Evaluation of a transportation project with the analytic hierarchy process: best parking angle selection

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Abstract

The design, planning and construction scheduling of the infrastructure works to meet the needs for the Olympic Games of 2004 in Athens are major challenges that the engineers of our country are faced. The location of facilities and the organisation of the transportation system of the capital are prerequisites for the even waging of the Olympic Games. In this paper the Analytic Hierarchy Process is used for the alternatives evaluation for an Olympic transportation project in order to estimate spatial parameters, such as the parking angle, for the facilities of Olympic Tennis Stadium.

1 Introduction

It is well known that the methodological approach for the planning and the operation in Parking Areas constitutes an issue of high scientific and financial interest. When the planning is achieved without methodology, control, rationality and innovations, in specialised subjects important for the regular traffic, such as the pedestrians and vehicles safety, important problems arise [1, 2, 3, 4]. The heavy traffic and the without rules passing of pedestrians and vehicles, the lacks in the labelling are some of them. Planning of parking areas acquires even more interest when it is focused to the case of Stadiums in which the athletic events for the 2004 Olympic Games will take place.

In this paper we are dealing with the planning of a parking area, for the 10,000 spectators Tennis Olympic stadium, defining the principles of planning,
and the needs for safety and functional use at the duration of the games. The criteria are determined in order to evaluate the priorities of the alternatives concerning the overall goal, which is the selection of the optimal parking angle of the vehicles parking. The evaluation of the alternatives was based on a multicriteria approach for which the Analytic Hierarchy Process (AHP) was used. The AHP has been selected due to its efficacy in analysing 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 technical study in which the urban, engineering and environmental characteristics of the problem are fully analysed [5]. 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 [7, 8, 9]. 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 (\( A_i, A_j \) 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, an \( n \times n \) 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 CI of the matrix

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]
where $\lambda_{\text{max}}$ is the principal eigenvalue of the matrix.

The consistency index $CI$ is in turn divided by the \textit{average random consistency index} $RI$ to obtain the \textit{consistency ratio} $CR$.

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

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 normalised 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 Principles of planning

The diagram of flow, the determination of allowing movements, the traffic lane and the traffic nodes constitute important parts of the road network because its traffic capacity depends on the rational design in order to provide effectiveness, road safety, avoidance of the traffic tails, etc. For these reasons, the traffic regulation plan must satisfy the following parameters:

- Unhindered traffic flow.
- Safe traffic flow in order to separate and ensure the ways for the pedestrians and the vehicles.
- Sufficient traffic capacity in the diagram of flow, the roads, the nodes, the intersections, the parking areas and finally at the checkpoints.
- Acceptable construction and operational cost.
- Satisfactory adaptation in the requirements of Olympic installations, taking into account the existing road network as well as the requirements of the auxiliary tennis stadiums.
- Satisfactory adaptation in the architecture of the stadium and the environment.

The unhindered and safe traffic flow depends on the general regulation of the traffic (diagram of flow, the geometrical design, nodes, pavements, the labelling, etc). The safety of the traffic flow is depending on the system of the providing information to the users of the parking area (particularly to those that have not visited the auxiliaries or the country before) and the providing guidance to the drivers, at the entry and the exit to the space of tennis athletic installations. Taking into account that the arrival of the spectators, journalists and VIP's, is starting only a few minutes before the beginning of the event and the departure is tak-
ing place immediately after the end of the game, we should notice that the traffic flow which will be guided at the road network as well as to the pedestrian passages will be increased. As a consequence, the traffic capacity of the road network will be judged from the number of the movements that a driver need in order to park, so that excessive waiting time will not arise in the traffic of the vehicles and the buses as well.

The construction and operational costs are considered as acceptable when the total expenses of construction, operation and maintenance remain in low levels and at the same time it is ensured a high level of safety, traffic capacity and adaptation to the environment.

Figure 1: Parking with 60 and 70 degrees angle.

4 Parking angle and parking areas

Parking angle ($\theta$) is defined from the axis of the parked vehicle and the axis of passage access to the parking area (fig. 1). This angle defines the type of the parking area. Thus, accordingly with the values, that the angle receives, the following categories are determined:

- Parallel Parking ($\theta = 0^\circ$).
- Vertical Parking ($\theta = 90^\circ$).
- Parking with angle ($45^\circ \leq \theta < 90^\circ$).
Angles with values smaller than 45° are not recommended because of the large surfaces of manoeuvres that are created.

The use of angles in the parking allows increasing the parking ability for every meter in length of kerb. This advantage increases up to the vertical parking (θ = 90°), where 2.5 to 3 times more vehicles are served in contrast with the parallel parking. As long as the parking angle increases, bigger space of road surface is required because of the increase in the parking depth and the manoeuvres needed for a vehicle to park.

In the design of the whole transportation network concerning the spectators’ and athletes’ displacement from or to the stadiums has taken into account the under study parking area. The dimensions of the parking place are determined from the dimensions of a typical vehicle, the distances between the vehicles and the existing obstructions. The distance between the vehicles ensures a space of safety round the vehicle. This space is essential for the access, door opening and the essential manoeuvres while leaving the stadium.

The choice of width for each parking place is determined by taking into account the types of cars and the needs of persons that are going to make use of the parking area. In Greece it is mentioned that the distance between two vehicles will be 0.70 m. For the determination of depth for each parking place it is essential to determine two depths: one for the case of parking place next to a wall, a kerb or any kind of obstacle and another for the case of parking place next to a neighbouring place in which the depth is limited.

5 The problem hierarchy

The hierarchy in order to approach the problem is structured in four levels (fig.
2). On the first level lies the overall goal, i.e. the selection of the optimal parking angle. On the second level of the hierarchy lie the basic criteria that are used for the evaluation of the alternatives. These criteria are the traffic criteria, the safety assurance of the pedestrian passages, the environmental and architectural component and finally the cost of the project. The cost criterion includes not only the capital cost but also the maintenance and operational costs.

Table 1: Results of the hierarchy.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Normalized eigenvectors</th>
<th>Relative Composition Priorities</th>
<th>Normalized eigenvectors of the scenarios according to the criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic</td>
<td>0.511</td>
<td>0.511</td>
<td>Scenario 1 0.153 Scenario 2 0.372 Scenario 3 0.334 Scenario 4 0.344</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>0.392</td>
<td>0.392</td>
<td></td>
</tr>
<tr>
<td>Environmental &amp; arch.</td>
<td>0.153</td>
<td>0.153</td>
<td></td>
</tr>
<tr>
<td>Costs</td>
<td>0.045</td>
<td>0.045</td>
<td></td>
</tr>
<tr>
<td>Reliable service</td>
<td>0.451</td>
<td>0.246</td>
<td>0.500 0.167 0.167 0.167</td>
</tr>
<tr>
<td>Tim saving</td>
<td>0.078</td>
<td>0.040</td>
<td>0.500 0.167 0.167 0.167</td>
</tr>
<tr>
<td>Regular traffic flow</td>
<td>0.078</td>
<td>0.040</td>
<td>0.500 0.167 0.167 0.167</td>
</tr>
<tr>
<td>Complications &amp; obstr.</td>
<td>0.108</td>
<td>0.188</td>
<td>0.500 0.167 0.167 0.167</td>
</tr>
<tr>
<td>Parking of pedestrians</td>
<td>0.833</td>
<td>0.243</td>
<td>0.600 0.200 0.300 0.300</td>
</tr>
<tr>
<td>Minimum distance</td>
<td>0.167</td>
<td>0.049</td>
<td>0.093 0.476 0.354 0.177</td>
</tr>
<tr>
<td>Green places</td>
<td>0.109</td>
<td>0.115</td>
<td>0.141 0.455 0.263 0.141</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>0.250</td>
<td>0.038</td>
<td>0.696 0.140 0.082 0.241</td>
</tr>
<tr>
<td>Total Priorities</td>
<td>0.396</td>
<td>0.235</td>
<td>0.193 0.176</td>
</tr>
</tbody>
</table>

The third level is consisted of subcriteria in order to obtain a more comprehensive description of the problem.

In detail, the traffic criterion is formed by:

- The assurance of safety and the reliable service for the vehicles.
- The avoidance of manoeuvres causing the bad positioning of the vehicles in the parking place.
- The assurance of traffic flow under normal conditions into the parking area.
- The avoidance of complications and obstacles to the mass transport system.

The subcriteria that characterise the safety for the pedestrians are:

- The assurance of safe passages for the pedestrians and handicapped people from/to the stadium and to/from the parking area.
- The minimisation in the walking distance.

The subcriteria that characterise the environmental and architectural parameters are:

- Green areas.
- Aesthetic parameters and the adaptation to the stadium architecture (circular elements).

The evaluation of the hierarchy parameters is taking place in order to rate the alternative scenarios, which are placed at the last level of the hierarchy. In our model four scenarios are evaluated: scenario 1 (θ = 90°), scenario 2 (θ = 45°), scenario 3 (θ = 60°), and scenario 4 (θ = 75°). The best results are achieved with the use of three main tools. Firstly, the matrices of pairwise comparisons are formed. Secondly, the parameters are evaluated using the Analytic Hierarchy Process weight scale. Finally, the consistency of the pairwise comparison matrices is examined.
The final ranking of the alternatives is formed by the sum of the relative composite priorities. In order to derive the relative priorities, we multiply the normalised eigenvectors of each scenario by the corresponding relative priority of the subcriteria. From the final ranking of the alternatives (table 1), we conclude that scenario 1 with a total priority of 39.6% is the most preferred.

6 Conclusions

The main objective of this paper is to present the advantages of the multicriteria analysis in the design of engineering projects, especially when it is difficult to obtain a mathematical formulation. Alternative scenarios according the specifications were formed in order to determine the best parking angle. The Analytic Hierarchy Process method was used to modelise the problem and to evaluate the priorities of alternatives according the criteria, which concern the parameters of traffic, security for the pedestrians, vehicles movements, the environmental standards, the architectural design and the cost parameters.

References