Eighth International Conference on Construction in the 21st Century (CITC-8)
"Changing the Field: Recent Developments for the Future of Engineering and Construction"
May 27-30, 2015, Thessaloniki, Greece

Comparative evaluation of alternative design concepts of the "Underwater Road Artery of Thessaloniki" by using the AHP Multi-criteria method

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Abstract

The large-scale project of "Thessaloniki Underwater Road Artery", which has been under discussion since the mid-1980s, was intended to bypass the center of Thessaloniki by the side of Thermaic Gulf, and decongest the city center by receiving most of the East-West car traffic. In the present study two alternative design concepts of the above project, proposed in different periods, are comparatively examined. The first design concept consists of an underwater tunnel across the Thermaic Gulf, whose western end will be at the port area in West Thessaloniki, while the eastern end will be close to the "Makedonia Pallas" hotel, in Central East Thessaloniki. The second concept provides a significant extension of the aforementioned underwater tunnel, combined with an additional long floating bridge which ends up in East Thessaloniki in the district of Kalamaria, functioning as a peripheral ring road. The purpose of this study is to perform a comparative evaluation of these two alternative design concepts, using multi-criteria analysis and specifically the method of Analytic Hierarchy Process (AHP). In the context of this analysis, the hierarchy of the problem is structured, while suitable criteria that concern the main impacts of large-scale road projects are considered. Depending on the extent of their correspondence with these weighted criteria, the two design concepts are evaluated in a systematic way. The design project with the highest ranking is proposed for implementation.

Keywords

Underwater Road Artery, Comparative evaluation, Multi-criteria analysis, Analytic Hierarchy Process, Decision making

1. Introduction

Large-scale complex construction projects, such as an underwater road artery, apart from their high construction cost, are also related to a number of multiple impacts on the project's area of influence, on the daily life of the population, on the quality of life, on the environment, etc. In that sense, it is of great importance to ensure the sustainable design of these projects, as well as the selection of the best design solution among all possible alternatives, by using a reliable method.

In the context of the present study, the project of Thessaloniki Underwater Road Artery is being examined. The above large-scale project has been intended to constitute a road artery that will bypass the center of Thessaloniki by the side of Thermaic Gulf, in order to decongest it in terms of traffic and to

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carry most of the East-West traffic loads, which currently have to cross the city center. It is worth mentioning that the project of the Underwater Artery was included in the Master Plan of the greater area of Thessaloniki (1985), as well as in the General Urban Plan of the Municipality of Thessaloniki (1993). What follows is the presentation of the two main alternative design concepts of the project, which were proposed in different periods, while they are characterized by a different degree of maturity. These two design concepts will be comparatively evaluated by using multi-criteria analysis, according to their contribution to the achievement of an Overarching Objective, which in the context of this study is defined as "Traffic improvement in Thessaloniki".

2. The first design concept of the Project

The first design concept of the project was named "Thessaloniki Submerged Tunnel" (for brevity, "Solution 1" in the context of the study) and it progressed to the level of preliminary design (METE-SYSM, 1999), while it was approved in 2006 by the Ministry of Environment, Physical Planning and Public Works. However, due to various conflicts, combined with some unquestionable technical difficulties, funding problems and consecutive delays, its implementation reached a stalemate in 2009.

2.1 Route description of the Road Artery

The road layout of Solution 1 provides a new link between the Western Entrance of Thessaloniki and Megalou Alexandrou Avenue, bypassing the city center partially underground but mostly underwater. More specifically, the Artery will start from Koletti Street at the Western Entrance of the city and then, near the building of the Administrative Court of Thessaloniki it will proceed underground, heading south-eastwards. Thereafter the Artery will run through the Gulf of Thessaloniki in the form of an underwater tunnel alongside the seafront, at a distance of 80-120 m. away from it. The tunnel will emerge eventually at street level right after the "Makedonia Palace" Hotel, joining into Megalou Alexandrou Avenue (where the tunnel exit is located), until the Artery ends at the junction with P. Syndika Street.

Figure 1: Road layout of the first design concept of the Underwater Artery

2.2 Geometric and technical characteristics - Construction cost of the Project

The proposed Artery is planned as an expressway with a total length of 6.5 km. Approximately 4 km of them, which constitute the 6-lane main body, will be in a tunnel (including 1,5 km immersed tunnel under Thessaloniki harbour basin and approximately 2,5 km cut & cover tunnels and ramps at either end of the immersed tunnel). The underwater section is to be constructed by the immersed tube method, while the roof of the tunnel will be at least one meter underneath the seabed. As far as its budget is concerned, the construction cost of "Thessaloniki Submerged Tunnel" amounted to 472 million euros (2006).

2.3 Connections to the existing road network - Urban and traffic interventions

The Artery of Solution 1 will have entrances and exits on both sides of the city center. At its western end, apart from its main 2-lane entrance/exit (Western Entrance of Thessaloniki), an additional access road from Kountouriotou Str. to the Artery is planned, as well as an additional exit road in the opposite direction, towards Polytechniou Str. Correspondingly, at the eastern end of the Artery, other than the main 2-lane entrance/exit (Megalou Alexandrou Ave.), an additional access road from the junction of Stratou Ave. and Kaftantzoglou Str. is planned.

Moreover, the project of "Thessaloniki Submerged Tunnel" will be complemented by some further urban and traffic interventions. Among them, the most important will be the proposed pedestrianization of Nikis Avenue, the conversion of Megalou Alexandrou Ave. to bidirectional and the simultaneous widening of it, along with some smaller-scale interventions such as the decongestion and regeneration of Tsimiski Ave. (street width reduction by one lane) and Vas. Olgas - Vas. Georgiou Avenue.

3. The second design concept of the Project

The second design concept of the project ("Integration of the Underwater Artery via Floating Bridge" or "Solution 2" in the context of the study) was developed in 2007 by a working group which was formed at the initiative of the Prefectural Administration of Thessaloniki, in partnership with Aristotle University of Thessaloniki (Kalogirou N., Angelides D., Koutitas Ch., Giannopoulos G. et al., 2007). This proposal consists of an attempt to improve the first design concept of the Underwater Artery, through a new design solution for expansion of the project, which, however, didn't progress to an advanced design phase.

3.1 Route description of the Road Artery

The road layout of Solution 2 offers a link not only between the Western Entrance and East Central Thessaloniki, but also between the Western Entrance and the district of Kalamaria in the Southeast. This design concept is proposed to be completed in three phases:

- Phase A involves the initial underground and underwater section of the Artery, which is relatively similar to the corresponding section of Solution 1, with a slight shift of the road layout towards the sea side, farther from the quay.
- Phase B refers to the south-eastwards expansion of the Artery, initially through an additional underwater section and afterwards through a long floating bridge, parallel to the city's coastline and at a distance of 350 m. away from it. This floating avenue is planned to start right from the point where the underwater tunnel will emerge on a small artificial island, opposite the "Makedonia Palace" Hotel, while it will end up in Kalamaria, through a floating curved bridge.
- Finally, Phase C includes the construction of a complex underground interchange located at the terminating point of the Underwater Artery, in the area of Old Electric Company. The interchange provides multiple links between the Artery and the existing road network of the area.

3.2 Geometric characteristics - Construction cost of the Project

The total length of the floating bridge will be approximately 3 km, including a line segment which will be about 2.2 km long, and a curved bridge, 800 m long. The height of the floating bridge above sea level will be 1-2 m. With regard to the construction cost of Solution 2, since it hadn't been accurately determined by the proposition -due to its low degree of maturity-, an indicative calculation was performed in the context of the study. To that end, the Project was divided into four independent sections, whose separate costs were estimated empirically. These were: a) the relatively similar to the first Solution 6-lane section, b) the complex interchange plus the additional 4-lane underwater segment, c) the 4-lane line segment of the floating bridge and d) the 4-lane curved bridge. Their approximate cumulative cost was 969 million euros.

Figure 2: Road layout of the second design concept of the Underwater Artery

3.3 Connections to the existing road network - Additional urban interventions

Through the complex underground interchange, connections are made possible between the project and all the major arteries of East Central Thessaloniki (M. Alexandrou Ave., Vas. Georgiou Ave., 3rd September Str., etc), by multiple 2-lane entrance/exit ramps. Moreover, the termination point of the floating bridge in Kalamaria district provides the distribution of traffic in Southeast Thessaloniki and furthermore, through the local street network, its canalization towards the regional road network and the hyperlocal destinations of the greater area (Thessaloniki Inner Ring Road, National Road of Thessaloniki - Chalkidiki, Airport, etc). It is also worth mentioning that in this design concept the existing road network of the city will remain relatively intact.

An essential component of the proposal of floating bridge is related to the additional urban interventions, which it includes. Specifically, the construction of an extended floating pedestrian bridge combined with a linear park is planned (with a total width of 25-30 m), parallel to the floating avenue. Three movable footbridges will connect this floating pedestrian bridge to the city's seafront. Also, the creation of two new urban squares is planned, one of which will be located above the complex underground interchange, while the other one will be located on the aforementioned artificial island (starting point of the floating bridge). Lastly, the presence of the floating avenue creates a basin which is protected from strong waves; thus, it gives the opportunity of developing water sports, marine activities, or even the construction of an Olympic rowing center.

4. Application of AHP method for the comparison of two Solutions

After the presentation of the two alternative design concepts of the Underwater Road Artery, a decision-making problem emerged, about the choice of the best solution between them for implementation. As a decision-making tool was required for its solution, the Analytic Hierarchy Process (AHP) multi-criteria method was considered to be the most compatible with the needs of the problem. The aim of the application of AHP method in this study is a systematic evaluation of the two alternative design concepts of the project, based on certain criteria (which represent the various impacts of the project), and the scoring of the two solutions in an algorithmic way, depending on their correspondence to these criteria.

4.1 Conceptual Framework of AHP

The Analytic Hierarchy Process constitutes a multi-criteria decision analysis method which was developed by T.L. Saaty in USA in the 1970s, having broad applications since then (Saaty and Forman, 1996). The method is particularly applicable in cases where various alternative activities are proposed for achieving the same objective, under conflicting criteria. Its main advantage is that it organizes tangible and intangible factors in a systematic way, providing a structured yet relatively simple solution to the decision-making problems (Kamal et al., 2001).

With regard to its mode of functioning, AHP structures hierarchically a complex multicriteria problem; essentially it decomposes the problem into its constituent parts, and then focuses separately on each hierarchy level. At the top of the hierarchy is the objective, at the intermediate levels are criteria (on which subsequent levels depend), while the lowest level contains the list of alternatives (Kamal et al., 2001). At each level, successive pairwise comparisons of its elements are performed, by using Saaty's 1-9 numeric scale (Table 1). With this scale the decision-maker can express quantitatively his perception, experience and knowledge regarding the extent to which one factor dominates over another one of same level (Saaty and Vargas, 1994). This stepwise procedure results to the determination of the relative weights (priorities) of the criteria initially, and alternatives afterwards, while eventually it provides the final rank of the alternatives.

Table 1: Saaty's fundamental scale for pairwise comparisons (Saaty, 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Moderate importance of one over another	Experience and judgment slightly favor one over the other.
5	Essential or strong importance	Experience and judgment strongly favor one over the other.
7	Very strong importance	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.
9	Extreme importance	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.

In summary, the AHP method is applied in two general phases: 1) Construction of the hierarchy that describes the problem and 2) Evaluation of the hierarchy of the problem (Anagnostopoulos et al., 2001).

4.2 Application of AHP in the case study

4.2.1 Construction of the hierarchy of the problem
During the structuring of the hierarchy of the problem, selection of suitable evaluation criteria was required for the comparative evaluation of the two proposed Solutions. Taking into account the four classes of criteria which, according to Brans (1996), are considered as governing Human systems (Economical, Technical, Social and Environmental criteria), and adapting them to the special features and the objectives of the project of Underwater Artery of Thessaloniki, eventually the 6 Criteria which are distinguished in Figure 3 were inserted in the hierarchy of the problem.
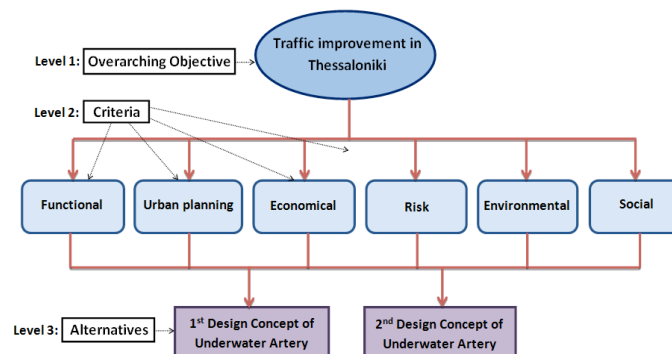

Figure 3: Schematic representation of the hierarchy of the problem

What follows is an analysis of the concept and the components of each Criterion:

The **Functional criterion** includes: a) the traffic functionality in terms of bypassing the city center, b) the overall distribution of traffic volume in Thessaloniki, c) the synergistic effect of each alternative on wider goals of spatial planning, related to accessibility and d) functional upgrading of insufficiently developed areas of the city.

The **Urban planning criterion** contains: a) the large-scale urban interventions (regenerations, creation of new public spaces, etc) accompanying each alternative solution, which contribute in the quality upgrading of urban space and b) the impacts on the urban spatial structure by the implementation of each solution (e.g. changes in land use, alteration in the ratio of open space to built-up areas, etc).

The **Economical criterion** refers to the overall construction cost of each alternative design concept of the project.

The **Risk criterion** expresses the technical risk related to each construction project, namely the probability that some critical characteristics of the system behavior exceed certain acceptable values, due to natural phenomena (wave loads, loss of buoyancy, seismic activity, leakage phenomena).

The **Environmental criterion** is divided into: a) impacts on air quality, b) impacts on water resources, c) impacts on the acoustic environment and d) landscape and visual impacts of each alternative.

The **Social criterion** reflects the social acceptance of each design concept and it is divided into: a) social acceptance among residents in the immediate area of the project and b) social acceptance among various social groups outside the immediate area of the project.

4.2.2 Evaluation of the hierarchy of the problem

The first step of the method consists of the pairwise comparisons of the Criteria, with regard to their relative importance, namely their contribution to the Overarching Objective that has been defined ("Traffic improvement in Thessaloniki"). To this end, the Pairwise Comparison Matrix of Criteria is constructed (Table 2). The justification and documentation of the performed comparisons are provided in Tegos, 2012.

Table 2: Pairwise Comparison Matrix of Criteria

Criteria	Functional	Urban planning	Economical	Risk	Environmental	Social
Functional	1	2	3	3	5	6
Urban planning	1/2	1	3	3	4	5
Economical	1/3	1/3	1	1	2	4
Risk	1/3	1/3	1	1	2	3
Environmental	1/5	1/4	1/2	1/2	1	3
Social	1/6	1/5	1/4	1/3	1/3	1

Then, the sum of each one of the six columns of Table 2 is calculated and presented in Table 3.

Table 3: Sums of columns of Comparison Matrix

Criteria	Functional	Urban planning	Economical	Risk	Environmental	Social
Sum	2.533	4.116	8.750	8.833	14.333	22

Subsequently, the Synthesized Matrix of Criteria is constructed (Table 4). Each element in this matrix is the quotient of each element of Table 2 divided by the corresponding sum of its column (which appears in Table 3). The average of the elements of each row of the Synthesized Matrix is the relative weight (priority) of the corresponding criterion, which reflects the contribution of the criterion to the Overarching Objective. It should be mentioned that the consistency ratio (CR) calculated is 0.0268 (<0.10), which is a very acceptable value, proving that the pairwise comparison matrix is sufficiently consistent.

Table 4: Synthesized Matrix and relative weights of Criteria

Criteria	Functional	Urban planning	Economical	Risk	Environmental	Social	Relative weights of Criteria
Functional	0.395	0.486	0.343	0.340	0.349	0.273	0.367
Urban planning	0.197	0.243	0.343	0.340	0.279	0.227	0.274
Economical	0.131	0.081	0.114	0.113	0.140	0.182	0.125
Risk	0.131	0.081	0.114	0.113	0.140	0.136	0.118
Environmental	0.079	0.061	0.057	0.057	0.070	0.136	0.075
Social	0.066	0.049	0.029	0.038	0.023	0.045	0.041

What follows is the calculation of local priorities of the two alternative Solutions, with respect to each criterion, which are presented all together in Table 5. These local priorities received their values after a thorough comparative evaluation of the Solutions, regarding the extent of their correspondence with every individual component of the Criteria, as they were described in subsection 4.2.1. The evaluation, performed by the authors of this paper, was based mainly on qualitative comparison of these criteria with the scale of Table 1; detailed documentation of the rationale for the comparisons is provided in Tegos, 2012.

Table 5: Summary table of local priorities of the two Solutions with respect to each criterion

Solutions \ Criteria	Functional	Urban planning	Economical	Risk	Environmental	Social
Solution 1	0.2	0.25	0.667	0.667	0.75	0.5
Solution 2	0.8	0.75	0.333	0.333	0.25	0.5

The last step of the application of AHP consists in the determination of the overall priorities (overall scores) of the two Solutions. This is achieved by multiplying the above "Summary table of local priorities of the two Solutions with respect to each criterion" by the relative weight (priority) of the corresponding criterion, which is presented in Table 4. For example, concerning Solution 1: with respect to Functional criterion, the multiplication that is performed is: 0.2 x 0.367 = 0.0734 and so on, for the rest of the criteria and then correspondingly for Solution 2.

Eventually the overall priority of each Solution is calculated by summing the six above individual products regarding each criterion (namely by summing its weighted local priorities regarding each criterion). The overall score of each Solution / Design concept is **0.395** for **Solution 1** and **0.605** for **Solution 2**.

Consequently, Solution 2 of "Integration of the Underwater Artery via Floating Bridge" received the highest overall rating (60.5%) between the two alternatives, with a noticeable difference of 21%, and thus it is deemed selectable for implementation, in the context of the present study. Furthermore, the validity of the result was tested through a sensitivity analysis. Specifically, the particularly high priorities of two criteria, in which Solution 2 has significant predominance (Functional and Urban planning), were alternately decreased by 0.1 each; then, still, Solution 2 maintained its clear superiority over Solution 1

(+15% and 17% respectively). On the other hand, even when the priorities of two criteria in which Solution 1 predominates (Economical, Environmental), were alternately increased by 0.2 each, Solution 2 eventually maintained a considerable difference (+9% and 5% respectively).

5. Conclusions

Through comparative evaluation, some essential differences were demonstrated in the design principles, the priorities and the targeting of two alternative design concepts of a large-scale road project, an Underwater Artery. While the first proposal of "Thessaloniki Submerged Tunnel" aims mainly at bypassing the city center and decongesting traffic in it, the second one of "Integration of the Underwater Artery via Floating Bridge", apart from that goal, aims at supporting a much wider range of traffic volume and providing a large-scale urban intervention to the city. Specifically, the proposal attempts to link the western end of the Peripheral Ring Road of Thessaloniki to the eastern end by the side of the sea, contributing to a broader goal of accessibility, while at the same time it tries to upgrade the quality of urban space in the city, through the proposed pedestrian bridge, urban squares, etc. Therefore, it becomes clear that large-scale projects should be a part of an integrated spatial and transport planning.

With regard to the application of the multi-criteria analysis in this case study, it indicated that the AHP method constitutes an especially practical tool for comparative evaluation and decision making in an algorithmic way. A noteworthy characteristic of the method is that, apart from quantitative attributes, it is able to consider also qualitative goals and attributes within a common framework, thus combining objectivity with the judgment and intuition of the decision-maker. Another crucial advantage of AHP is its flexibility, as it is totally compatible with problems in which it is extremely difficult, if not impossible, for some elements of the decision to be quantified otherwise (such as the long-term effects of a large scale project, like the Underwater Artery). Lastly, this study consisted of an attempt to provide an appropriate evaluation framework for the alternative design concepts of large-scale road projects, taking into account all the main impact areas of them (road traffic - functionality, urban space, available financial resources, safety/risk, environment, society) in the form of individual criteria with different weights. Nevertheless, it should be mentioned that some kind of subjectivity is almost inevitable in the process, especially in the stage of the criteria comparisons.

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