Multicriteria evaluation of transportation infrastructure projects: the case of Eastern Macedonia and Thrace region

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Abstract

In this paper the Analytic Hierarchy Process is used in order to evaluate priorities for the planned transportation infrastructure projects in the Eastern Macedonia and Thrace region. This evaluation is in accordance with the region’s development objectives as determined by the Regional Operation Plan and the 3rd Community Support Framework. Two different hierarchies, one for the benefits and one for the costs, are formed and the rank of a project is determined by its benefit-cost ratio. The proposed projects can be divided into three categories, depending on their benefit-cost ratio.

1 Introduction

The resulting development from the uncoordinated construction of transportation infrastructure works in a region can cause a wide range of pressures. The pursuit of the desirable development in the transportation field through processes that recognise the significance of spatial dimension, under conditions that protect the natural and cultural environment, has already started to become noticeable from the constitutions of relevant responsibilities. The need to maximize the benefits resulting from the planned interventions in a region imposes not only the coordination of the actions taken on a national or regional level towards this direction, but also the establishment of priorities in the realisation of the proposed projects.

This paper aims in determining the priorities of the 69 projects of the 3rd
Community Support Framework in order to serve the development goals of the Eastern Macedonia and Thrace region, a bordering region in the Northeast end of Greece. These goals are in accordance with the land-planning policy of the 3rd Community Support Framework and the Regional Operational Plan, with emphasis on the sustainable development [1]. A particular emphasis is given on the dynamic development of the region's six urban centers, which have a restricted population basis, low range and they do not respond to their functional role.

The evaluation of the transportation infrastructure works was based on a benefit-cost analysis for which the multicriteria method Analytic Hierarchy Process (AHP) was used [2, 3, 4]. The AHP has been selected due to its efficacy in analyzing a problem by decomposing it into subsystems, its inclusion of possible interactive effects and its power to handle several criteria. The application of the method was supplied by data deriving from a Ministry of National Economy study [5] as well as the recent Eastern Macedonia and Thrace Development Plan, in which the demographic, social, urban and environmental characteristics of the region are fully analyzed [6]. The hierarchies structuring, the checking of the inconsistencies of the judgments and the sensitivity analyses were realised using Expert Choice 9.0, a software package developed for AHP analysis.

2 The Analytic Hierarchy Process

AHP is a systematic procedure for dealing with complex decision-making problems in which many competing alternatives (projects, actions, scenarios) exist. The alternatives are ranked using several quantitative and/or qualitative criteria, depending on how they contribute in achieving an overall goal.

AHP is based on a hierarchical structuring of the elements that are involved in a decision problem. The hierarchy incorporates the knowledge, the experience and the intuition of the decision-maker for the specific problem. The simplest hierarchy consists of three levels. On the top of the hierarchy lies the decision's goal. On the second level lie the criteria by which the alternatives (third level) will be evaluated. In more complex situations, the main goal can be broken down into subgoals or a criterion (or property) can be broken down into subcriteria. People who are involved in the problem, their goals and their policies can also be used as additional levels.

The hierarchy evaluation is based on pairwise comparisons. The decision-maker compares two alternatives \( A_i \) and \( A_j \) using a criterion and assigns a numerical value to their relative weight. The result of the comparison is expressed in a fundamental scale of values ranging from 1 (\( A_i \) and \( A_j \) contribute equally to the objective) to 9 (the evidence favoring \( A_i \) over \( A_j \) is of the highest possible order of affirmation). Given that the \( n \) elements of a level are evaluated in pairs using an element of the immediately higher level, a \( n \times n \) comparison matrix is obtained. If the immediate higher level includes \( m \) criteria, \( m \) matrices will be formed. In every comparison matrix all the main diagonal elements are equal to one (\( a_{ii} = 1 \)) and two symmetrical elements are reciprocals of each other (\( a_{ij} \times a_{ji} = 1 \)).

The decision-maker's judgements may not be consistent with one another. A comparison matrix is consistent if and only if \( a_{ij} \times a_{jk} = a_{ik} \) for all \( i, j, k \). AHP
measures the inconsistency of judgments by calculating the *consistency index* $C_1$ of the matrix

$$C_1 = \frac{\lambda_{\text{max}} - n}{n - 1}$$

where $\lambda_{\text{max}}$ is the principal eigenvalue of the matrix.

The consistency index $C_1$ is in turn divided by the *average random consistency index* $RI$ to obtain the *consistency ratio* $CR$.

$$CR = \frac{C_1}{RI}$$

The $RI$ index is a constant value for an $n \times n$ matrix, which has resulted from a computer simulation of $n \times n$ matrices with random values from the 1-9 scale and for which $a_{ij} = 1/a_{ji}$. If $CR$ is less than 5% for a $3 \times 3$ matrix, 9% for a $4 \times 4$ matrix, and 10% for larger matrices, then the matrix is consistent.

Once its values are defined, a comparison matrix is normalized and the local priority (the relative dominance) of the matrix elements with respect to the higher level criterion is calculated. The overall priority of the current level elements is calculated by adding the products of their local priorities by the priority of the corresponding criterion of the immediately higher level. Next, the overall priority of a current level element is used to calculate the local priorities of the immediately lower level which use it as a criterion, and so on, till the lowest level of the hierarchy is reached. The priorities of the lowest level elements (alternatives) provide the relative contribution of the elements in achieving the overall goal.

### 3 Evaluation of projects

#### 3.1 The Eastern Macedonia and Thrace region

The Eastern Macedonia and Thrace region occupies the NE end of Greece, bordering on Turkey to the East, Bulgaria to the North, the Central Macedonia region to the west, while to the south lies the Aegean Sea.

The region consists of 5 counties, occupies an area of 14,154 km$^2$ (10.7% compared to the whole of Greece) and its population reaches 561,838 inhabitants (5.3% of Greece’s population) (National Statistic Agency of Greece estimation, 1998).

The region’s urban centers are situated on the basic transport network and with the exception of Orestiada, the smaller (population of 15,000) and newer (1922) extremely bordering urban center, consist a grid whose elements lie either on the plains (Drama, Xanthi, Komotini) or are situated by the coast and serve as ports (Kavala, Alexandroupoli). These centers are 50-60 km apart one another and characterized by the same population range (40,000 people, Kavala being the bigger with a population of 60,000) [7].

The Eastern Macedonia and Thrace region’s intra- and inter-regional relations of major significance have been formed during the course of time according to the national and historical circumstances of the country and the region in particular. The region’s geographical position in combination with the presence of national and inter-european transport networks, the natural and man-made envi-
vironment, the available natural resources (water potential, mining wealth) and the newly acquired industrial basis due to investment motives can be considered as competitive advantages in forming a development strategy. On the other hand, the negative population evolution and macroeconomic magnitudes that are intensified by their unequal spatial distribution can be considered as limitations [1].

The 3rd Community Support Framework is expected to finance facilities of functional organisation and exploitation of the already planned projects (which are not included in the present planning data) and also to promote the development of combined transport systems.

The already planned and in progress projects mainly concern the completion of the Egnatia Road (inter-european road axis with 680 km of total length, 258 km of which are developed within the region) and the upgrade and expansion of the two national significance ports and the two state civil airports of the region.

The projects under evaluation concern: a/ Vertical connections between Egnatia road and the urban centers, the airports, the ports and other areas of activities development, b/ Port infrastructures mainly for the development of tourism, c/ Completion-improvement of the present transportation axis, reinforcement of the counties’ road network, and d/ Updating of the railway network as well as its expansion and connection with the ports and industrial areas of the region.

3.1.1 The hierarchy for the benefits
To approach this particular problem two hierarchies are formed, one for the benefits and one for the costs that arise from the realisation of the projects. For every project two priorities will occur from these hierarchies: one based on their contribution to the overall benefit and one based on their effect on the overall cost. These projects will be ranked by forming the ratio of these two priorities.

The evaluation of the proposed projects is carried out based on the optimistic scenario of the social and economic records of the area, which is in accordance to the land-planning policy of the 3rd Community Support Framework. This development is characterised by completion of the big-scale projects, decrease of time-distances and new connections with Bulgaria. Here appears to be an improvement in competitiveness and simultaneously the functional organising of the urban centers is reinforced. The region is upgraded in its new inter-regional-Balkan role and the public sector is reinforced by according services. The Regional Organization is characterized by wise management of natural resources, evolving urban planning and improvement of living quality.

The hierarchy of the benefits is formed into four levels: On the first level lies the overall benefit from the realisation of the works, as the main goal of the hierarchy. On the second level lie the problem’s economic, social and environmental components. On the third level of hierarchy lie the subcriteria in order to obtain a more comprehensive description of the problem so that the study will acquire an overall view of its parameters. In detail, the economic benefits is formed by:

- The competitive restructuring of the region through promotion and acceleration of the productive sectors’ rationalisation, with priority to activities lending competitiveness and flexibility.
The connection with the broader economic area, in order the region to act as a base through the European mainland in combination with the attract of international and investment interest. In this framework, the emergence of the regional urban centers' development role and the amplification of the relations with the markets of the broader area are pursued.

The increase in jobs, as a result of the productivity growth, the articulation of the population pyramid and the rising of living standards. The social benefits is formed by:

- The assuring of safety, reliability and comfort in transport, with a consequent reduction of traffic accidents.
- The facilitation of intraregional communications by incorporating the highlands or the insular areas and their inhabitants to the social tissue.
- Time saving as a result of the reduction of transport time.
- The strengthening of the infrastructures with supplementary actions in already tailored infrastructures or infrastructures that already belong to the region's planning.

The environmental benefits is formed by:

- The emergence and upgrading of natural landscape areas.
- The accessibility of the natural environment (reinforcement of fire protection,
wiser management of the natural resources etc).

Figure 2: The analytic hierarchy for the costs.

- Aesthetic considerations.
  On the last hierarchy level the intensity scales of the subcriteria by which the proposed projects are evaluated, are placed. In this application three intensity scales are used: high, medium and low (intensity A, B, C respectively).

3.1.2 The hierarchy for the costs
On the first level lies the overall cost from the realisation of the projects, as the main goal of the hierarchy. On the second level several economic, social and environmental costs, resulting from the planned interventions, are used as criteria. On the next level the subcriteria of the aforementioned level are placed. The economic cost is formed by:
- The investment cost.
- The maintenance and operation cost after the completion of construction.
- The economic consequences by abandoning or downgrading activities that were directly associated with the use of the infrastructures being replaced.

The social cost is formed by:
- The surcharge of the built environment to the limits of the new interventions.
due to the increment of vexation, the arbitrary building, etc.

Table 1: Results of the hierarchy for the benefits.

<table>
<thead>
<tr>
<th>Positive impacts</th>
<th>Normalized eigenvectors</th>
<th>Composite relative priorities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>0.649</td>
<td>0.649</td>
</tr>
<tr>
<td>Social</td>
<td>0.202</td>
<td>0.202</td>
</tr>
<tr>
<td>Environmental</td>
<td>0.149</td>
<td>0.149</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Subcriteria</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Restructuring</td>
<td>0.101</td>
<td>0.065</td>
<td>0.04459</td>
</tr>
<tr>
<td>Connection</td>
<td>0.674</td>
<td>0.437</td>
<td>0.29978</td>
</tr>
<tr>
<td>Increase in jobs</td>
<td>0.226</td>
<td>0.146</td>
<td>0.10015</td>
</tr>
<tr>
<td>Safety and reliability</td>
<td>0.050</td>
<td>0.010</td>
<td>0.00700</td>
</tr>
<tr>
<td>Communication</td>
<td>0.244</td>
<td>0.049</td>
<td>0.03430</td>
</tr>
<tr>
<td>Time saving</td>
<td>0.139</td>
<td>0.028</td>
<td>0.01960</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>0.567</td>
<td>0.115</td>
<td>0.08050</td>
</tr>
<tr>
<td>Upgrading landscapes</td>
<td>0.188</td>
<td>0.028</td>
<td>0.01803</td>
</tr>
<tr>
<td>Accessibility</td>
<td>0.714</td>
<td>0.106</td>
<td>0.06826</td>
</tr>
<tr>
<td>Aesthetic</td>
<td>0.099</td>
<td>0.015</td>
<td>0.00966</td>
</tr>
</tbody>
</table>

- The cost of modernisation.
- The rise of government and municipal taxes.
- The environmental cost is formed by:
  - The pollution increase.
  - The distortion of the ecosystem.
  - The downgrading of the human and natural environment.

On the last hierarchy level, the intensity scale of the subcriteria is formed in a similar way with the benefits hierarchy.

3.2 Hierarchies evaluation

Two pairwise comparison matrices, one for each hierarchy, are formed in order to calculate priorities for the second level criteria. The priorities of the economic, social and environmental factors have been calculated to hold the values 0.649, 0.202 and 0.149 for the benefit hierarchy and 0.656, 0.207, 0.137 for the cost hierarchy respectively (fig. 3 and 4).

In the next step, the subcriteria are evaluated, via six pairwise comparison matrices, three for each hierarchy, according to their relative importance to the criteria. The economic subcriteria for the benefit hierarchy acquire the priorities of 0.101, 0.674 and 0.226, with respect to the economic criterion, and 0.065, 0.437, 0.146 with respect to their contribution to the overall goal of the hierarchy. Similarly, the social subcriteria for the cost hierarchy are evaluated with priorities of 0.181, 0.729 and 0.09 with respect to their contribution to the social cost and with 0.037, 0.151 and 0.019 with respect to their contribution to the
Afterwards the contribution of intensity scales to each subcriterion is also evaluated. For this purpose nineteen pairwise comparison matrices, ten for the benefit hierarchy and nine for the cost one, are formed. For example, for the increase in jobs subcriterion, the priorities of the intensity scales A, B, C based on their contribution in the overall benefit, acquire the values of 0.10015, 0.036 and 0.0099, respectively. The overall priority calculated for a project is formed by the sum of the intensity scales priorities with which it participates in the satisfaction of every subcriterion.

The final ranking of a proposed project is formed by its priority resulting from the benefit hierarchy to its respective priority from the cost hierarchy.

4 Conclusion

In this paper a multicriteria evaluation of the 3rd Community Support Framework projects with the Analytic Hierarchy Process is presented in order to serve the development goals of the Eastern Macedonia and Thrace region. This method can significantly contribute to the rationalization of decision making.

The final ranking of the proposed projects presents a particular interest. The projects can be divided in three categories depending on their benefit-cost ratio. In the lowest category belong all projects with a benefit-cost ratio up to 1.25. In these projects the priorities are formed by their low contribution to the benefits' criteria despite their similarly low cost, while projects with high contribution to benefits criteria show a high cost as well.

In the second group, consisted of projects with priorities ranging from 1.25 to 1.7, belong all projects that are characterized by low cost and relatively high contribution to criteria of medium priority (e.g. the entirety of the social and envi-
ronmental benefits) as well as to a high priority criterion. In this last case, a high operation and maintenance cost, a rise in taxes and a surcharge of the build environment appear mostly.

The third group includes high priority projects that are characterized by a satisfactory and in some cases a high contribution to the entirety of high dominance criteria (31 out of 69 projects). The criteria that strengthen this group are the connection of the Region with the broader economic region, the increase in jobs, the strengthening of the infrastructures and the accessibility to the natural environment.

In spatial terms, the third group projects are equally distributed among the three counties of the region, while a slight supremacy can be observed in the remaining two. In detail, 6 belong to Evros county, 4 to Rodopi county, 5 to Xanthi county, 9 to Kavala county and 7 to Drama county. The overall priority for the projects in Kavala and Drama is due to the necessity of constructing the vertical and complementary to Egnatia roads which will strengthen the connection of the region with the broader economic area and especially with Bulgaria, while contributing as well to a more competitive restructure of production.

In relation to the urban centres, a framework of nine interventions exists for the completion of projects that emancipate and reinforce their local activity. Five of these interventions are located in Drama county in order to ensure the connection of the county with Egnatia road and to construct road axes to Bulgaria, and the rest are distributed to the remaining counties of the Region.

In more detail, nine projects concern interventions to the national network, that runs through the region horizontally, two projects concern the formation of detours and the improvement of the urban centers entrances and exits. The 17 remaining projects directed in interventions for the development of provincial roads in order to boost up the local production and to develop commercial activities with the border countries. These projects also contribute to the administrative unification of the municipal departments that form the new municipal structure. High priority is calculated for the projects of portal facilities (3 projects) as well, due to their contribution to restructuring the production, facilitating the endo-regional communication and tourist exploitation of the Region’s resorts.

Finally, the benefits-to-cost ratio of the railroad infrastructure projects is small, not only due to their high construction cost but also due to the high priority of that cost in respect to the other criteria. However, because of the fact that the benefits priority is high, it is concluded that the realisation of these projects will, in the future, positively affect every social-economic indicator.

References

[3] Saaty T.L., Vargas L.G., Decision Making with the Analytic Hierarchy Proc-

