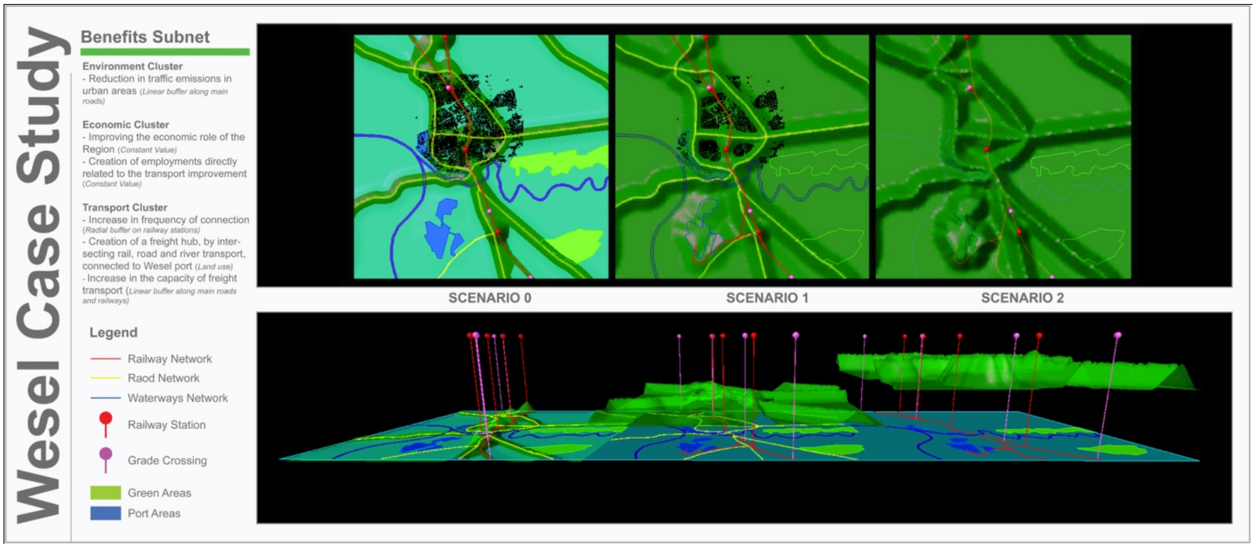

Figure 2 Visualization of Benefits by 3D diagrams: scenario comparison.

The same tendencies of Benefits maps are visible in the subnet of Opportunities (Figure 3). The elimination of the grade crossing in Scenario 1 and the river connection in Scenario 2 confirms that the latter is more indicated for people mobility while the former is more indicated for economic development.

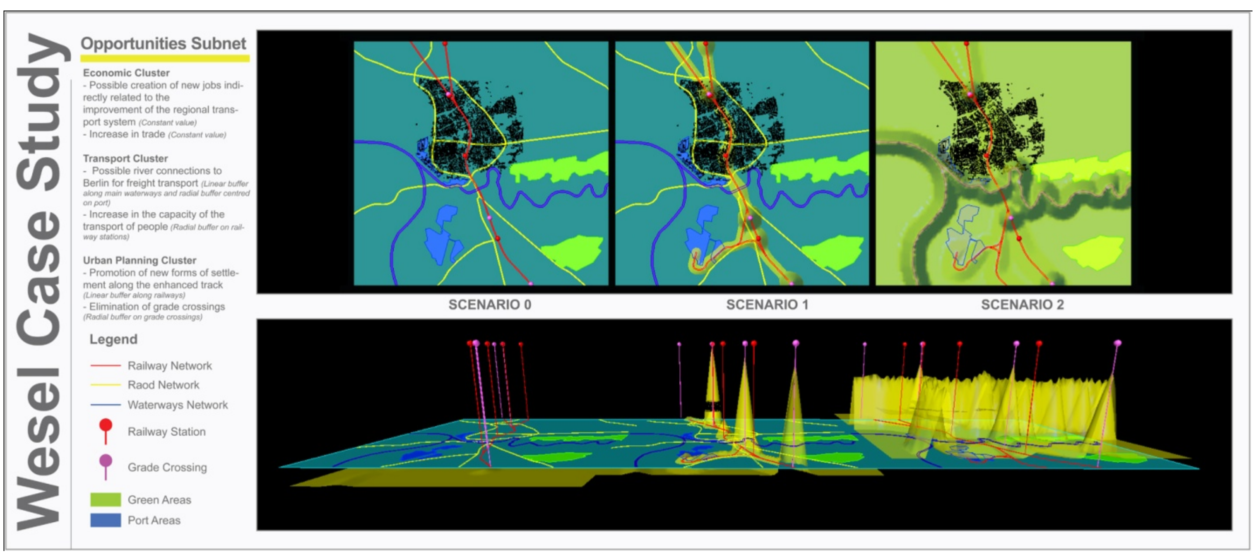

Figure 3 Visualization of Opportunities by 3D diagrams: scenario comparison

The Costs subnet shows that Scenario 1 is more expensive than Scenario 2 (Figure 4). Scenario 0 has a smaller investment cost, but it is characterized by the lack of noise barriers shown by a sequence of peaks along the railway due to visual and vibration impact of trains.

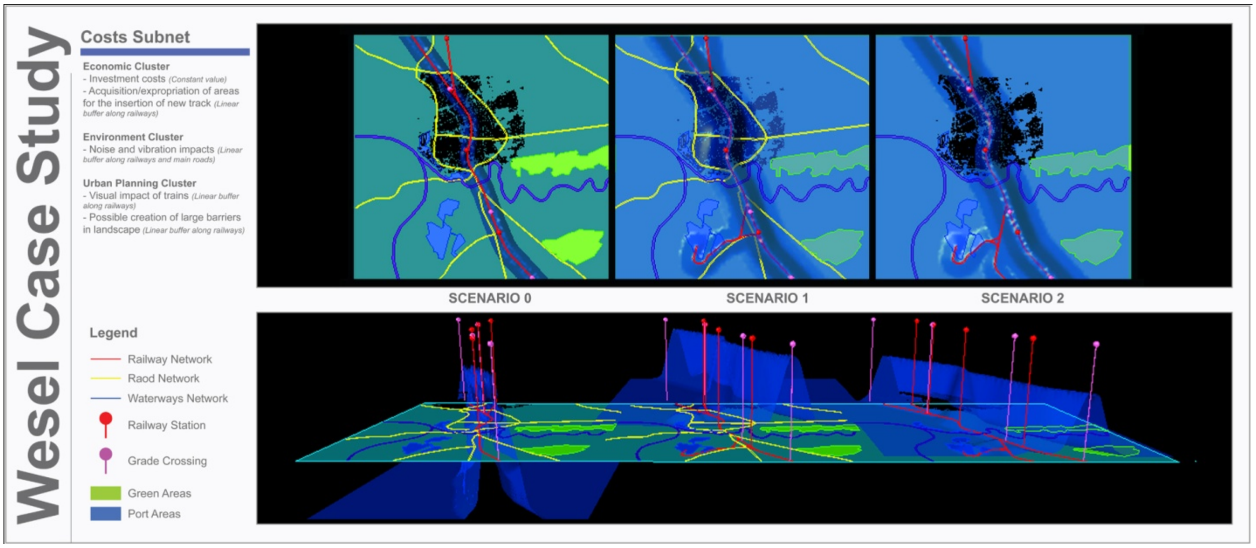

Figure 4 Visualization of Costs by 3D diagrams: scenario comparison.

It is important to emphasize that the modelling system permits the visualization of the assessed impact of each cluster, considering the three scenarios separately. Visualisation allows the perception of the impact problem components to be considered during a focus group and facilitates understanding by all stakeholders. For example, Figure 5 illustrates for the subnet of Costs the perception of the distribution of economic costs (investment costs and acquisition/expropriation of areas for the insertion of new track) arising on the territory in the three scenarios. In this specific visualisation, when only the financial costs are taken into account, it would seem that Scenario 0 has no costs, while, in Figure 4 where all the aspects of the problem are considered, it becomes apparent that there are costs along the railway, due to noise and visual impact.

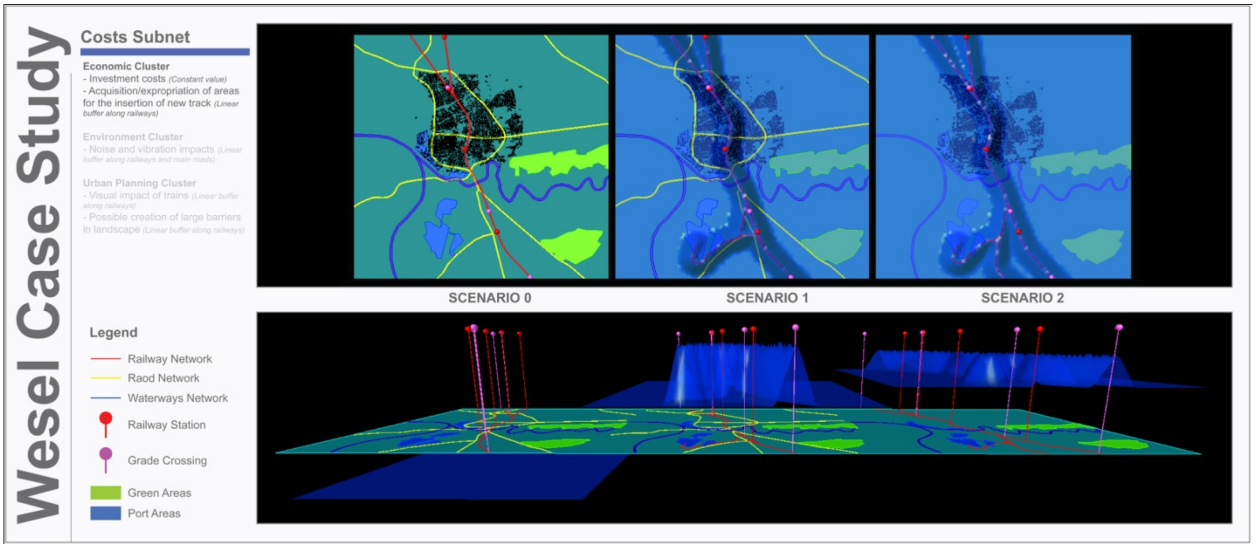

Figure 5 Visualization of the economic cluster in Costs subnet by 3D diagrams: scenario comparison

Also in the Risks subnet (Figure 6), Scenario 0 is strongly influenced by the lack of noise barriers. In both Scenarios 1 and 2, the extension of implementation time determines the increase of risks, but in Scenario 2, the use of an old track and the bypass of the urban area could reduce the possibility of local conflicts.

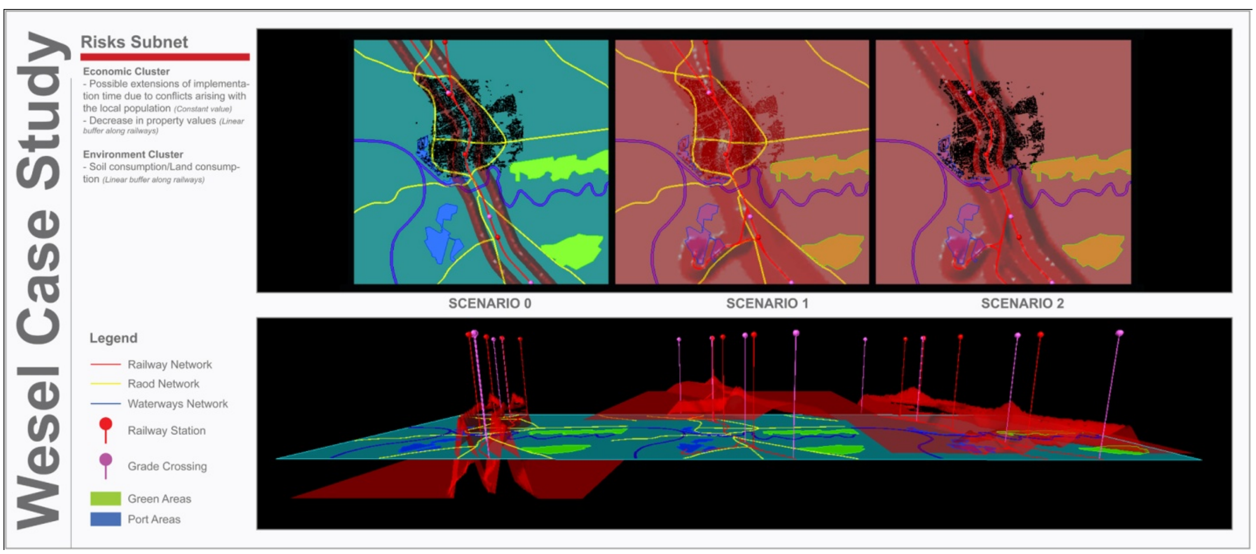

Figure 6 Visualization of Risks by 3D diagrams: scenario comparison

The modelling system also provides the ability to compare scenarios using different combined views of subnets. For example, the switching of Benefits and Costs maps (Figure 7) shows that the lack of barriers in Scenario 0 causes the costs to outweigh the benefits. In Scenario 1, the benefits are greater than the costs, but there is a clear conflict along the rail tracks as a consequence of the weight of the urban planning cluster. Only in Scenario 2 do benefits completely outweigh costs.

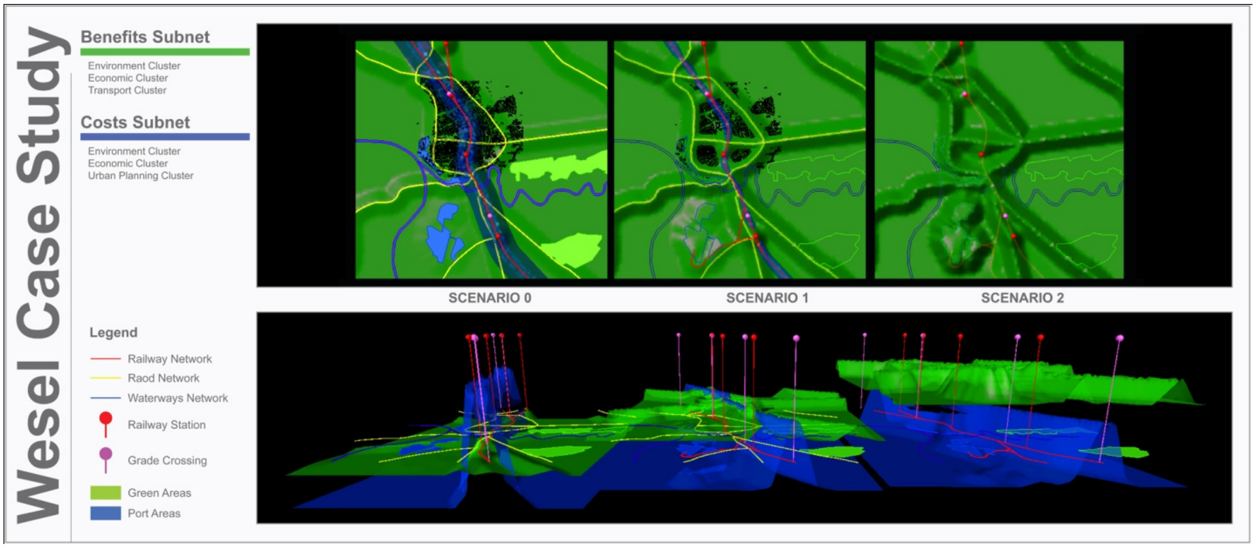

Figure 7 Comparison of the visualization of Benefits and Costs

Finally, according to the ANP methodology, the weighted supermatrix 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.

The analysis development for the four subnets leads to the identification of the final priorities of all the elements of the model. In order to obtain the ranking of the alternatives, it is necessary to synthesize the raw priorities obtained from the limit supermatrix by normalizing them. In the case of the BOCR network structure, it is necessary to synthesize the outcome of the alternative priorities for each of the four subnets in order to obtain an overall synthesis. Different aggregation formulas are available; Figure 8 shows the final ranking of the alternative scenarios according to Additive (reciprocal) formula.

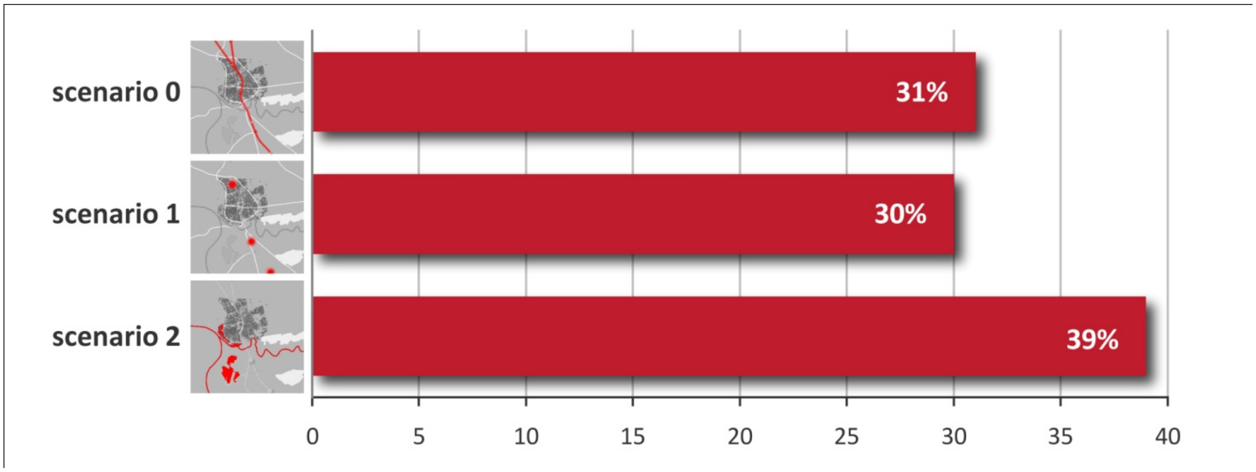

Figure 8 Final ranking of the alternatives

The model shows that the best scenario for upgrading the connectivity of the areas of Northwest Germany is the one which exploits the Betuwe railway line to Wesel, where an existing but unused by-pass has to be restored in order to connect Wesel with both its port on the Rhine and Oberhausen through the countryside.

4. Conclusion

This paper presents a new approach to the integration of visualization with the Analytic Network Process. The ANP methodology is capable of taking both tangible and intangible criteria into consideration without sacrificing their relationships, and it can deal with various interdependencies systematically. This is particularly important for evaluating urban and regional transformation processes, as in the real-world case presented here. The paper tries to take a further step towards facilitating the DM in handling all of the data collected during the decision process, and to analyze the influences among the different elements of the system as perceived by the same DM, using specific 2D and 3D maps created by the modeling system. The application of this evaluation tool shows that no other new software is needed, but rather, a more creative use the existing ones.

The results obtained are sufficiently promising, even if many questions remain to be answered. The spatial visualization of the ANP application is coherent with input choices. Parametric and generative features of the modelling system for symbolic spatial visualization conform well to the use of weights in ANP. The weights assigned to the elements of BOCR analysis were related to spatial forms and represented through dynamic maps. This means that the spatial model correlates quantitative and qualitative values with their effects on spatial form, providing a 3D spatial localization of planning choices. It constantly updates its form reflecting the effects that weights assigned in ANP have on spatial form. In particular, the ability to change the weights and relations among BOCR elements in real time makes this tool an interesting resource for generating discussion in multi-actor processes, such as territorial and urban contexts.

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