Evaluation Of Variant Construction Projects Supported By Expert Opinion Systems Based On Multi-Criteria Methods

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Abstract: At the stage of planning a construction project, variant solutions of its performance are often evaluated. When applying multi-criteria methods, first criteria for the assessment of variants are defined and next their weights (importance) are assigned. Both when selecting criteria and making an evaluation, expert opinions are taken advantage of. However, opinions may vary substantially and it might be difficult to arrive at an average assessment Yet, this is one of the most important stages, as the final outcome of a completed construction development depend on this initial evaluation. The paper will discuss an approach to selecting a group of experts and to the further analysis of their opinions, which the author has developed. An expert system is based on multi-criteria analytical methods.

Keywords: expert opinions, multi-criteria methods, variants of construction projects.

I. INTRODUCTION

Most investment projects in the construction industry necessitate an elaboration and analysis of several variant solution of their execution. Variants most frequently include available technical and technological solutions, economic aspects and, more and more prevalent, issues connected with nature protection [1, 3].

Making a decision about building any structure must be preceded by an analysis of numerous and diverse factors that will affect the ultimate shape of a construction and its surroundings. This is a complicated process and the choice of a variant solution which will best satisfy predefined requirements needs an efficient decision-supporting method [2, 3]. It is advisable to adopt an approach that allows us to consider all significant aspects (criteria) and that will identify which of the analysed variant solutions fulfills these criteria to the highest degree. A classical approach is depicted in fig. 1.

It is certainly difficult to choose and apply a single method. Hence, the author would like to suggest a multi-stage approach, which employs a few methods to which an organised expert system is added [4].

II. SELECTION OF EXPERTS

Supporting multi-criteria decisions necessitates the participation of experts who express their opinions on the subject specified in surveys [7, 11]. Expert opinions are solicited with the help of various surveys, tailor designed in each case and responding to individual needs in a given case. Experts typically occupy different standpoints because of having specific perceptions of the reality and ongoing processes. Differences in opinions are also a consequence of different functions which experts play in a construction investment process. Thus, both expert opinions and the final outcome of their analysis may be burdened with some error, the fact that should be borne in mind. Subjectivity is what we most often encounter when using methods which involve qualitative factors. In order to achieve an objective assessment of non-measurable factors, descriptive assessments or quantitative scales are adopted. For further analyses, it is essential to reach appropriate groups of experts, with sound knowledge of the specific nature of a given project. The better we assemble our experts, the more reliable and coherent data we will obtain.

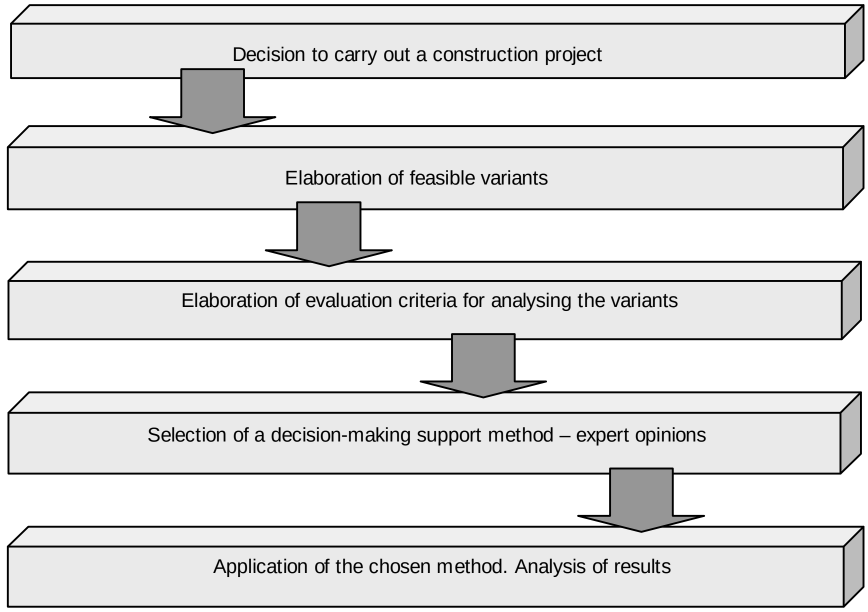

Fig.1. Scheme of the traditional approach

A procedure designed for the purpose of identifying criteria important for evaluation of variants may proceed as follows: first, the analyst prepares a group of criteria and then he invites a group of experts to evaluate these criteria (fig.1.). An alternative, and slightly more time consuming procedure presumes that experts are first asked in a survey which criteria will be important for the subsequent analysis of a project, and then make an assessment. The latter approach (a two-stage one) takes a little more time but is more effective (figs 2 and 3).

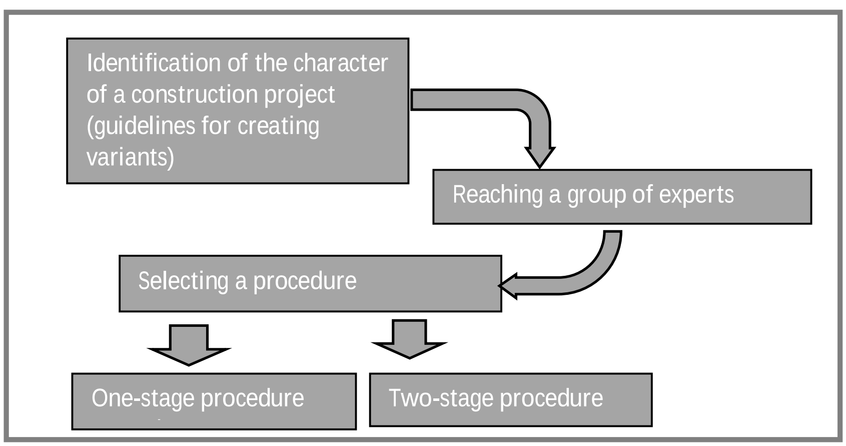

Fig. 2. Scheme of the preliminary stage

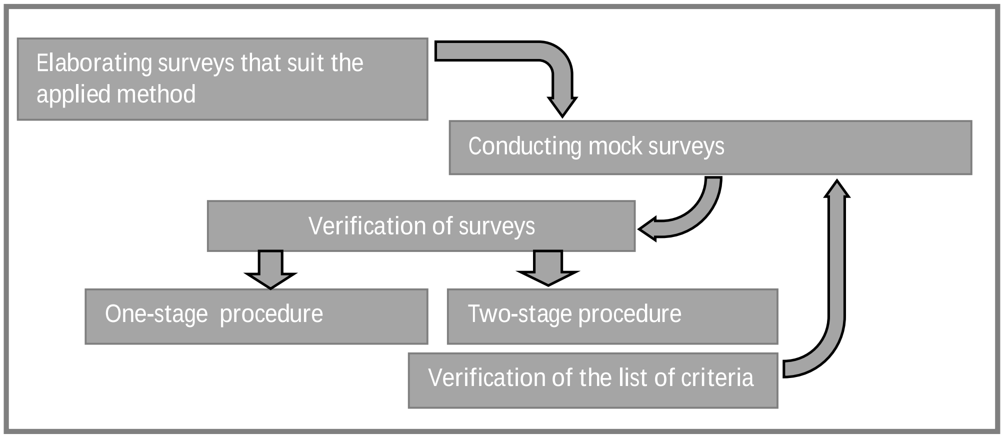

Fig. 3. Steps towards a one- or two-stage procedure

It is sometimes problematic to determine the final (average) weight of each criterion, especially when expert opinions are highly discrepant. If this is the case, it is suggested to subdivide the group of experts depending on their specialty and field of professional knowledge and then assign weights to their opinions (fig. 4).

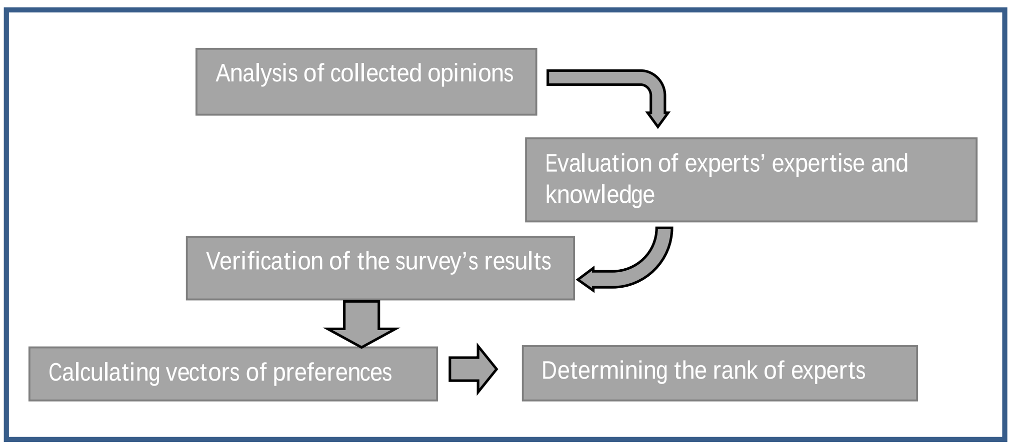

Fig 4. Scheme presenting the process of verification of experts

In some more challenging cases, the stage of conducting a survey will have to be repeated and descriptions of the criteria may have to be modified or else additional explanatory notes will be needed. A much more practical way of assigning weights to criteria is the AHP method [10], which involves pairwise comparison of criteria. This method also presumes that the resulting comparison matrices will be assessed in terms of cohesion, which prevents analytical results from being excessively discrepant.

III. Assessment of weights with a multi-criteria analysis

The Analytic Hierarchy Process (AHP) allows one to consider diverse criteria which are decisive for attaining a set aim. The principal assumption is that a goal is attainable and, wherever necessary, partial aims leading to reaching the main goal can be analysed [5, 6]. A distinguishing feature of this method is the procedure which involves pairwise comparisons of all criteria at the level being analysed. Mutual relationships between criteria are identified and it is demonstrated which criteria and to what extent are more essential for the achievement of the main goal, such as the successful completion of a given project. An assessment is made on a scale from 1 to 9, designed by Saati [5, 10] and presented in the form of tables. The literature contains calculations formulas for the subsequent steps leading to the

calculation of the value of a priority criterion.
These are: calculations of the value of a normalised matrix:

$$\overline{w_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (1)$$

Determination of the value of the vector of sub-priorities:

$$\overline{w_j} = \sum_{j=1}^{n} w_j a_{ij} \qquad (2)$$

where:

$$w_j = \frac{\sum_{i=1}^{n} w_{ij}}{n} \qquad \text{i,j = 1…n} \qquad (3)$$

To verify whether the above procedure has been correct, we determine:
the matrix's own maximum value:

$$\lambda_{\max} = \frac{1}{w_i} \sum_{i=1}^{n} a_{ij} w_j \qquad (4)$$

value of the consistency index:

$$C.I. = \frac{\lambda_{\max} - n}{n-1} \qquad (5)$$

consistency ratio:

$$C.R. = \frac{C.I.}{R.I.} \qquad (6)$$

where the CR should reach a value <10%

R.I. - random index whose value depends on the 'n' number of compared components.

Weights determined in this way take into account the relationship between the analyzed criteria and their assessment based on a comparison of their significance.

IV. Method for Evaluation of Variants

The indicator method used for evaluation of variants employs matrices (constructed as tables), in which particular effects on the natural environment are described, and each consecutive criterion has its weight assigned (significance of the impact on nature) [8, 9]. Specification of the data of interest to the researcher comprises all the analysed variants of the location of a construction project. Table I shows the guidelines for constructing a matrix.

TABLE I. The sample of matrix for the analyses

No	Criter-ion	variant 1 of the investment			variant 2 of the investment			variant 3 of the investment			Weight of the criterion
1	A1	P_{11}	Q_{11}	R_{11}	P_{12}	Q_{12}	R_{12}	P_{13}	Q_{13}	R_{13}	W_1
2	A2	P_{21}	Q_{21}	R_{21}	P_{22}	Q_{22}	R_{22}	P_{23}	Q_{23}	R_{23}	W_2

The number in the upper, left-hand corner in each cell describes a direct effect, whereas the one in the lower, right-hand corner corresponds to the indirect effect of the same criterion on the natural environment. The sum of effects multiplied by the weight is documented in the middle of a cell.

The partial assessment on the effect of the jth variant on the ith criterion:

$$Qij = (Pij+ Rij) * Wi \qquad (7)$$

where:

Pij – direct effect of a subsequent variant in the context of criterion A;
Rij- indirect effect of a subsequent variant in the context of criterion A;
Wi– weight of criterion A

V. AN EXAMPLE OF APPLICATION

The case study presented here included a survey as indicated in the table. Expert opinions were analysed and, having discarded extreme ones, a resultant assessment of direct and indirect effects on nature was determined. Weights of individual criteria were also assessed. For example, a degree of interference with protected nature sites was assessed through the length of road running across protected areas (C1). By analogy, the total length of sections of the planned road routes crossing woodlands (C2) was analysed. However, the values obtained were smaller because it was difficult to evade afforested areas completely when designing a new road, but transgression of nature reserves could be eliminated. On the other hand, when a road cuts through a forest, a certain number of trees must be felled. Another problem (C4) is transgressing wildlife trails. Without adequate infrastructure, this could lead to a higher number of road collisions, in which wild animals are killed. Planning a road across watercourses (C5) is often unavoidable in the engineering practice. Such cases require designing specific infrastructure elements, which minimize problems caused by underground water flow or the flow of water in a watercourse channel. Values of weights were based on expert opinions, but their evaluation was conducted according to the AHP method. Calculations are presented in the tables.
The following sub-criteria have been defined:

C1. interference with nature protected sites
C2. total length of the route going through forests
C3. number of trees to be cut down
C4. the road crossing wild animals' trails
C5. the road crossing watercourses

Below, you will find a brief characterization of the variants.

Variant 1. It fulfills the environmental and spatial criteria to the highest degree; less so does it meet the transportation demands and it is the least economically viable variant. This is a longer route but it evades compact forest areas and does not collide with paths travelled by wild animals.

Variant 2. It is the least expensive, in terms of both the costs of construction works and the costs of purchasing the land and due compensation; it meets the transportation demand and partly fulfills the environmental requirements. This is the shortest route but it interferes with protected nature sites. Its implementation will mean felling a large number of trees and crossing wild animals' trails.

Variant 3. It satisfies most closely the transportation expectations and design-related requirements, including the ones that regulate the delineation of transportation routes; economically speaking, it is better than variant 1 but worse than variant 2; to some extent it satisfies the environmental criteria, although it interferes with protected areas and a long section of the planned road will run through forests.

TABLE II. THE COMPARISON MATRIX FOR THE ANALYSED CRITERIA

Criteria	1	2	3	4	5
1	1	0,5	2	1	4
2	2,00	1	5	2	5
3	0,50	0,20	1	1	7
4	1,00	0,50	1	1	7
5	0,25	0,2	0,14	0,14	1
sum a_{ij}	4,750	2,400	9,143	5,143	24,000

TABLE III. THE VALUE OF THE NORMALISED MATRIX AND THE PRIORITY VECTOR

Superior criteria	1	2	3	4	5	Sum aw_{ij}	Vector of priorities w_j
1	0,2105	0,2083	0,2188	0,1944	0,1667	0,9987	0,1997
2	0,4211	0,4167	0,5469	0,3889	0,2083	1,9818	0,3964
3	0,1053	0,0833	0,1094	0,1944	0,2917	0,7841	0,1568
4	0,2105	0,2083	0,1094	0,1944	0,2917	1,0143	0,2029
5	0,0526	0,0833	0,0156	0,0278	0,0417	0,2210	0,0442

$\lambda_{max} = 5{,}44$; $C.I. = 0{,}11$; $C.R. = 0{,}0977$ x 100% =9,77% < 10% ; *R.I. = 1,12*

In the case solved here, a survey was conducted according to the model presented in tab. I. Expert opinions were submitted to analysis and, having discarded extreme ones, a resultant assessment of the direct and indirect effects was proposed. The degree of interference with protected nature sites was assessed according to the length of the routes running through protected areas (1). The length of the planned roads going through forests was assessed in the same manner (2). However, when a new road is planned to run through a forest, it entails (3) felling a certain number of trees. Another problem (4) is the crossing of wild animals' trails. Without proper infrastructure, this can lead to a higher number of collisions, in which animals are killed. Crossing watercourses (5) seems unavoidable in road engineering, but it means that certain elements of road infrastructure must be built so as to avoid problems caused by water flows either underground or in a watercourse trough. Values of weights were established based on the experts' opinions, but their analysis was performed with the Analytic Hierarchy Process (a hierarchical analysis method). All calculations are presented in tables II and III.

The evaluation of the hierarchy of the criteria showed that the criteria concerning the length of the route through forests and the crossing of wild animals' trails were the most important ones.

The values of the priority vector allow us to determine the weights and proceed onto making an assessment supported by the indicator method. The calculations are included in table IV.

TABLE IV. AN EXAMPLE OF A MATRIX FOR THREE ALTERNATIVE VARIANTS OF A ROAD INVESTMENT PROJECT

No	Cri terion	variant 1 of the investment			variant 2 of the investment			variant 3 of the investment			Weight of the criterion
1	C1	-1	0	1	-1	-4	-1	-1	-4	-1	2,0
2	C2	-1	8	3	-1	4	2	-1	-4	0	4,0
3	C3	-2	-1,5	1	-1	-3	-1	2	1,5	-1	1,5
4	C4	-1	2	2	-1	-4	-1	-1	2	2	2,0
5	C5	1	1	1	1	1	1	-1	0	1	0,5
	sum		9,5			-6			-4,5		

The value found in the last line corresponds to the final assessment of the variants with respect to the environmental criterion. The highest score was achieved by variant 1, mostly owing to the high assessment values assigned to subcriteria 2 and 4. This is the variant that interferes the least with forests and cuts the smallest number of wild animals' trails. These are the reasons why it received the highest score.

VI. CONCLUSION

The approach discussed in this article consists of an orderly series of actions which allows for attainment of a goal, such as the right selection of a variant that will most closely satisfy expectations of a developer and future users of a construction to be raised. Using the expert system can assure better and more reliable data. The evaluation of criteria with the AHP method makes it possible to take into account mutual relationships between criteria. The incorporation of the indicator method at the final stage of analysis gives us a chance to consider also potential negative effects of the planned construction, expressed thorough negative values. The whole system proposed above, by taking advantage of characteristic features of all the methods is aggregates, creates a wide range of opportunities for evaluating variants of a planned construction development.

REFERENCES

[1] Abu Dabous S., Alkass S., Decision support method for multi-criteria selection of bridge rehabilitation strategy. „Construction Management and Economics", 26 (8), 2008.
[2] Brown M. A., Construction management: the management of the development, conservation and improvement of the built environment, Organization, Technology & Management in Construction: An international Journal 4(2)(2012) p.457–460,
[3] Marques G., Gourc D., Lauras M., Multi-criteria performance analysis for decision making In Project management, International Journal of Project Management 29(8) (2011) p.1057–1069,
[4] Morris P.W.G.1998, Lessons in managing major projects successfully in a European context, Technology in Society 10(1)(1988)p.71–98,
[5] Saaty T.L., Fundamentals of decision making and priority theory with the analytic hierarchy process. RWS Publications, Pitsburgh 1994.

[6] Šelih J., Kne A., Srdić A., Žura M., Multiple-criteria decision support system in highway infrastructure management. „Transport", 2008, 23/4,
[7] Szafranko E., Multi-criteria methods in an analysis of variants of a construction project, International Scientific Publication, Materials, Methods & Technologies, Volume 9/2015, p.155-168,
[8] Szafranko E,. Applicability of the indicator method to evaluation of road building projects, News in Engineering 1/ 2015 p.1-7,
[9] Szafranko E., Applicability of the indicator method to evaluation of the impact of road building projects on the natural environment, 3rd Electronic International Interdisciplinary Conference EIIC 2014, 1st-5th September, 2014. p:519—523,
[10] Szafranko E., Application of the analytic hierarchy process (AHP) to evaluation of variants of a planned road investment project, Journal of International Scientific Publications; Materials, Methods and Technologies, Volume 7, part 1(2013), p.152-163.
[11] Zavadskas E.K., Kaklauskas A., Peldschus F., Turskis Z.,(2007) : Multi-attribute assessment of road design solutions by using the COPRAS method, The Baltic Journal of Road and Bridge Engineering, 2, 4/ 2007 , p.195-203.

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