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Research Article

APPLICATION OF MULTI-CRITERIAL ANALYTICAL METHODS FOR RANKING ENVIRONMENTAL CRITERIA IN AN ASSESSMENT OF A DEVELOPMENT PROJECT

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ABSTRACT
Building investment projects, both during the construction work and afterwards, have a certain impact on the natural environment when a raised structure is used. Depending on the character, size and location of a planned structure, such influences will vary. At the stage of planning a new development, investors are obliged to execute several procedures connected with the preservation of nature, for example they prepare several variants of the planned investment and evaluate which one will have the weakest effect on the environment. Assessment of variants is based on a series of criteria, and the final outcome is not always unambiguous. Hence, when trying to establish the importance of each criterion, it is advisable to apply efficient decision support methods. One option is to use multi-criteria analytical methods. However, for such methods to be applicable, an investor must prepare a wealth of information. The first stage preceding the actual analysis of variants is to define the assessment criteria and assign to them appropriate weights (importance). This stage requires the participation of experts, who – through questionnaires and interviews – express their opinions on the criteria that must be included and on their importance. This article contains a model procedure implemented for the sake of determination of the importance of parameters, which includes the methodology used for assessment and ranking of parameters. The approach presented in this paper demonstrates the usefulness of multi-criteria analytical methods when making an evaluation pertaining to the impact of a building investment on the environment.

Keywords: building investments, environmental impact, assessment criteria, multi-criteria analysis

INTRODUCTION

Construction of buildings is inextricably linked with the economic and social development of regions and whole countries. It is impossible to engage in a business without new buildings. Construction Law identifies numerous building structures having different functions and use [Law regulations]. They include residential buildings, ranging from single family houses to blocks of flats, commerce and service buildings, elements of street architecture. The most diverse group comprises non-residential building structures, which consists of industrial buildings and facilities, hydrotechnical facilities, electric power facilities, linear structures, roads, bridges and flyovers. These are just a handful of examples, but they are sufficiently numerous to realize that on account of their nature such building structures can exert strong and adverse effects on the natural environment. Hence, our focus of attention will be on how to identify and evaluate environmental criteria while making an assessment of a development project, such as the construction of a road [Rodriguez-Pose and Fratesi 2004, Šelih et al. 2008.].

The execution of a building investment invariably means large intrusion in the environment because it involves the performance of actions which have an influence on the close and further surroundings. An idea underlying the contemporary construction industry is to ensure that such intrusion does not cause a deterioration of the environment nor does it disturb the environmental balance [Isaac and Navon 2008, Brown 2012]. For this purpose, an assessment on the environmental impact of a planned construction development is made, where the predicted effects are specified, the current state of the environment is diagnosed and measures are proposed to minimize the negative influence of a planned building on nature. One possible approach to an analysis of the current situation and preparation of future actions, inclusive of the environmental requirements, is to analyze variant solutions of a given investment project [Szafranko 2015b]. A feasibility study is a very important and useful document, the aim of which is to answer the above-mentioned questions and to help select the best variant, which will take many key aspects into consideration [Shen et al. 2010].

FUNCTIONS OF A FEASIBILITY STUDY – VARIANTS OF AN INVESTMENT

A feasibility study is a document which covers many technical and economical questions as well as the technical feasibility analysis. This document is essential for making a decision whether or not to carry out a project. The fundamental goals of the feasibility study include an analysis of the general feasibility of an investment, an assessment of the investment from the socio-economic angle, preliminary identification of the most important technological parameters and the calculation of financial inputs, as well as possible acquisition and sources of funds. While conducting a feasibility study, one cannot omit the stage of preparing alternative variants of the planned development project. By balancing all the developed variants we should be able to select the one which will best satisfy our expectations. Many variants with different characteristics are prepared [Rodriguez-Pose and Fratesi 2004].

The ones mentioned most often are:

- zero variant (when the construction project is abandoned),
- investment variant (when the construction project is executed – there are usually a few investment variants),
- the most eco-friendly variant,
- an alternative variant.

The feasibility study must include a zero variant, as all other variants will be compared to it. The feasibility study also presumes that a multi-criteria analysis of the variants will be made [Shen et al. 2010]. The content of a typical Feasibility Study is shown in figure 1.

The recommendation to perform a multi-criteria analysis arises from the identification of a larger or smaller group of criteria, determination of their importance and assessment of variant solutions, including the degree to which they meet the set criteria. Thus, the starting point for all analyses is the identification of the assessment criteria and assignment of their weights. This procedure can be made more efficient if a ranking list of assessment criteria is prepared separately for each analyzed case. In turn, the analyses can include mathematical support methods [Abu Dabous and Alkass 2008]. In this article, the application of the Analytic Hierarchy Process (AHP) method is suggested.

THE AIM OF THE RESEARCH WORK

This research contains an attempt to apply the AHP (Analytic Hierarchy Process) method to establish the ranking list of criteria for an assessment of variants prepared for the construction of a section of a road. The first stage comprises the

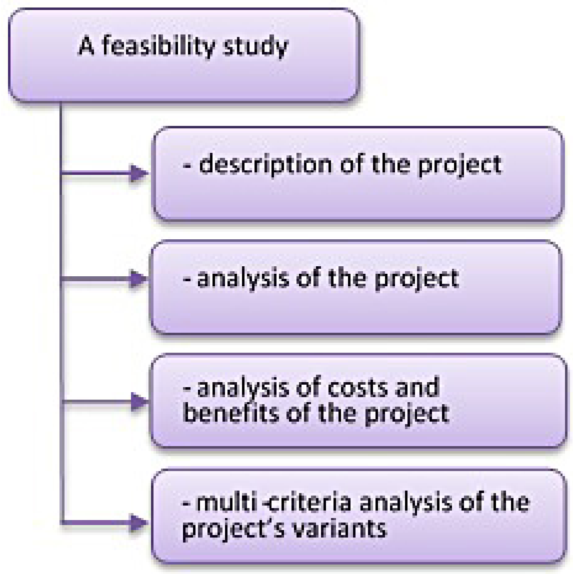

Fig. 1. Diagram of the content of a typical Feasibility Study.

identification of criteria and their analysis so as to prepare the data for an interview and collection of opinions among experts, which will be necessary to carry out subsequent steps in the procedure.

The analyzed investment is a road which will run through environmentally valuable areas and the investor's goal is to leave as many of the protected natural objects as possible intact. The function of the planned development is to improve the local transportation network and to build a connection with a state road running in the vicinity. In order to make an assessment process more efficient, it was decided to specify assessment criteria related to environmental protection. In interviews and surveys, the experts defined a group of such criteria and determined their importance by direct evaluation. As criteria can be highly diverse and difficult to compare directly, they were divided into three groups:

1. connected with the investment: technology of building the surface of the road, time of completing the works depending on the adopted variant, waste management systems, length of the access roads, transport of building and raw materials, options for unloading and storing the delivered materials, location of the associated facilities;
2. the route of the new road and consequently: intrusion into migratory routes of wild animals, number of trees to be felled, crossing over watercourses, crossing through environmentally valuable areas, habitats which could be damaged;
3. environmental protection infrastructure: number of required passages for wild animals, length of protective fences, length of noise barriers, method employed to handle the road runoffs – surface dewatering of the road.

The structure of the above-mentioned considerations is presented in figure 2.

The main aim of this study has been to develop a ranking list of model criteria with the help of the AHP method by performing calculations in three stages. Thus, the following step in the procedure is to evaluate the defined criteria. The outcome consists of a hierarchy of environmental determinants, obtained according to the procedure described in the article.

METHODOLOGY

With a large number of highly diverse criteria, direct comparisons would be difficult and making an overall assessment would encounter many problems. However, it would be incorrect to try and reduce the number of assessment criteria because such a limited assessment might not be reliable [Marques et al. 2011]. It is therefore recommended to apply multi-criteria analytical methods, which are best at dealing with problems of this type. Multi-criteria methods enable the user to evaluate the measurable and non-measurable criteria. As regards the measurable criteria, their assessment with respect to a given criterion is obvious. On the other hand, an objective assessment of quality factors can be achieved in two ways. One is through a descriptive evaluation of the importance of a criterion, while the other one

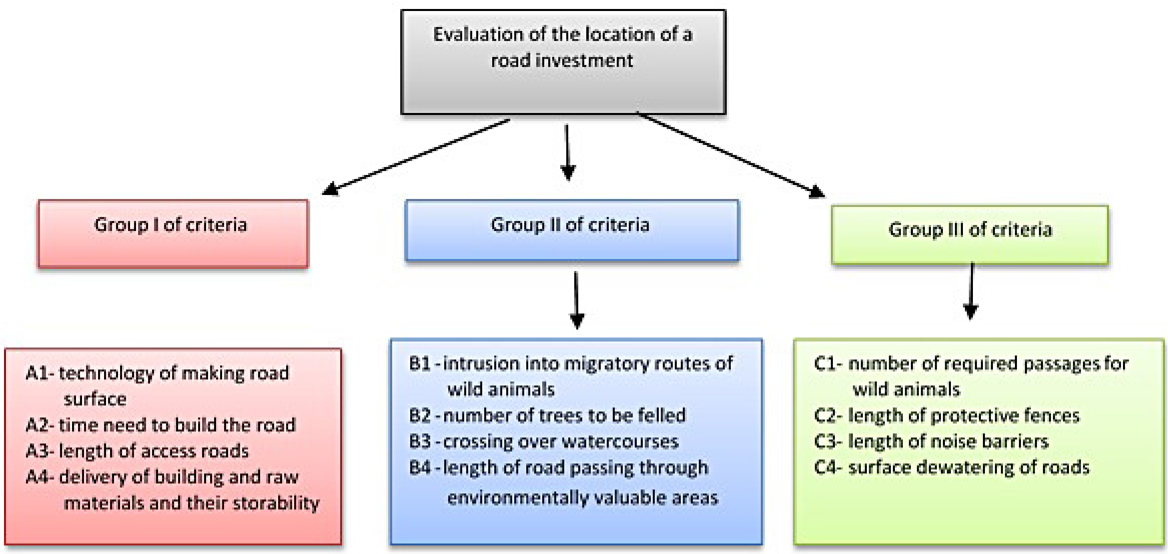

Fig. 2. Structure of the analyzed problem

requires that a numerical measurement scale is adopted. Non-measurable criteria often appear at the stage of planning an investment project. The above-mentioned methods necessitate the participation of experts who express their opinions on predefined questions [Negahban et all 2012, Szafranko 2015a]. Expert opinions serve as the basis for the identification of criteria significant in the further procedure. On the other hand, experts express their opinions on the importance of the previously defined criteria. There are various multi-criteria methods, e.g. MCE analysis, AHP [Saaty 2014], indicator methods, which allow us to take non-measurable criteria into consideration while making decisions [Al-Harbi 2001, Szafranko 2013]. All the afore-mentioned methods need a large set of data collected that will lead to the determination of values of criteria. For this purpose, surveys and interviews are carried out among different groups of experts. Because of the diverse character of the criteria described above, the AHP method seems most suitable. It allows the user to evaluate various, non-comparable parameters, which are divided into groups of criteria, each assessed separately, in order to ensure that they are analyzed properly [Marques et al. 2011, Negahban et al. 2012, Saaty 2014] .

Analytic Hierarchy Process is one of the multi-criteria analytical methods [Al-Harbi 2001, Szafranko 2013] which enable, for example, to analyze the criteria whose various degrees of attainment allow us to achieve the main goal. The degree to which the main aim is achieved by a decision variant depends on the degrees to which the sub-criteria are achieved. Decomposition of a decision problem facilitates an assessment and is the core of the AHP approach. There are three steps to solving a problem in the AHP method, and they are connected in an integrated and logical series:

1. Presentation of the structure of a problem and development of a hierarchical model,
2. Assessment of criteria by pairwise comparisons on a 9-point scoring scale,
3. Assessment and arrangement of the criteria by establishing priorities (assigning weights), including an analysis of the concordance and sensitivity of solutions.

The hierarchical structure, presented in figure. 2, distinguishes the superior aim (level 1), which consists of the successful performance of a planned investment project, main criteria connected with the achievement of the goal and sub-criteria, which are defined within the main criteria and which make the requirements more specific.

When using the AHP method, it is important to remember that only a few criteria can be compared on the same level, and that they should be comparable, as this will enable the user to build a coherent matrix of comparisons. It is equally important to take into account certain simplifications when modelling an analyzed problem, and to collaborate with experts at this stage, or else to carry out survey-based investigations. During the procedure [Al-Harbi 2001, Szafranko 2013], all criteria on a given level are compared pairwise, and their mutual relationships are identified. In this way, it can be decided which criteria, and to what extent, are most important for the execution of the analyzed undertaking. The assessment is made on a scoring scale developed by professor Saati, presented in the form of a table (tab. 1) [Al-Harbi 2001, Szafranko 2013, Saaty 2014]. The number of pairs creating a matrix and submitted to the analysis depends on the number of previously defined criteria.

Number of nodes:

$$a_{ij} = \frac{n(n-1)}{2} \tag{1}$$

The next step involves the construction of a comparison matrix ***A***, in which the scores determined while evaluating the criteria are placed. The matrix has certain specific features: the diagonal consists of values equal one because it contains a comparison of each criterion to itself, $a_{ij} = 1$ for i=j; the elements a_{ij} are a reciprocal of

Table 1. AHP fundamental scale [Al-Harbi 2001, Szafranko 2013, Saaty 2014]

Score	Specification
9	Predominance of one criterion over the other is absolute and proven to the highest degree
7	One criterion is very strongly preferred to the other and the preference is proven in practice
5	One criterion is preferred to the other
3	One criterion is slightly more preferred to the other
1	Both criteria contribute to the same degree to attaining the goal
2, 4, 6, 8	Intermediate values, used only when necessary

the elements a_{ji}. Logically, all a_{ij} >0. When the preferences (a_{ij}) are established, we can calculate elements a_{ij}

$$a_{ji} = \frac{1}{a_{ij}}$$

The pairwise assessment and establishment of other elements enables the user to construct a preference matrix. A matrix constructed for 4 criteria is shown below (formula 2).

$$A = \begin{vmatrix} a_{11}=1 & a_{12} & a_{13} & a_{14} \\ a_{21}=\frac{1}{a_{12}} & a_{22}=1 & a_{23} & a_{24} \\ a_{31}=\frac{1}{a_{13}} & a_{32}=\frac{1}{a_{23}} & a_{33}=1 & a_{34} \\ a_{41}=\frac{1}{a_{14}} & a_{42}=\frac{1}{a_{24}} & a_{43}=\frac{1}{a_{34}} & a_{44}=1 \end{vmatrix} \quad (2)$$

The literature contains calculation formulas for the subsequent steps leading to the calculation of the value of a priority criterion (formulas 3–7). These are:

I. Calculations of the value of a normalized matrix:

$$\overline{w_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (3)$$

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

$$\overline{w_j} = \sum_{j=1}^{n} w_j a_{ij} \quad (4)$$

where:

$$w_j = \frac{\sum_{i=1}^{n} w_{ij}}{n} \quad i,j = 1 \ldots n \quad (5)$$

In order to verify whether the above-mentioned procedure has been correct, we determine:

- the matrix's own maximum value:

$$\lambda_{max} = \frac{1}{w_i} \sum_{i=1}^{n} a_{ij} w_j \quad (6)$$

- value of the consistency index:

$$C.I. = \frac{\lambda_{max} - n}{n-1} \quad (7)$$

- consistency ratio:

$$C.R. = \frac{C.I.}{R.I.}$$

where the CR should reach a value <10%
R.I. – random index, the value of which depends on the 'n' number of compared components (tab. 2).

RESULTS

Calculations were completed according to the above-mentioned procedure (Table 3–10). The evaluation of individual criteria compared in pairs included the conditions presented previously.

For the main criteria:

- we set the matrix's own maximum value:

$$\lambda_{max} = \frac{1}{w_i} \sum_{i=1}^{n} a_{ij} w_j = 13 \text{ x } 0.0714 + 1.311 \text{ x } 0.7482 + 6.333 \text{ x } 0.1804 = = 3.0521$$

- the value of the consistency index:

$$C.I. = \frac{\lambda_{max} - n}{n-1} = \frac{3.0521 - 3}{3-1} = = 0.0261$$

- the inconsistency ratio:

$$C.R. = \frac{C.I.}{R.I.}$$

where C.R. should reach the value < 10%
R.I. = 0.58 (Tab.2.)

$$C.R. = \frac{0.0261}{0.58} = 0.0449 \text{ x } 100\% = = 4.49\%$$

In order to perform a complete analysis and to determine the ultimate hierarchy of the criteria involved in an assessment of the environmental im-

Table 2. Value of the random index (RI). [Al-Harbi 2001, Szafranko 2013, Saaty 2014]

n	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3. The comparison matrix for the main criteria

Superior criteria	A	B	C
A	1	0.111	0.333
B	9	1	5
C	3	0.200	1
Sum a_{ij}	13	1.311	6.333

Table 4. The value of the normalized matrix and the priority vector for the superior criteria

Superior criteria	A	B	C	Sum w_{ij}	Vector of priorities W_i
A	0.0769	0.0847	0.0526	0.2143	0.0714
B	0.6923	0.7627	0.7895	2.2445	0.7482
C	0.2308	0.1525	0.1579	0.5412	0.1804

Table 5. Comparison matrix for the sub-criteria A

Variant	A1	A2	A3	A4
A1	1	5	7	7
A2	0.2000	1	0.5	1
A3	0.1400	2	1	1
A4	0.1430	1	1	1
Sum	1.4857	9.0000	9.5000	10

Table 6. Value of the normalized matrix and priority vector for the sub-criteria A

wij	A1	A2	A3	A4	Sum w_{ij}	Vector of priorities W_i^w
A1	0.6731	0.5556	0.7368	0.7000	0.6664	0.99003
A2	0.1346	0.1111	0.0526	0.1000	0.0996	0.89631
A3	0.0962	0.2222	0.1053	0.1000	0.1309	1.24364
A4	0.0962	0.1111	0.1053	0.1000	0.1031	1.03132

λ_{max} = 4.1613 ; *C I.* = 0.05376 ; *C.R* = 0.05974 x 100% =5.97% < 10% ; *R.I.* = 0.9 (Tab.2.)

Table 7. Comparison matrix for the sub-criteria B

Variant	B1	B2	B3	B4
B1	1	5	3	1
B2	0.2000	1	2	0.3333
B3	0.3333	0.5	1	1.1428
B4	0.5	0.3333	0.5	1
Sum	2.5333	9.5030	13.0028	2.4758

Table 8. Value of the normalized matrix and priority vector for the sub-criteria B

w_{ij}	B1	B2	B3	B4	Sum w_{ij}	Vector of priorities W_i^w
B1	0.3947	0.5261	0.2307	0.4039	0.3889	0.98516
B2	0.0789	0.1052	0.1538	0.1345	0.1181	1.12252
B3	0.1316	0.0526	0.0769	0.0577	0.0797	1.03625
B4	0.3947	0.3160	0.5386	0.4039	0.4133	1.02326

λ_{max} = 4.1671 ; *C I.* = 0.0557 ; *C.R* = 0.06192 x 100% =6.192% < 10% ; *R.I.* = 0.9 (Tab.2.)

Table 9. Comparison matrix for the sub-criteria C

Variant	C1	C2	C3	C4
C1	1	3	5	3
C2	0.3333	1	2	1
C3	0.2000	0.5	1	0.333
C4	0.3333	1.00	3.00	1
Sum	1.8667	5.5000	11.0030	5.3330

Table 10. Value of the normalized matrix and priority vector for the sub-criteria C

w_{ij}	C1	C2	C3	C4	Sum w_{ij}	Vector of priorities W_i^w
C1	0.5357	0.5455	0.4544	0.5625	0.5245	0.97913
C2	0.1786	0.1818	0.1818	0.1875	0.1824	1.00330
C3	0.1071	0.0909	0.0909	0.0624	0.0878	0.96655
C4	0.1786	0.1818	0.2729	0.1875	0.2052	1.09437

λ_{max} = 4.0433 ; *C I.* = 0.01444 ; *C.R* = 0.01605 x x 100% =1.6% < 10% ; R.I. = 0.9 (Tab.2.)

pact of each investment variant, it is necessary to analyze the sub-criteria described in sub-groups, respectively for each group of main criteria. The need to analyze sub-criteria is dictated by the limited number of criteria comparable directly and, on the other hand, by the fact that some of them would be difficult to compare directly.

The last step in the analytical process is to determine which of the criteria are the most significant in the assessment of variants prepared for the construction of a road. The hierarchy of criteria is built in the following stages:

a) calculation of the value of the vector of priorities (formulas 6 and 7) for each of the superior (main) criteria,
b) calculation of the component values of the vector of sub-criteria in each group within the main criteria (formulas 6 and 7),
c) calculation of the final value of the vector of priorities (according to formula 11) as the sum of products of component values of vectors of priorities of sub-criteria respective to main criteria, and their arrangement according to the values thus obtained. For example, the values of priorities (weights) of sub-criteria from group A are calculated from the formula:

$$w_j^A = \sum \overline{w_i^K w_i^w} \tag{11}$$

where: w_j^A – general value of the priority of a sub-criterion
w_i^K – value of the priority of a sub-criterion in the group of sub-criteria
w_i^W – value of the priority of the main criterion.

The calculations are presented below in a table (tab. 11)

Table 11 shows the results of the calculations. It is evident that the experts assigned the highest value to the criterion connected with the route of the planned road. The most important factor which influences the choice of a variant was the

Table 11. Hierarchy of criteria and sub-criteria

Sub-criteria	Vector of priorities in group of sub-criterion W_i^w	Vector of priorities global	Hierarchy of variants
A1	0.6664	0.0476	6
A2	0.0996	0.0071	12
A3	0.1309	0.0093	10
A4	0.1031	0.0074	11
B1	0.3889	0.2910	2
B2	0.1181	0.0884	4
B3	0.0797	0.0596	5
B4	0.4133	0.3092	1
C1	0.5245	0.0946	3
C2	0.1824	0.0329	8
C3	0.0878	0.0158	9
C4	0.2052	0.0370	7

length of the road crossing through environmentally valuable areas (including nature protected ones). The second most important criterion was the intrusion into migratory routes of wild animals. The third position in the ranking hierarchy was occupied by the necessity to build passages for animals. This is a sub-criterion which belongs to the second group, comprising infrastructure accompanying the main investment project, but as it is closely connected with the environmental criteria, and was evaluated equally high. It is a very important factor, and the choice of a specific solution can decide about the extent of the environmental impact, both while constructing the planned road and later on, while using it.

CONCLUSIONS

Execution of investment projects in the construction business is an extremely complicated matter. Among possible building structures, the ones which can have a considerable influence on the environment deserve our attention. These include the transportation structures. The major problem which occurs while building road constructions is their size. For instance, roads run for tens of kilometers through undeveloped land, where the conditions underlying any investment undertaking can be highly varied. This explains why it is essential to develop several variants of a construction project and to submit them to an assessment procedure, which will take into account various environmental factors.

The calculations performed in this study have shown how multi-criteria analytical methods can put all the relevant criteria in order, which can help us to decide whether a planned road should go across a given area or should another solution be chosen instead. The criteria associated directly with nature protected areas scored the highest. After arranging all the analysed criteria, the following ranking list can be proposed:

1. Length of the road cutting through environmentally valuable areas,
2. Intrusion into routes travelled by migratory wild animals,
3. Number of necessary passages for wild animals,
4. Number of trees to be felled,
5. Crossing over watercourses,
6. Technology of making the road surface,
7. Surface dewatering of the road,
8. Length of protective fences,
9. Length of access roads,
10. Delivery of materials and raw materials and their storage,
11. Time needed to build the road.

The example of an analysis presented in this article proves that multi-criteria analytical methods can be helpful in an assessment of criteria connected with the selection of a variant of an investment project, which in our case study was the expansion of a road network. Application of multi-criteria methods can facilitate the process of making important decisions.

REFERENCES

1. Abu Dabous S., Alkass S. 2008. Decision support method for multi-criteria selection of bridge rehabilitation strategy. Construction Management and Economics, 26 (8), 883–893.
2. Al-Harbi K.M. 2001. Application of the AHP in project management. International Journal of Project Management, (19), 19–27.
3. Brown M. A. 2012. Construction management: the management of the development, conservation and improvement of the built environment. Organization, Technology & Management in Construction: An International Journal, 4(2), 457–460.
4. Isaac S., Navon R. 2008. Feasibility study of an automated tool for identifying the implications of changes in construction projects. Journal of Construction Engineering and Management, 134(2), 139–145.
5. Marques G., Gourc D., Lauras M. 2011. Multi-criteria performance analysis for decision making in Project Management. International Journal of Project Management, 929(8), 1057–106.
6. Negahban S., Baecher G.B., Skibniewski M.J. 2012. A decision- making model for adoption of enterprise resource planning tools by small –to –medium size construction organizations. Journal of Civil Engineering and Management, 8(2), 253–264.
7. Rodriguez-Pose A., Fratesi U. 2004. Between development and social policies: the impact of European Structural Funds in Objective 1 regions. Regional Studies, 38(1), 97–113.
8. Saaty T. 2014. The Analytic Hierarchy Process. McGraw-Hill. New York.
9. Šelih J., Kne A., Srdić A., Žura M. 2008. Multiple-criteria decision support system in highway infrastructure management. Transport, 23 (4), 299–305.
10. Shen L. Y., Tam V. W., Tam L., Ji Y. B. 2010. Project feasibility study: the key to successful imple-

mentation of sustainable and socially responsible construction management practice. Journal of Cleaner Production, 18(3), 254–259.

11. Szafranko E. 2013. Application of the analytic hierarchy process (AHP) to evaluation of variants of a planned road investment project. Journal of International Scientific Publications: Materials, Methods & Technologies, Volume 7(1), 152 -164.
12. Szafranko E., 2015a. Multi-criteria methods in an analysis of variants of a construction project. International Journal of Scientific Publication, Materials, Methods & Technologies, Volume 9, 155–168.
13. Szafranko E. 2015b. Evaluation Of Variant Construction Projects Supported By Expert Opinion Systems Based On Multi-Criteria Methods. International Journal of New Technologies in Science and Engineering, 2(5), 39–46.
14. Law Regulations in Civil Engineering