EVALUATING MAJOR TRANSPORTATION INFRASTRUCTURE IMPACTS USING GIS AND MULTICRITERIA DECISION ANALYSIS: THE CASE OF EGNATIA MOTORWAY IN GREECE

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Abstract

Renowned for their ability to deal with spatial problems, commercial GIS software packages can play crucial role in spatial decision making processes, given that they are provided with sophisticated tools that allow both private and public organizations to manage and analyze spatial referenced data. In order to expand GIS abilities to the consideration of decision criteria, OR/MS researchers strongly pronounce in favor of developing synergies between GIS and multicriteria decision making tools. The rationale of this integration is the GIS ability to store and manage and visualize geographically referenced data and the efficiency of Operational Research tools for modeling decision problems. As a result MultiCriteria Spatial Decision Support Systems (MC-SDSS) provide a consistent framework that allows alternatives ranking combining both spatial data and DMs preferences according to a selected decision rule. Regarding to their applicability in situations that involve classification, ,multiattribute decision models are considered as a very attractive procedure in urban and regional planning concerning the appraisal of transportation infrastructure construction.

In the present a spatial multicriteria evaluation of the impacts derived by the realization of Egnatia Motorway is performed. Egnatia Motorway is considered one of the most significant interventions that have taken place in Greece during the early pre-Olympic Games period and up to the year 2007. With a length of 670 km, it crosses 12 prefectures starting from the Igoumenitsa Port, which provides links by boat to Italy, ending to Kipi in Evros (Greek-Turkish borders). It is a dual carriageway with two traffic lanes per direction with an overall construction cost of about 6b€. Aiming to enrich Northern Greece’s potential in transport industry and tourism, European Union has heavily invested in its construction.

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1. Introduction

Land-use suitability mapping and analysis, that aim to identify appropriate spatial patterns for future land uses according to specific requirements, preferences, or predictors of some activity, have been widely accepted as one of major fields of interest between GIS analysts (Collins et al, 2001). The ability of the contemporary GIS software packages to support geoprocessing tools such as overlay procedures led both scientists and practitioners to refer to them as Spatial Decision Support Systems (SDSS). However, there is growing consensus about the limited role of GIS as SDSS (Pereira & Duckstein, 1993). This criticism is mainly addressed to the lack of adequate techniques that allow DMs preferences contribution to the final result; and to the fact that Boolean overlays identify as solutions only those that simultaneously satisfy all the analysis' criteria (Laaribi et al, 1996; Chakhar & Martel, 2003).

Recent advances in both GIS technology and Multi Criteria Decision Making methods (MCDM) led many authors to recommend integrations between the two research areas. The rationale of this integration is the GIS ability to store and manage geographically referenced data and the efficiency of Operational Research tools for modeling decision problems. As a result, MultiCriteria Spatial Decision Support Systems (MC-SDSS) provide a consistent framework that allows alternatives' ranking combining spatial data and DMs preferences according to a selected decision rule (Anagnostopoulos & Vavatsikos, 2007).

At the same time evolutions in software technology allowed the development of tools in order to support decisions for semi structured problems. Concerning the development of build-in modules in the commercial GIS packages, ESRIs ArcGIS, Microimages Inc. TNT GIS and Clark Labs IDRISI provide tools for suitability index estimation according to a weighted average of the criterion maps. In particular, IDRISI supports estimations based on Ordered Weighted Average decision rule and a calculator-like module for criterion weights estimation of a pairwise comparisons matrix (Eastman, 1993). The last decade efforts focus on the development of more comprehensive solutions in order to meet DMs requirements. These efforts were encouraged by the provided mediums for preparing, compiling and running macros and development platforms, which permit application programs writing using objects and their build-in properties as well as methods in compliance with programming languages such as Visual Basic and C++.

Transport infrastructure is considered as a regional development project. The new European transport policy (EU–European Commission, 2002), has acquired a clear development dimension, and is directly linked to the policies for the social, economic and territorial cohesion of Europe. This is enhanced by evidence from numerous research studies (Vickerman, 1996; Faludi, 2006).European Spatial Development Perspective (ESDP) explicitly refers to the significance and the consequences of the European transport policy for the organization and development of the European area (EU–European Commission, 1999). It is suggested to assess the spatial impacts of European transport infrastructure on the basis of the following criteria: (a) impact on land use, (b) impact on productive systems of regions, (c) impact on spatial structure, (d) impact on the income and production, (e) impact through regional reinforcement measures, and (f) impact through the spatial differentiation of public intervention.

In Greece, transport infrastructure constitutes a valuable tool in spatial policy. The General Framework of Spatial Planning and Sustainable Development and the Special Spatial Planning Frameworks consider the investments in transport infrastructure as works of regional development (Ministry for the Environment, Planning and Public Works, 2007). The assessment and evaluation of spatial impacts caused by transport infrastructure is a special multidisciplinary task and requires systematic investigation and monitoring, but it has not yet been explored in Greek bibliography.

The Egnatia Motorway (Figure 1) is one of the largest transport projects constructed lately in Europe, and was included in the top priority projects of the Trans European Transport Networks (TENs-T). The motorway, 670km long, crosses Northern Greece horizontally from Igoumenitsa to Kipi on the Greek – Turkish border and is connected via vertical axes northwards to the Pan – European Corridors and via the PATHE (Patra-Athens-Thessaloniki) motorway and the western Ionian axis, to the rest of Greece. It is designed and built as a dual closed carriageway of international standards and comprises numerous long twin bridges, a large number of tunnels, 50 interchanges, 350 underpasses and overpasses, and 720 km of service roads. Moreover, it links all major urban centres, 4 ports and 6 airports (Egnatia Motorway Observatory, 2005).

Figure 1. Egnatia Motorway horizontal axis

At the national level, the Egnatia Motorway represents the backbone of the Northern Greek transport system, making it possible to break the isolation of remote Regions such as Epirus, Western Macedonia and Eastern Macedonia and Thrace. At the European level, it links Greece to Europe and the Middle East, while it operates simultaneously as a point of confluence for the merging transport flow from the Balkans and South-Eastern Europe. It is expected to operate as a zone of cooperation promoting selected economic activities, transport and energy networks, exchanges of technical knowledge, as well as the effective preservation of the environment and of cultural heritage. It is there that the Pan-European Corridors IV (Berlin-Sofia-Thessaloniki), IX (Helsinki – terminating at Alexandroupoli) and X (Vienna-Belgrade-Thessaloniki) terminate (Spiekermann & Wegener, 2006).

The importance of the project and the investment size necessitate supplementary actions, beyond construction, that would multiply benefits and mitigate the impacts from operation. It is necessary to monitor and assess the impacts of the Egnatia Motorway, not only on transports and the operation of the road network, but also on the economic, social and territorial cohesion, the environment, and the general spatial arrangement of the geographical zone crossed and influenced (Fourkas & Papasiopi, 2006).

In the present paper an integration among GIS functionalities and multi-attribute decision making models such as Analytic Hierarchy Process (AHP) (Saaty, 1977) is proposed in order to estimate the impacts provoked by the construction and operation of Egnatia Motorway in regional level. For that reason the 12 prefectures crossed by the motorway, are evaluated with the use of socioeconomic, environmental and transportation indicators. The proposed framework can be used as a valuable tool that allows public investments' evaluation in regional level, as well as inter-regional inequalities' estimations.

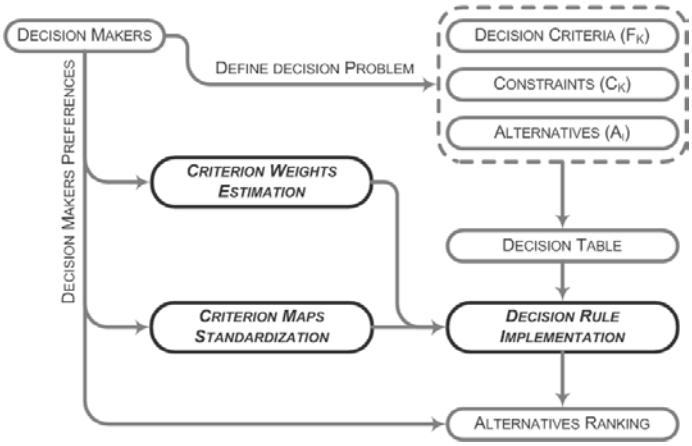

Figure 2, Decision making flowchart

2. Spatial Multicriteria Decision Analysis

Rational decision making is characterized by a coherent sequence of actions that ensures DMs from dubious results in the final outcome. The methodological framework, as it has been stated by H. Simon (1960), can be distinguished in three phases (Figure 2). In the intelligence phase, decision space is well stated by the objectives and sub-objectives identification, and constraints criterion maps determination. In the design phase, feasible alternative scenarios are determined performing Boolean overlays among the constraints criterion maps. After the analysis decision table formation, criterion maps relative importance is estimated and utilization procedures of the geographical data are performed. Finally, in the choice phase suitability index maps are derived as the synthesis result of the per criterion utilities under a certain decision rule implementation. Moreover, the stability of the final outcome is tested to changes regarding the former steps of the analysis, including either the consideration of new criteria or alternatives to stakeholders' preferences. When conflicts arise a compromise solution for implementation in the study area is identified.

At the most rudimentary level, GIS-based multicriteria decision analysis can be thought of as a procedure for combining geographical data and value judgments (the DMs preferences) to obtain information for decision making (Malczewski, 2006). Spatial multicriteria analysis aims to the ranking and/or the selection among candidate locations through estimations regarding a graded variation of suitability. The nature of the above integration is complementary given that GIS is a powerful tool for managing spatially referenced data, while MCDM methods are efficient tools for modeling spatial problems (Chakhar & Martel, 2003). Furthermore GIS based land use suitability evaluation expands the aspatial nature of traditional MCDM methods given that evaluation criteria vary across space. On the other hand MCDM allows the consideration of decision criteria allowing suitability mapping (Malczewski, 1999). The last is most commonly achieved by scaling attributes data to a common ratio scale and then to combine them by means of weighted average.

2.1 Analytic Hierarchy Process

Developed in the late 70s, AHP is a scaling method for deriving priorities (weights) for a set of activities according to their importance (Saaty, 1977). Since its release, the method has been widely used because it elicits DMs' preferences in a friendly and easily understood manner. As a procedure, AHP belongs to the family of methods that use pairwise comparisons in order to estimate relative preferences among decision analysis parameters in semi-structured decision problems. The method is based on three principles: the decomposition of the decision space to its fundamental elements, the comparative judgments, and the composition or synthesis of priorities.

The first of these principles is accomplished by breaking down the decision problem to its components by developing decision hierarchies. In general, the objectives tree is defined exclusively by the DMs aiming to represent their experience and intuition over the problem. Comparative judgments principle has to do with the development of a solid base for establishing priorities among the decision parameters. Local priorities are obtained by comparing qualitatively each node against each of its peers with respect to its parent node using the nine levels of the fundamental scale of preferences (Saaty, 1995). Technically this is achieved by forming pairwise comparison matrices $A = [a_{ij}]_{n \times n}$, where the ratio a_{ij} assigned by the DMs expresses the dominance relation of the factor in row i when it is compared against the factor in column j. The measure of the dominance relation is determined by using the strict preference (A_iPA_j) and indifference (A_iIA_j) preference structures (Equations 1,2). Consequently pairwise comparison matrices are positive and reciprocals (Equation 3), and the elements in the diagonal equal to 1 (Equation 4). Local (or relative) priorities or weights are then established as the principal eigenvalue $\lambda_{\max}$ of the pairwise comparison matrix solving the system of Equations 5. When the transitive property holds (Equation 6), the matrix is consistent and $\lambda_{\max}$ equals to n. Since in real-life situations it is quite rare to obtain consistent judgments by the DMs, AHP provides measures of inconsistency as a function of the deviation between $\lambda_{\max}$ and n.

$$A_i PA_j \rightarrow a_{ij} > 1 \quad (1)$$

$$A_i IA_j \rightarrow a_{ij} = 1 \quad (2)$$

$$a_{ij} = 1/a_{ji} \quad (3)$$

$$a_{ii} = 1 \quad (4)$$

$$(A - \lambda_{\max} I) \times w = 0 \quad (5)$$

$$a_{ij} = a_{ik} \times a_{kj} \quad (6)$$

2.2 Spatial Analytic Hierarchy Process

The framework for applying AHP in site suitability analysis studies, known as spatial AHP, has been firstly introduced by Banai-Kashani (1989) in the late 80s. According to this approach in a GIS environment, the overall priority Sj of an alternative location j is estimated as the weighted summation of the standardized criterion maps (Equation 7). As a procedure, standardization enables the transformation from the natural and constructed scales of measurement to the DMs' preferential system enabling the addition of commensurate attribute maps ensuring coherent results estimation. Standardization with respect to a specific objective can be performed using both relative and absolute measurements. Technically spatial AHP in GIS environment is implemented as the weighted average of the standardized attributes row data. Summarizing, the method is carried out in the following steps (Voogd, 1983; Malczewski, 1999):

Step 1: Analysis overall goal determination.
Step 2: Constraints implementation and alternatives determination.
Step 3: Define a consistent family of criteria for the alternatives evaluation and their spatial patterns (criterion maps).
Step 4: Standardize attributes row data x_{ij}.
Step 5: Obtain ratio weights w_j for the analysis decision criteria.
Step 6: Calculate the per criterion suitability index S_{ij} by multiplying standardized attributes row data x_{ij}^s with the corresponding criterion weight w_j.

Step 7: Generate suitability index S_i using the sum operator on the S_{ij}.

Step 8: Rank alternatives according to S_i.

$$S_i = \sum_{j=1}^{n} w_j r_{ij} \qquad (7)$$

3. Problem formation and Evaluation Criteria

3.1 Egnatia Motorway Observatory Indicators System

Egnatia Odos S.A. (EOSA) established and operates the Observatory of the Egnatia Motorway, which collects, processes, and provides valid and updated data regarding parameters in order to: (a) support the integrated management of the motorway, (b) contribute to the utilization of the project in the cohesion and development of a greater area, and (c) contribute to the harmonized assessment of TENs-T impacts on the cohesion of the European area (Vickerman, R., 2004).

A central element for the operation of the Observatory is the organization of the information system that provides a potential for recording, calculating, and monitoring of 50 various indicators. Raw data originate from official and reviewed sources except raw data for some traffic and environmental indicators originate from measurements undertaken by component EOAE Units. The indicators are compatible and comparable with the indicators used by basic EU programmes (ESPON, 2005; ASSEMBLING, 2005; EEA, 2004). The indicators concern specific properties and are grouped in three categories related to socio-economic and territorial changes, environmental impacts and the transport infrastructure and operation of the road network.

Figure3. Egnatia Motorway and the examined alternatives

Among these indicators, twenty have been chosen for this particular application and have been subjected to the necessary changes and modifications in order to become suitable for the purposes of the research. The examined influence zone includes the transit route of the axis, which is directly influenced. For its definition, the spatial level which is represented by the Prefectures is considered more useful in operational terms. Therefore, the transit route from the West to the East consists of the following twelve Prefectures, which are part of five Regions: Thesprotia, Ioannina (Region of Epirus), Trikala (Region of Thessaly), Grevena, Kozani, (Region of of Western Macodonia), Imathia, Thessaloniki, Serres (Region of Central Macedonia), Xanthi, Rodopi and Evros (Region of Eastern Macedonia and Thrace). This area covers 32.000 Km^2, representing 49% of the total surface of Regions and 24.5% of the national territory. According to the 2001 Census, the actual population adds up to 2.319.052 inhabitants. The Prefecture of Thessaloniki is the most populated of the Prefectures, since it concentrates 27% of the population.

3.2 Decision Hierarchy Formation

The need for performing MCDA approaches in order to gauge the examined prefectures occurs given that there is no effective solution that dominates all the others in the analysis. Figure 4, shows the rankings of the alternatives to the examined indices. Granted that, it is rather difficult for both practitioners and researchers to handle effectively the amount of information. In order to avoid the above drawback AHP is used in the present paper aiming to establish a composite index of suitability enabling thus sufficient ranking of the alternatives.

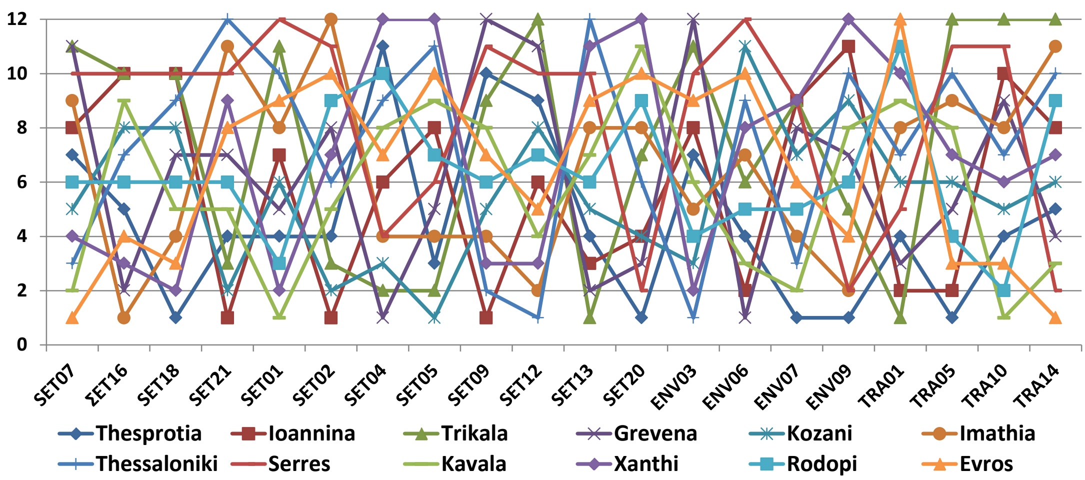

Figure 4. Alternatives profile to the analysis criteria

In order to enable coherent evaluations among the analysis objectives and subobjectives a five level hierarchy is formed (Figure 5). The first level consists of the analysis goal which is the effective ranking of the examined prefectures while in the last level is occupied by the analysis alternatives. The twenty indices that are used for the alternatives evaluation are grouped under socioeconomic, environmental and transportation objectives that should be improved by the Egnatia Motorway realization. Moreover socioeconomic objective is further subdivided into socioeconomic and planning indicators in order to build clusters that ensure coherent evaluations during the process of deriving relative priorities i.e. the contribution of each objective to the final outcome. Finally the contribution of each alternative to the indices satisfaction is standardized using the maximum score method (Voogd, 1983). The last is a linear utilization approach which allows sufficient transformation from the natural scales of measurement to the DMs' preferential systems and thus the performance of weighted average as decision rule for synthesizing the per criterion impact scores.

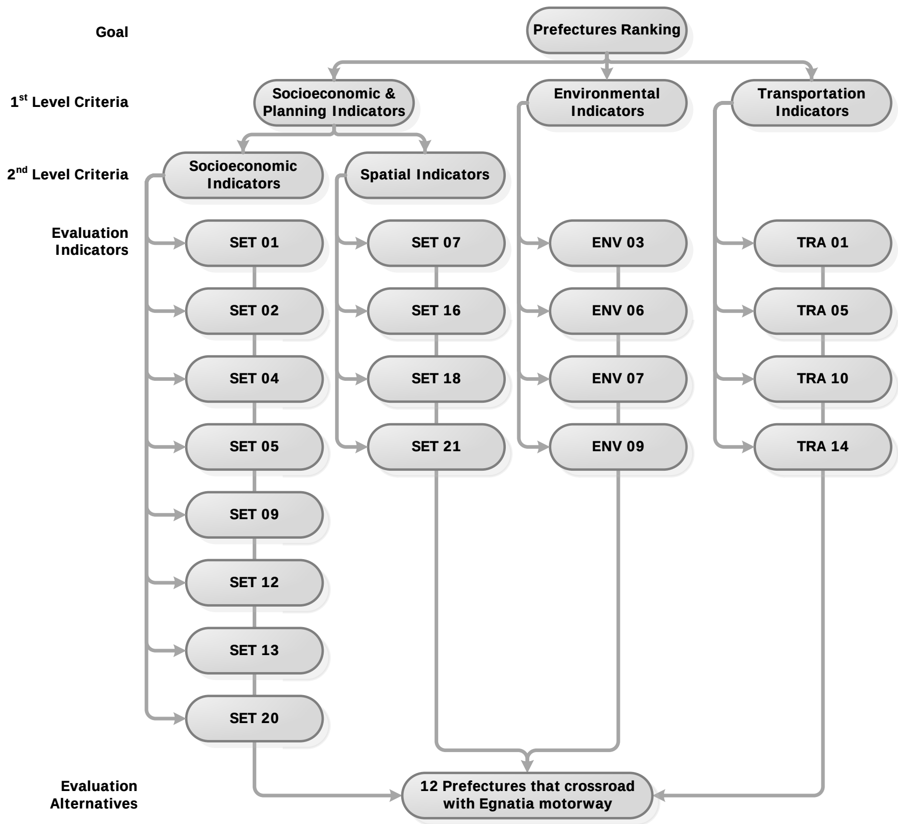

Figure 5. Decision hierarchy

3.3 Socioeconomic Indicators

SET01: It defines the percentage of 2011 population of every prefecture's municipalities which have the main axis of Egnatia Motorway passing within their boundaries comparing to the total population of the prefecture. The indicator's purpose is to assess the population which is potentially benefited directly from the road axis on the level of everyday trips.

SET02: It defines the Annual Average Domestic Product (GDP) 2000-2007 per prefecture. The improvement of transport infrastructure results in an increase of the production factors' mobility and markets' improvement of accessibility.

SET04: It records the average annual rate of change of the declared income per taxpayer 2002 – 2007 in constant prices 2000, per prefecture, as a factor of the area's level of development and prosperity.
SET05: It records the percentage of the unemployed change 2004-2008 per prefecture. The unemployment rate is considered to be one of the main indicators of the development status of a region.
SET09: It determines the population change 2001-2007, per prefecture. The objective of monitoring this indicator is the identification of the macroscopic effects of transport infrastructures improvement on the increase, retaining or decrease of a region's population.
SET12: It determines the change of density population 2001-2011 per Prefecture. Density is a basic indicator of the distribution of population in relation to the motorway's axis.
SET13: It records the Total Gross Value Added (GVA) Annual Rate Shift 2000-2007. The GVA is a basic structural characteristic of a regional economy and it is affected, among others, by the improvement of the movement of goods or the markets' accessibility.
SET20: It refers to the change of total work circle of the Enterprises 2000 – 2005, per prefecture. Entrepreneurship is potentially enhanced by the operation of transport infrastructure, as enterprises improve the accessibility and have an impact on increasing the production factors' mobility and on market integration.

3.4 Spatial Indicators

SET07: It records the distance (km) of the Industrial Areas and certain other productive infrastructure located in each prefecture from the closest intersection of the motorway. The optimum connection of the road network with the productive infrastructure is generally a basic development parameter of the productive activities.
SET16: It defines the percentage of change of urban land use (continuous, linear and un-continuous development) in the areas around the nodes of each prefecture.
SET18: It estimates the average change of land value 1998 – 2007 within the direct influence zone of the axis as well as in selected areas in each prefecture. The purpose of calculating this indicator is to examine the effects of the operation of the road axis on land value.
SET21: It records the change of attraction that takes place among the prefectures' capitals after the improvements in distance brought by the construction of Egnatia Motorway and depends on the exact distance from the road network before and after the operation of the Egnatia Motorway and on 2001 population.

3.5 Environmental Indicators

ENV03: It presents the change of fragmentation of organized settlements before and after the axis' operation per prefecture. The fragmentation of settlements is calculated as follows: [number of settlements] x [average permanent population] / [average area]x(1/100) and has important implications in their urban organization, proper operation as well as safety of their residents.

ENV07: It defines the change (%) of the technical surfaces along the Egnatia Motorway 1998 – 2007 per prefecture in the areas nearby the interchanges. The conversion of rural and natural land into technical surfaces is a cause of biodiversity loss and reduction of natural resources.
ENV08: It indicates the relation between the environmentally sensitive areas and the road network as well as the potential options that they would be affected by human activities.
ENV09: It captures the change in density of the crossings of the national road network with surface waters per prefecture (crossings/km), before and after the operation of the Egnatia Motorway and intents to identify the sensitive spots from the perspective of the potential impacts of the axis on water supply.

3.6 Transportation Indicators

TRA01: It records the change (%) 2000 – 2005 in the average daily distance travelled (in km) per prefecture of the vehicles that travelled between two successive interchanges of the Egnatia Motorway during one year. The traffic volume is the basic indicator for the depiction and examination of the movement on the axis.
TRA05: It estimates the change of the average time distance between the capital cities of each prefecture after the operation of the Egnatia Motorway by road means of transport. The time distance between these cities is a basic indicator for the estimation of the transport cost of persons and goods.
TRA10: It estimates the change of the average time distance between the prefectures' capitals after the operation of the Egnatia Motorway by road transport modes. The time distance between these cities is a key indicator for assessing the accessibility and provides basic information for the calculation of the transport cost of persons and goods.
TRA14: It records the change (%) of the trips 1996 – 2006 before and after the operation of the axis within the boundaries of each prefecture. The impacts of the axis on the trips' characteristics are related to the change in mobility, the trips' extension and the operational linkage of the areas.

Table 1. Analysis Scenarios Criterion Weights

	Crit. 1	Crit. 1.1	Crit. 1.2	Crit. 2	Crit. 3
Scenario 1	0,540	0,333	0,667	0,297	0,163
Scenario 2	0,333	0,333	0,667	0,333	0,333
Scenario 3	0,333	0,500	0,500	0,333	0,333
Scenario 4	Each index derives a weight of 1/20=0,05				

4. Results analysis and discussion

In the present four scenarios are examined according to the estimation of the criterion weight. In the first (Scenario 1) the relative importance is estimated through the performance of pairwise comparisons as it is imposed by the AHP. On the other hand the last scenario (Scenario 4) considers the case where all the analysis indices correspond equally to the analysis. Scenarios 2 and 3 correspond to compromise situations. In particular scenario 2 reflects the situation where the first level criteria are of equal importance while the third scenario the previous assumption to the second level criteria as well. Table 1 summarises the weights for each evaluation scenario.

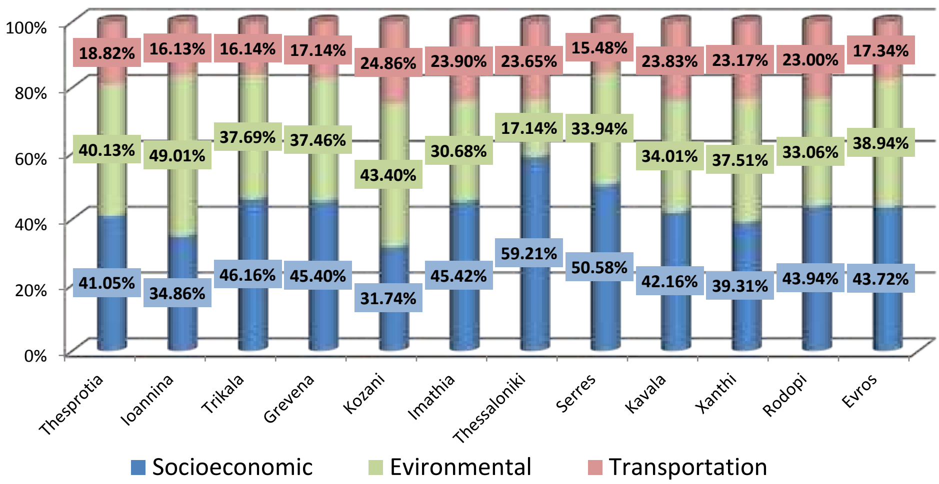

Figure 6. First level criteria impact to the prefectures rankings

With respect to the first Scenario (AHP) it is noted that for the majority of prefectures, the socioeconomic criteria have the highest impact on their final ranking (Figure 6). Exceptions are the prefectures of Ioannina and Kozani the performance of which on the environmental and transportation indicators impacts more on their final ranking. This can be explained by the fact that these prefectures include areas of outstanding natural beauty and moreover, they have significantly improved their transportation infrastructure. It is worth mentioning that the ranking of Thessaloniki Prefecture which includes the metropolitan area and adds up to around one million inhabitants, is mainly shaped by the socioeconomic indicators and secondarily by the transportation ones.

The rankings of the twelve prefectures to the examined scenarios of the analysis are presented in Figures 7. From the spatial distribution (Figure 8) of the suitability index it is obtained that Thesprotia and Kavala prefectures are ranked in the first two places while Trikala and Serres are ranked last to all the analysis scenarios. Thesprotias' ranking can be explained by the fact that emerges as one of the most important entrance gates in Greece given the presence of significant port infrastructure. Respectively, the role of Egnatia Motorway seems to be less beneficiary for Trikala and Serres given that only a limited part, close to their administrative borders, is crossed by the horizontal axis.

With respect to the differences that occur in the alternatives ranking, it is noticeable that Evros which is ranked 10th and 9th to the first two scenarios, is ranked 3rd in scenario 3. On the contrary Ioannina suffers the most in the third scenario ranked in the 9th place from the 4th that possesses in the first two scenarios. The above can be explained by the good performance that receives Evros prefecture to the environmental and transportation indices that gain high relative importance to the third scenario. Regarding to the other prefectures the changes to the ranking series it is not noticeable. Shortly, Kozani Prefecture remains in the 3rd ranking place while three others (Rodopi, Grevena, Imathia) improve their rankings by one place, while two other are downgraded by two places (Thessaloniki, Xanthi).

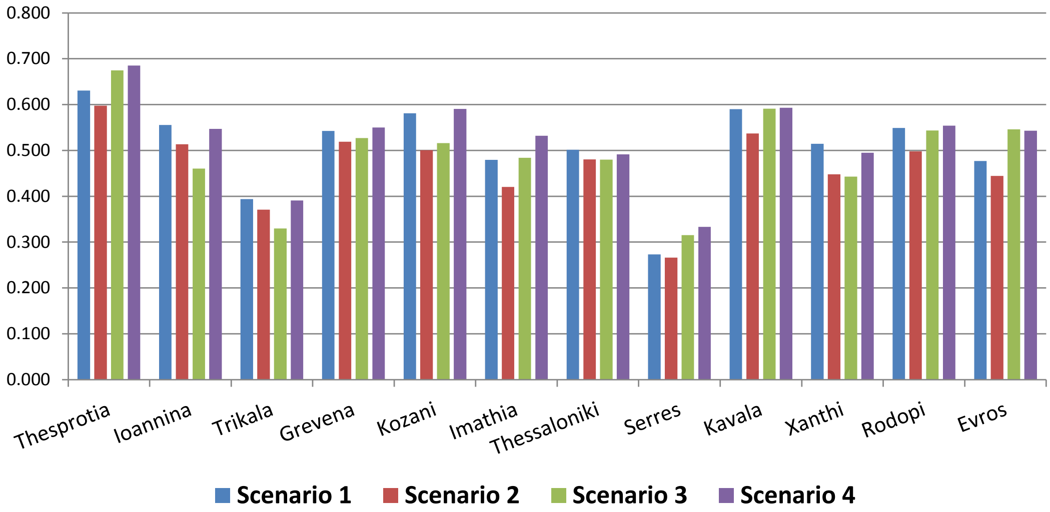

Figure 7. Prefectures rankings to the analysis scenarios

5. Conclusions

The realization of Egnatia Motorway consists one of the most important intervention that have been utilized in northern Greece during that last two decades aiming to enrich connectivity among the capital cities and with the major international transportation axes. Since the establishment of the Observatory services by the Egatia Odos S.A. a variety of socioeconomic, environmental and transportation indices have been developed in order to monitor and assess the spatial impacts of the motorway. In the present twenty of these indices are combined in order to derive a composite index for ranking the prefecture that crossroad with the horizontal axis of the motorway. Technically this is achieved combining GIS technology and Multicriteria Decision Analysis methods. The approach combines GIS abilities for managing and visualizing spatial data while AHP provides a consistent framework for the integration of decision makers' preferences to the planning of future interventions. The above synergy allows practitioners and policy makers to identify and visualize the impacts provoked by the operation of significant public works and in the same time to identify the presence of intraregional inequalities. Thus, the proposed approach can be proved significant in order to support future decision related with the planning of future interventions in the examined area.

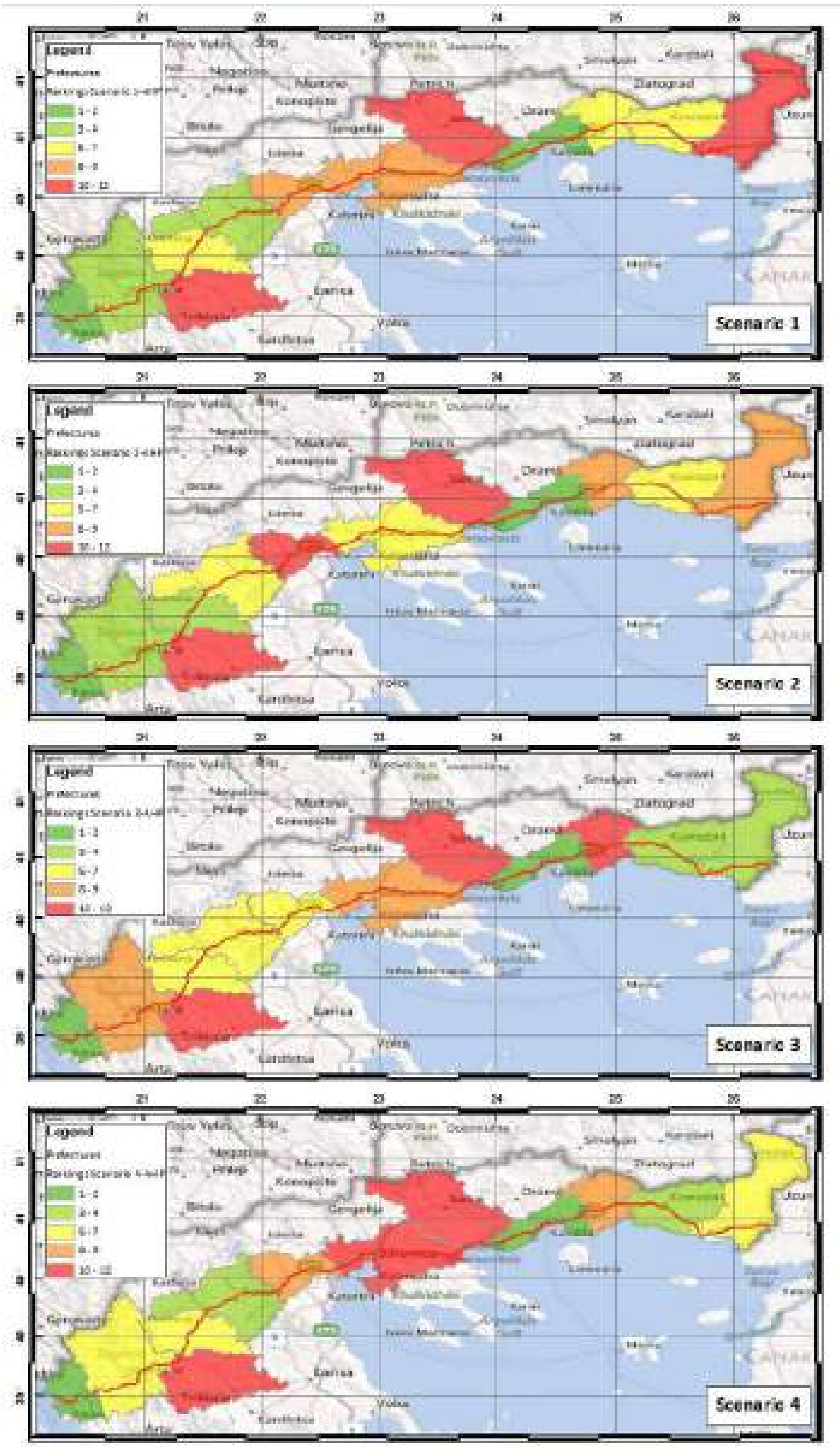

Figure 8. Prefectures rankings according to the examined scenarios

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