TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

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WAYS TO DETERMINE CRITERIA IN MULTI-CRITERIA METHODS APPLIED TO ASSESSMENT OF VARIANTS OF A PLANNED BUILDING INVESTMENT

SPOSOBY OKREŚLANIA KRYTERIÓW W WIELOKRYTERIALNYCH METODACH OCENY WARIANTÓW PLANOWANEJ INWESTYCJI BUDOWLANEJ

A b s t r a c t

When planning a construction investment, an evaluation is often performed. In order to make the best possible choice, it is necessary to define the correct specification of the evaluation criteria which will guide us through the decision-supporting procedure. Some criteria refer to measurable phenomena, hence they can easily be defined. Others, however, need to be described with linguistic methods and require adequate scale and identification methods. This article presents methods used to prepare and choose the correct criteria for carrying out an assessment of the building investment, applicable to various criteria and different multi-criteria methods.

Keywords: building investment, multi-criteria methods

S t r e s z c z e n i e

Na etapie planowania inwestycji budowlanych często przeprowadzana jest ocena wariantów ich realizacji. Aby dokonać optymalnego wyboru, należy właściwie określić kryteria oceny, którymi będziemy się kierować, przeprowadzając procedurę wspomagania wyboru. Niektóre kryteria dotyczą zjawisk mierzalnych i są łatwe do definiowania i wagowania. Inne natomiast wymagają opisu metodami lingwistycznymi, ustalenia właściwej skali i odpowiednich metod ich identyfikacji. W artykule zaprezentowano metody właściwego doboru kryteriów oceny wariantów inwestycji budowlanej dla różnych kryteriów i różnych metod analizy.

Słowa kluczowe: inwestycje budowlane, analiza wielokryterialna

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1. Introduction

A decision is when a decision-maker wishes to make a change to the existing situation. Each decision comprises some elements of randomness and its economic, social, organizational and market consequences are not easy to predict. In practice, a decision-making process focuses on analyzing alternatives which – to a greater or lesser extent – fulfill the set of desired goals. Thus, a decision means choosing one of these options. In the construction industry, decisions are made and alternatives chosen at the stage of planning a building investment and selecting a variant solution [1, 4]. When analyzing all executable variants, we deal with a series of criteria regarding the location, impact on the environment, construction solutions, costs and benefits, social and economic costs, etc.

In order to solve multi-criteria problems [6], we often try to capture our expectations with the aid of a single criterion which aggregates all significant consequences related to the problem. If that is the case, we face the task of performing a single-criterion analysis, in which each potential variant is valued against an a *priori* chosen criterion, e.g. costs, inputs, time of execution, profit, rate of return, benefits. The following are used to solve the type of problems listed above using: linear programming methods, parametric programming, target programming, margin analysis, stochastic programming, non-linear programming, etc. Although this approach can only be justified in some *albeit* very simple cases, using a single-criterion reference cannot be recommended for complex investment processes, being not completely reliable and lacking the properties that would enable the presentation and analysis of the whole spectrum of questions and problems connected with the process of planning and preparing building constructions. A multi-criterion decision-making process, unlike a single-criterion analysis, enables one to express a cohesive family of criteria as an instrument of full and exhaustive communication, which should facilitate the formation, justification and transformation of preferences during the decision-making process.

2. Characteristics of a criteria's variety in the multi-criterial analysis

Multi-criteria decision supporting requires the participation of many individuals, who are experts providing their opinions on specific topics [6, 7]. Expert opinions are the basis for determining the criteria which will be significant for further steps in the decision-making process. Typically, experts express different viewpoints, which are the result of their different perception of the reality and process which are taking place in real world. This diversity of opinions presented by specialists is also due to the different functions they play in the investment process. This is why both the assessment and its final outcome can be burdened by some error, which should be kept in mind. Subjectivity can mainly be encountered when applying methods which include the analysis of quality-type factors. When so-called 'measurable factors' are assessed, the result of an assessment against a given criterion are obvious. Two methods for obtaining an objective assessment of quality-type factors can be considered. One is a descriptive evaluation of the importance of a criterion. The other one requires adopting a numerical measurement scale. Non-measurable factors often appear when planning an investment project. They can be taken into consideration in such multi-criteria methods as the MCE analysis, the AHP analysis or indicator methods. However, the final results of these analysis can be difficult to evaluate.

The MUAT (Multi Attribute Utility Theory) method is frequently used to analyze the effects a development project may have on the environment. It relies on two assumptions. Firstly, there is often incomplete input data regarding the natural environment around the site where a building investment will be located. Second, the person who performs an environmental impact analysis is under pressure to hide ongoing events and their consequences, whose occurrence is uncertain and difficult to predict [4, 6, 8]. The first step in an analysis carried out according to the MUAT method is to determine the measurable parameters of the natural environment at the site of a future construction object, such as the level of noise, exhaust fumes, surface water pollutants, etc. The characteristics chosen for the analysis are those which enable a quantitative evaluation of the state of the environment. There may be various measures or states for each type of impact, which can be calculated with the aid of forecasts or models worked out from multi-year monitoring procedures. The second stage is to express the utility function $U(x)$ on a 0–1 scale, where 0 means the least utility and 1 stands for the highest utility. Once utility functions $U_i(x_i)$ are determined for individual characteristics of the environment, it is possible to present mutual connections by determining weights or scaled values for each parameter describing the natural surroundings. Scaled values are a reflection of the relative value in which decision-makers perceive different attributes. The total utility or a complex index of the quality of the analyzed natural environment ***WJ*** can be derived from the formula:

$$\boldsymbol{WJ} = U(x) = \sum_{i-1}^{n} K_i \cdot U_i(x_i) \tag{1}$$

where:

K_i – an index of scaling an attribute which describes the i^{th} element of the analyzed environment,

$U_i(x_i)$ – utility function of the i^{th} attribute (parameter) of the analyzed environment.

This method has many advantages, such as the introduction of numerical values which describe individual characteristics of the environment. A possible disadvantage is that the outcome may not be easily readable, depending on how detailed the analysis has been. This method is mainly applied to considerations of the variant locations of the building investment.

The MCE (*Multi-Criteria Evaluation*) analysis is applied to support a decision-making process when several or more than criteria are at hand. The aim is to achieve one, shared result [6, 8]. The first step in an MCE analysis is to determine the criteria which will lead to the achievement of the set aim. The criteria appearing in the MCE can be divided into two groups: hard ones, known as *constraints*: barriers, limitations, and soft ones, called *factors*: parameters, factors.

When using constraints, the results are achieved in the form of a juxtaposition of variants which may or may not fulfill the set requirements. In turn, by using soft criteria, one arrives at a degree of the suitability of given variants for attaining a goal which is set during the analysis. The result thus obtained is not as uni-vocal as the one attained through the application of hard criteria [6]. The suitability is calculated from the formula:

$$S = \sum_{i-1}^{n} w_i \cdot x_i \quad i \in \langle 1, n \rangle \tag{2}$$

where:

S – suitability,

w – weight of a criterion,

x – value of a parameter,
i – a criterion,
n – number of criteria.

In an analysis which also contains barrier-type criteria, the formula looks as follows:

$$S = \sum_{i-1}^{n} w_i \cdot x_i \Pi c_j \tag{3}$$

where there is an additional symbol, namely c_j – j^{th} constraint [6].

The criteria taken for an analysis relate to the need of meeting set requirements by the analyzed variant. Using the Boolean overlay method, for example when selecting a site to be developed, criteria are defined as barriers (e.g. at least 200 m away from a water body, an area with the land slope less than 3°). We then achieve a one-zero suitability raster image (where 1 stands for a suitable site and 0 – for an unsuitable site). The final suitability raster is a simple product of unit suitability raster maps (except for the conjunction in formula 2). In some cases, such criteria can be defined with softer ones, e.g. the further away from a water body the better, the less steep the site, the better, etc. However, this precludes any direct comparison of the distance to a water body and the degree of land slope at a given point. This is the reason why certain standardization of thus defined criteria is carried out according to this formula:

$$x_i = \frac{R_i - R_{\min}}{R_{\max} - R_{\min}} \cdot d \tag{4}$$

where:

x_i – a parameter corresponding to a given condition after standardization,
R_i – value of the parameter before standardization,
R_{min}, R_{max} – the minimum and maximum value of the parameter of the criterion,
d – standardization interval [6].

Standardization is run within a set range, e.g. 0–255. Then, the maximum suitability is 255 and the minimum one is 0. Having completed the standardization, each point in the analyzed variant has an assigned value of suitability within the range of 255.

The method is based on the Analytic Hierarchy Process (AHP) which enables consideration of various criteria which ensure the attainability of a given goal. The underlying assumption is that the goal is attainable through the achievement of partial aims leading to the main goal. The analyzed solution variants meet to a greater or lesser extent the achievement of the major goal. The degree to which the major goal is satisfied by each decision variant is determined by the degree to which main criteria and adequately grouped sub-criteria are fulfilled. The decomposition of a problem makes it easier to perform an assessment and is the essence of the AHP [7, 9]. Three steps (stages), connected in an integrated and logical series, are taken to solve a problem:

1. Structuring a hierarchical model (determination of criteria);
2. Evaluation of the criteria on a 9-point evaluation scale;
3. Evaluation and ordering the variants against the established the priorities (main weights), taking into account the analysis of vectors of partial priorities.

The references [7, 9] contain formulas for calculations carried out in three subsequent stages, which lead to the calculation of values of the priority index. These are:

– calculation of the value of a normalized matrix:

$$\overline{w_{ij}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{5}$$

– determination of the value of the vector of partial priorities

$$\overline{w_j} = \sum_{j=1}^{n} w_j a_{ij} \tag{6}$$

where:

$$w_j = \frac{\sum_{i=1}^{n} w_{ij}}{n} \quad i, j = 1 \ldots n \tag{7}$$

In order to verify whether the procedure was correct,

– we determine the maximum own value of the matrix:

$$\lambda_{\max} = \frac{1}{w_i} \sum_{i=1}^{n} a_{ij} w_j \tag{8}$$

– the value of the consistency index:

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \tag{9}$$

– – and the value of the consistency ratio:

$$C.R. = \frac{C.I.}{R.I.} \tag{10}$$

where the *C.R.* should reach the value < 10%

The *R.I.* – an index of random consistency depends on the *n* number of compared elements. The consistency index and ratio can serve as verification of the correctness of setting data which represent mutual relations between determined criteria.

Index methods are based on matrices, in which individual criteria are described with the help of indices and weights defining their importance for the execution of the analyzed project. The number in the top left-hand corner of each cell is the index which describes the immediate effect, while the one in the lower right-hand corner stands for the indirect effect on the examined element of the natural environment. In the middle of each cell there is a sum of effects multiplied by the weight. For both the assessment of the effects on the environment and determination of weights it is necessary to secure expert opinions. This method is especially useful when the analysis must take negative effects into consideration, which in the model table above are represented by negative values of the criteria.

Literature presents many other methods of multi-criteria analysis such as: based on artificial neural networks and fuzzy logic.

3. Selection of significant criteria

To a large extent, choosing the best possible variant of construction investment depends on being able to correctly define and estimate the assessment criteria. They may vary in character [2, 3]. Depending on the phenomenon they describe they can be expressed in measurable units (km, tons, items) or in a non-measurable manner (impact on the environment, formal and legal requirements, a social effect, etc.). These may be strict or soft criteria. When strict criteria (constraints) are applied, the feedback tells us whether or not a given variant satisfies the set requirements. The information obtained from an analysis of soft criteria (factors) shows to what degree the goal which was set during the analysis has been fulfilled [7]. The degree of satisfying the expectations pertaining to the analyzed building project is differentiated by assigning weights to the said criteria. Examples of constraints concerning the selection of a building site are flood plan (At risk of being flooded), private land – can it be purchased?, protected lands. Constraints answer the question whether it will be possible to carry out a building investment project on a given piece of land. Other aspects, e.g. construction solutions or the unwanted impact on the environment, can be considered in a similar fashion.

Soft criteria [7] refer to gradable phenomena. They can be presented in a descriptive form or by assigning weight points for fulfilling the requirements to a higher or lesser degree. Examples of soft criteria are: distance to a public road (in km), costs of the investment (in PLN), attractive surroundings, e.g. parks, recreational grounds, entertainment facilities (a descriptive scale), effect on the surrounding environment – different aspects (a descriptive scale), number of trees to fell (in items).

The starting point for a multi-criteria analysis conducted with any of the mentioned methods consists of an estimation of the importance of predefined criteria. This stage must be completed with the contribution of many experts. Their participation and numerous opinions are required due to the different perceptions of the reality and ongoing processes. Expert opinions tend to vary and standpoints are subordinated to different priorities, systems of values, different scopes of knowledge, education and experience. Expert opinions are collected through interviews, which consist of survey forms. Different survey forms should be prepared for different analytical methods and the questions should be formulated in such a way as to allow the analyst to distinguish the basic input data for further procedures. The assessment of criteria in the MUAT and MCE methods is performed with the criteria being divided into constraints and factors. The assessment can be a one- or two-stage procedure. In a one-stage protocol experts are given a survey with a prepared list of criteria and answer questions about their importance, using a scale proposed in the questionnaire for this purpose. Following an analysis of the results, it is possible to verify the proposed list of criteria. In a two-stage procedure, the first step involves asking experts to state what criteria they consider important. Based on the replies given, a list of criteria is structured and submitted to an evaluation in the second stage of the procedure. In the AHP method, a person gives their opinion (using an AHP fundamental scale of comparisons) and responds to two types of questions, regarding the power of the advantage of compared elements versus a given criterion (which is more advantageous?): – which of the two given sub-criteria affects to a greater extent the third element, which is the main criterion? Apart from pairwise comparisons, in a decision support AHP protocol it is also possible to employ real (actual) numerical data or statistical data related to our problem or some of it (e.g. values representing costs, achieved technical parameters of an investment, etc.).

In the indicator method, the survey addressed to experts is different from other questionnaires in that that the analysis will also include evaluations of the negative consequences of the planned investment. The surveys therefore also contain questions about the consequences with a different scale for replies. When analyzing variants of an investment with this method the criteria can be assessed on a scale, for example, from –5 to +5. This approach also enables respondents and analysts to evaluate the adverse effects of a given development project.

4. Basic methods of aggregating opinions and preferences

Experts chosen to provide data for an analysis usually work according to one of the two paradigms. The first one involves cooperation while making an assessment of the criteria within the group examined. By sharing and exchanging opinions, individual experts assign the importance (weights) or evaluate the effect on attaining the goal and the results of their assessment are then averaged. Typically, a geometrical mean of the assessments provided by individual experts is applied to this aim. Divergent opinions can be obtained, hence there is a possibility to discard some information which is too discrepant from the rest of the data. This method needs experts who are familiar with it but it also enables analysts to obtain data ready for analytical processing. The other type of protocol relies on surveys in the form of tables, so that experts work independently and assign points according to the scale imposed by the analyst. The data thus obtained requires further processing and may need to be completed, while the whole survey may have to be repeated several times due to some inconsistency of the results.

If expert opinions are gathered in order to perform an AHP analysis, then all criteria and sub-criteria on the same level are compared pairwise [2, 3]. The assessments refer to a group of n attributes and generate a matrix of assessments, which are composed of assessed elements *aij* (*k*). In other methods, it is necessary to assign weights to individual criteria. Some preliminary analysis is required before information about weights is gathered, or else reasonable intervals must be set for which points or descriptive assessments will be assigned. These intervals should be established so that the status that will decide on the higher or lower value given to each attribute can taken into consideration.

Values of weights expressing preferences relative to subsequent attributes can be determined, for example, by using one of the most highly recommended methods: the logarithmic least squares method (LLSM) [10], better known as the simple geometric mean (SGM) method [2, 3]. Values of weights of attributes are:

$$P_i = \sqrt[n]{\prod_{j=1}^{n} r_{ij}} \tag{11}$$

For practical reasons, associated with the aggregation of hierarchies of sub-criteria, it is generally expected that weights should add up to one. This is why [2, 3] it may be necessary to perform normalization of weights:

$$\overline{p}_i = \frac{p_i}{\sum_{j=1}^{n} p_j} \tag{12}$$

While analyzing results derived from reports worked out by experts one should take various circumstances into account. Due to the degree of complexity of the decision to be taken, it is justifiable to make an attempt to secure diverse opinions. Another justification is that different expert may have gained different knowledge and know-how. Consequently, one may use vectors of preferences, defining hierarchical lists prepared by experts. Such hierarchies can, for instance, include experts' experience or usefulness of their knowledge in each specific case.

5. Conclusions

The nature of investments in the building industry means that while planning a construction project it is obligatory to consider opinions of different groups interested in a given development and to include some information which is difficult to measure. Dynamic changes in the environment and a huge variety of aspects which will eventually affect the shape of building structures make flexible decision-support instruments extremely useful. The great diversity of analyzed aspects translates into an equally great number of criteria, which should be considered by decision-makers. Multi-criteria analytical methods, briefly presented herein, should include many criteria, but before they are applied, some data about a series of conditions which will govern a planned investment should be collected and analyzed. The information discussed in this article proves that there are many approaches which enable us to take advantage of the benefits offered by these methods.

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