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DECISION MAKING WITH USE OF AHP METHOD IN CONSTRUCTION

PODEJMOWANIE DECYZJI W BUDOWNICTWIE Z WYKORZYSTANIEM METODY AHP

Abstract

One of the most difficult problems in construction having to take an objective decision, especially when selecting contractors. The decision making process is both complicated and time consuming (due to the complex nature of construction projects). Many experts, with extensive knowledge of the Construction Industry, take subjective decisions, related to verbal methods of decision making. The previously mentioned difficulties mainly relate to the creation of a relevant criteria set, answering the decision makers questions. A proper criteria set and mathematical tools (like computer calculation algorithms with multi-criteria analysis) could significantly improve objective decision making. The authors present a case study – selection of contractors – with detailed calculations of AHP method.

Keywords: informatics tool, multi criteria decision making, AHP, contractors choice, case study

Streszczenie

Jednym z najtrudniejszych problemów w budownictwie jest podejmowanie decyzji, zwłaszcza dobór odpowiednich wykonawców. Proces decyzyjny jest bardzo skomplikowany i czasochłonny (ze względu na złożony charakter projektów budowlanych). Wielu ekspertów, z rozległą wiedzą o budownictwie, podejmuje subiektywne decyzje, związane z werbalnymi metodami podejmowania decyzji. Trudności związane są głównie z doborem odpowiednich kryteriów, odpowiadających oczekiwaniom decydenta. Zestaw odpowiednich kryteriów i narzędzi matematycznych (takich jak komputerowe algorytmy obliczeniowe dla oceny wielokryterialnej) może znacznie usprawnić proces podejmowania decyzji. Autorzy przedstawili studium przypadku – wybór wykonawcy ze szczegółowymi obliczeniami w ramach metody AHP.

Słowa kluczowe: narzędzia informatyczne, kryteria podejmowania decyzji, AHP, wybór wykonawcy, studium przypadku

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1. Introduction

One of the main problems faced by every investor/project manager are decisions required regarding selection of the investment project implementation variant [13, 14]. The difficulty associated with this issue emerges as early as at the investment preparation stage, when the investors requirements and expectations of are defined in the functional and utility program. At individual stages during the life cycle of the undertaking, the phenomena analyzed are very complex, mainly due to the specific traits, characteristics, complexity and nature of construction processes and relations between them. On the other hand, a description of these relations, based mainly on expert opinions, should take into account factors which are both measurable and those which are difficult-to-measure [17], and its quality depends largely on the expert knowledge and experience of the decision-makers.

The issue of decision-making constitutes an integral part of every field of science and art. The decision-making process is an activity, which results in the making of a specific decision. For the entity of the decision-making process, the decision-maker is involved, expressing specific preferences, assessing, possibilities and results as well as choosing the final decision-making variant [2, 3, 5, 6, 10, 13–15]. Analyzing the decision-making situation is the first task of the decision-maker. The decision-making situation is a set of all elements, which are dependent and independent of the assessor, which exert an impact on the decision to be made. In the process of formulating the decision-making problem, the factors independent of the decision-maker include the set of variants being examined (the so-called conditions restricting the decision), while factors dependent upon the decision-maker include the criteria of the assessment of solutions, described by technical and economic indicators, most adequate for a given decision-making situation, expressed in specific units [2, 8–10, 15].

The assessment of variant characteristics may be both quantitative (objective) and qualitative (difficult to measure) [17]. The difficulty in decision-making is due not only to the level of complexity of the task and designation of the variants, but also the expectations of the person doing the assessing. On the other hand, the preferences of the expert are largely dependent upon the point of view of the decision-maker, who has caused the given opinion or assessment to develop. The authors believe that, due to the above reasons, computer-based implementation of calculation algorithms of the selected methods of assessment and ranging solutions is an efficient tool, allowing aggregated variant assessments to be obtained, making the decision-making process more efficient. Detailed information concerning the issues of the valuating criteria, as well as the psychological aspect of decision making have been presented in [1, 2, 10, 15]. An exemplary course of the decision-making process has been presented using the AHP method as an example [16].

2. The main assumptions of the methodology

According to the authors, calculation algorithms of various types of methods of multi-criteria assessment as well as theoretical apparatus, including sociological and psychological theories lay behind decision making. The decision-making analysis contributes to the greater effectiveness of the decision-making process help avoid substantial mistakes which could interfere with the quality and reliability of the decisions made. In practice, individual tools are often used selectively, which often garbles the assessment results. The experts are expected to make assessments in accordance with their professional knowledge and construction art – reliable, objective, taking the specific character of a given decision-making situation into account. It would be difficult, however, to clearly define individual preferences, systems of values and motivations of an expert. Expert opinions are formulated on the basis of their knowledge and experience and they depend upon such factors as availability of information and the level of complexity of the task, emotional state and mood, self-esteem and susceptibility to group influence as well as the perception of a given phenomenon [2, 10–12, 15]. In some cases, the difficulties associated with decision-making could be due to fear of assuming responsibility, making a mistake or being rejected by the community. In order to eliminate as many causes of interference associated with decisions to be made as possible, an original survey of decision-maker preferences has been developed, as well as a decision-making variant ranging procedure. The intention of the survey, developed within the framework of this research, in the opinion of the authors, was – in the first place – to clearly define and fine tune the assessment of variants, referring to the problem of selection of the best investment (e.g. premises, building) from the perspective of the expectations of potential recipients (users).

3. Definition of pre-qualification

Preliminary qualification is also called pre-qualification. Hatush and Skitmore [4] define pre-qualification as the process preceding the tender, used to examine and assess the contractor from a perspective of their capability to perform the contract successfully. This procedure is carried out on the basis of a set of preliminary qualification criteria. Thus, pre-qualification can be referred to as a selection of building contractors from the investor (or their proxy) on the basis of a subjective set of criteria, aimed at assessment of predispositions of the company to properly implement the construction project. In practice, this means that any contractor wishing to participate in the tender must first undergo the pre-qualification process. Two types of qualification procedure can be distinguished, which can also be applied as two of the stages of pre-qualification [7]: standing list and per project prequalification. Creation of a list of contractors able to perform specific types of projects (e.g. contractors having specialist equipment or specializing in performance of a given type of construction works). Such lists are created by public and private (large and small) investors. Only those companies included on the appropriate standing list are invited to participate in tenders for performance of specific types of works. A list of this kind needs to be updated at least once every two years and the group of contractors selected must be those most suitable for a given construction project; this form of qualification is more precise than the standing list, described above, and it is performed as necessary for a specific project. As a result, a short list of companies invited to tender is established.

4. Example of AHP method use – case study

During paired comparison (determination of key factors dominance) authors assumed grading scale suggested by Trzaskalik [16], based on Saaty solution (table 1). Hence grades entered in the matrix belong to the set: {1/9; 1/8; 1/7; 1/7; 1/5; ¼; 1/3; ½; 1; 2; 3; 4; 5; 6; 7; 8; 9}.

Table 1

Grade scale – pair-wise comparison (developed internally on the basis of [16])

Grade	Verbal judgments of preferences
1	Equally preferred
3	Moderately preferred (variant 1 better then variant 2)
5	Strongly preferred (variant 1 better then variant 2)
7	Very strongly preferred (variant 1 better then variant 2)
9	Extremely preferred (variant 1 better then variant 2)
2, 4, 6, 8	In-between assessments (variant 1 better then variant 2)
Reciprocal grades	Equivalent preference but variant 2 better then variant 1

Table 2

Average random consistency (RI) (developed internally on the basis of [16])

Size of matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

In this case study three contractors (A, B, C) are being assessed on the basis of four criteria: experience, financial stability, reputation and organizational skills. Contractors properties were assessed by experts (shown in Tab. 3). The following Tab. 4, 5, Fig. 1, 2 and formulas 1, 2, 3 show calculations for first criteria – experience. There is a need to prepare similar calculations separately for all selected criteria. So the first step of the procedure is to develop a set of comparison matrices. The pair-wise comparison should be made by qualified experts. Then, a synthesized matrix is created. This is achieved by dividing the relevant fields in the comparison matrix by the sum of values in the proper column. For example field AA = 0.652 was calculated as division of field AA of comparison matrix (table 4) = 1 by value of 1.533 (1.533 = 1 + 1/5 + 1/3). Priority vector is obtained by calculating average values of fields in synthesized matrix rows (Tab. 5). For example, for A row it is (0.652 + 0.625 + 0.667)/3 = 0.648.

Table 3

Contractors properties – criteria (own study)

	Contractor A	Contractor B	Contractor C
Experience	4 years on the market 3 similar projects	8 years on the market none similar projects	7 years on the market 1 similar projects
Financial stability	Average	Very good	Very good
Reputation	Excellent	Very good	Good
Organizational skills	Good	Very good	Average

Table 4

Comparison matrix – Experience assessment (bold lines) (own study)

Experience	A	B	C
A	1	5	3
B	1/5	1	1/2
C	1/3	2	1
Σ	1.533	8.000	4.500

Table 5

Synthesized matrix – Experience assessment (bold lines) (own study)

Experience	A	B	C	priority vector
A	0.652	0.625	0.667	0.648
B	0.130	0.125	0.111	0.122
C	0.217	0.250	0.222	0.230
				Σ = 1.000

The next step is to calculate maximum eigenvalue λ_{max}. To do so, a weighted sum matrix (Fig. 1) is created by multiplying the comparison matrix by the priority vector. Then the results are divided by the relevant elements of the priority vector (Fig. 2).

$$0.648 \begin{bmatrix} 1 \\ 1/5 \\ 1/3 \end{bmatrix} + 0.122 \begin{bmatrix} 5 \\ 1 \\ 2 \end{bmatrix} + 0.230 \begin{bmatrix} 3 \\ 1/2 \\ 1 \end{bmatrix} = \begin{bmatrix} 1.948 \\ 0.367 \\ 0.690 \end{bmatrix}$$

Fig. 1. Weighted sum matrix (own study)

$$\frac{1.948}{0.648} = 3.007 \ , \ \frac{0.367}{0.122} = 3.001 \ , \ \frac{0.690}{0.230} = 3.003$$

Fig. 2. Elements of weighted sum matrix divided by relevant elements of priority vector (own study)

The maximum eigenvalue for criteria – experience is the average of calculated values (formula 1). Consistency index *CI* is calculated on the base of formula 2, where n is the number of contractors. For $n = 3$, random consistency $RI = 0.58$. which is why the consistency ratio *CR* is derived from formula 3 (requested condition was fulfilled – comparison consistent).

$$\lambda_{max} = \frac{3.007 + 3.001 + 3.003}{3} = 3.004; ; \quad (1)$$

$$CI = \frac{ë_{max} - n}{n-1} = \frac{3.004 - 3}{3-1} = 0.00185 \quad (2)$$

$$CR = \frac{CI}{RI} = \frac{0.00185}{0.58} = 0.003187 < 0,1 \quad (3)$$

After calculations for all criteria it is necessary to follow the same calculations for all sets of criteria. The experts task is to compare all of the criteria – experience, financial stability, reputation and organizational skills.

Table 6

Comparison matrix – All criteria comparison (bold lines) (own study)

Criteria	Exp.	Fin. Stab.	Rep.	Org. Sk.
Experience	1	1/2	1/4	1/7
Financial Stability	2	1	1/2	1/5
Reputation	4	2	1	1/3
Organisational Skills	7	5	3	1
Σ	14.000	8.500	4.750	1.676

Table 7

Synthesized matrix – All criteria comparison (bold lines) (own study)

Criteria	Exp.	Fin. Stab.	Rep.	Org. Sk.	Priority Vector
Experience	0.071	0.059	0.053	0.085	0.067
Financial Stability	0.143	0.118	0.105	0.119	0.121
Reputation	0.286	0.235	0.211	0.199	0.233
Organisational Skills	0.500	0.588	0.632	0.597	0.579
					Σ = 1.000

Then, maximum eigenvalue is calculated (Fig. 3) for all criteria in the same manner as presented on Fig. 1, 2 and in formula 1.

The consistency index *CI* is calculated for all criteria on the basis of formula 4, where n is a number of criteria. For $n = 4$, random consistency $RI = 0.90$. which is why the consistency ratio *CR* is derived from formula 5 (requested condition being fulfilled – comparison consistent). The final step of the procedure is to calculate the overall priorities of each contractor and then create their ranking (hierarchy of contractors).

$$0.067\begin{vmatrix}1\\2\\4\\7\end{vmatrix}+0.121\begin{vmatrix}1/2\\1\\2\\5\end{vmatrix}+0.233\begin{vmatrix}1/4\\1/2\\1\\3\end{vmatrix}+0.579\begin{vmatrix}1/7\\1/5\\1/3\\1\end{vmatrix}=\begin{vmatrix}0.269\\0.487\\0.936\\2.352\end{vmatrix}$$

$$\frac{0.269}{0.067}=4.006,\quad \frac{0.487}{0.121}=4.019,\quad \frac{0.936}{0.233}=4.025,\quad \frac{2.352}{0.569}=4.062$$

$$\lambda_{\max}=\frac{4.006+4.016+4.025+4.062}{4}=4.028$$

Fig. 3. Maximum eigenvalue for all criteria – calculations (own study)

$$CI=\frac{\lambda_{\max}-n}{n-1}=\frac{4.028-4}{4-1}=0.00946 \tag{4}$$

$$CR=\frac{CI}{RI}=\frac{0.00946}{0.90}=0.010506<0.1 \tag{5}$$

The overall priority is calculated as show on Fig. 4 (values from criteria comparison priority vector – from Table 7 – are given without brackets and values from priority vectors for each criteria – in brackets).

Overall priority for Contractor A = 0,067·(0,648) + 0,121·(0,077) + 0,233·(0,557) + 0,579·(0,234) = 0,318
Overall priority for Contractor B = 0,067·(0,122) + 0,121·(0,462) + 0,233·(0,320) + 0,579·(0,688) = 0,537
Overall priority for Contractor C = 0,067·(0,230) + 0,121·(0,462) + 0,233·(0,123) + 0,579·(0,078) = 0,145

Fig. 4. Maximum eigenvalue for all criteria – calculations (own study)

Calculations show, that Contractor B is the best one, according to chosen criteria.

5. Conclusions

Mathematical and thus objective methods that support the decision-making process in construction undoubtedly help the everyday work of a construction manager. The AHP method allows an optimum solution to be selected among defined alternatives (evaluation problem) or in the identification of a preferred alternative among the potentially infinite, suggested set of alternatives, defined from the perspective of the set of restrictions (design problem). This support of the decision-making processes provides many advantages:

– allowing the decision-making process to be viewed from a different perspective, by ordering the criteria and variants within the framework of the established hierarchy;
– reduces the multi-criteria problem to a number of simple comparisons in pairs of individual criteria and variants within the framework of the established hierarchy;
– provides the possibility of joint analysis of measurable and non-measurable criteria and obtaining an aggregated assessment of variants;
– eliminates the risk of a decision being influenced by bias and manipulation;
– allows for the analysis of sensitivity (impact of changes of individual unit assessments upon the final decision).

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