Decision problems in management of construction projects

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Abstract. In a construction business, one must oftentimes make decisions during all stages of a building process, from planning a new construction project through its execution to the stage of using a ready structure. As a rule, the decision making process is made more complicated due to certain conditions specific for civil engineering. With such diverse decision situations, it is recommended to apply various decision making support methods. Both, literature and hands-on experience suggest several methods based on analytical and computational procedures, some less and some more complex. This article presents the methods which can be helpful in supporting decision making processes in the management of civil engineering projects. These are multi-criteria methods, such as MCE, AHP or indicator methods. Because the methods have different advantages and disadvantages, whereas decision situations have their own specific nature, a brief summary of the methods alongside some recommendations regarding their practical applications has been given at the end of the paper. The main aim of this article is to review the methods of decision support and their analysis for possible use in the construction industry.

1. Introduction
Management in a construction business entails making series of decisions. The solutions which are finally accepted will affect the course of building works as well as the final shape of an edifice or a structure, while consequences of the decisions will often be felt in many years to come, when the erected construction is being used. Dilemmas can emerge at every stage, from choosing the location of a new construction project, through the stage of making plans and designs, selecting technologies, materials and structures, to issues of the management of the project itself, project quality or risk. Any deeper insight into this problem calls for the clarification of the term ‘decision’ [1].

According to definitions quoted by many [2, 3], a decision is a choice of one option among available alternatives. If there is no alternative, there is no choice either. There are many decision support methods, which can help to solve a dilemma. One such possibility is a quantitative decision making technique. Its main assumption is to rely exclusively on data which undergo analysis so as to generate facts. If there is a sufficient amount of data justifying the purposefulness of an action considered, such information can play a decisive role. This perception of a decision problem excludes any subjective evaluation, intuition, premonitions or a bias in the way one sees a problem, and forces one to justify one’s decision, which entails exposing all assumptions and limitations that underlie the decision [4].

While making decisions, it is essential to adhere to previously established principles [5]. The absence of guidelines can cause chaos and eventually mislead one towards some erroneous solutions. Decisions are always subject to certain restrictions arising from preceding events or from the current circumstances. The main criteria, which are either overt or hidden, can be grouped as follows: a set of
goals and a system of priorities, an ordered sequence of alternative actions, consequences of each alternative, a system of selection criteria.

Another significant notion underlying the problem raised in this article is the question why decisions are made [5]. There are groups of activities in the construction business (planning, making building plans and designs, management, execution of construction work, organization, etc.) which force making decisions. Efficient decision making means more efficient management of building projects and opportunities to improve management methods. The reasons why decisions are made can be sought in many areas of everyday life, for example: economic reasons – including both costs of preparing an undertaking and its execution or future maintenance costs of a building, human motivation – fulfilment of biological, physical or social needs, organization – efficient and timely execution of the building work and schedules. A need to look for an appropriate solution arises whenever the guidelines are not coherent, the criteria for an evaluation of alternatives escape easy comparisons, or when too many goals have been defined and it is difficult to decide which are priority ones [5].

2. Decision making process in civil engineering and construction

The process of making decisions can be discussed including decision makers involved in three phases of a construction project [6]. Two of these phases lie in the scope of responsibilities of a person directly making decisions. Third and last phases comprise decisions which can be delegated to someone else.

Phase 1: Setting up goals; Identifying limitations outside the system; Identifying alternative strategies; Estimating significant advantages.

Phase 2: Selecting a strategy.

Phase 3: Implementing the strategy.

Four principal approaches to a decision making process can be distinguished: inductive, deductive, development of a benefit matrix, and marginal analysis. These approaches are distinctly different from one another, which is why they can be used separately, in a sequence, or in conjunction with each other [7]. The biggest problem in using the above tools lies not in their internal procedures, but in making a choice of which one to apply. What is essential here is to have adequate knowledge supported by reliability, regularities and economic factors.

When making decisions concerning building projects (often public purpose ones), it is unadvisable to consider only costs or economic profits. Other, non-economic criteria should be viewed separately, and costs should be used as additional information and can be compared directly. However, costs are often included into a group of criteria as economic parameters and then are assigned relatively much weight. To avoid a routine attitude and automatic adherence to regulations or the influence of strong groups and social pressure, it is suggested to perform a detailed analysis and to decompose decision situations into constituents, which should then undergo re-evaluation. Unfortunately, analyses at the preliminary decision making stage do not always proceed as described above. Often, they are optimized only in parts, e.g. with respect to just one parameter, or they are satisfactory albeit not optimal choices, which means that the analyzed criteria are satisfied to a lowest acceptable degree. Decisions which are not supported by a complete analysis can be unsatisfactory or even erroneous. Another problem worth noticing is that decisions optimized at the moment when they are being made, may not be perceived as optimal ones after some time (and vice versa). It is also important to remember that the execution of a construction project changes the environment and makes it respond to the change, which often means countereacting the ongoing development. Social protests have made many construction projects harder or impossible to complete. Optimization of decisions should also take into account the acceptance of the analyzed project in its environment, including the local community. Being aware of these difficult and complex conditions underlying decision making processes, we can now suggest different decision making support methods.

3. Methods for analysis of building projects

The choice of a method should be guided by such attributes as the method’s readability, quality of results and ease of their verification as well as the applied mathematical apparatus. The subjectivity of
assessment is also worth giving a thought because many commonly used methods are based on opinions of experts or persons involved in the analyzed project. Hence, their assessment as well as the final result of a performed analysis can be laden with error, fact which must not be neglected. Subjectivity occurs mostly in methods which revolve around the analysis of factors that are qualitative in character, and therefore not measurable. With regard to the so-called measurable factors, assessment based on such parameters is obvious. There are two approaches to obtaining an objective assessment of qualitative factors. One way is through descriptive evaluation, while the other requires that a numerical scale of measurements be adopted. An option to include such factors in a decision making process is provided by a variety of multi-criteria methods, e.g. MCE, AHP or indicator methods. However, it is difficult to estimate what error the final results are burdened with. An assumption can be made that these approximations are acceptable but require some additional interpretation before arriving at a rational decisions. Each of these methods has some specific characteristics, which variously affect the final outcome of an analysis [8].

Apart from methods based on analyses of many criteria via mathematical techniques, there are descriptive and graphical approaches. In different decision making situations, these methods can be as useful as computational solutions. Some methods possessing different features and characterized by different degrees of complexity will be presented underneath.

3.1. The Multi-Criteria Evaluation (MCE) Method

Method is applied to support a decision making process when several, sometimes more than a dozen, of criteria are at one’s disposal. The aim of this method is to achieve one, shared result for all criteria. The first step in an MCE analysis is to determine the criteria that will lead to the attainment of a pre-defined goal [9]. The criteria which appear in MCE can be split into two groups:

- hard criteria (constraints): barriers, limitations,
- soft criteria (factors): parameters, factors.

While applying hard criteria, the results are generated as a map that shows the locations which fulfill and which do not fulfill the set conditions. In other cases, following an application of hard criteria, some variants of a construction project are discarded. In turn, through the use of soft criteria, we achieve degrees of the suitability of the analyzed options for the purpose identified during the analysis. A result achieved through soft criteria is not as unequivocal as the one produced by hard criteria. Suitability is computed from the formula 1:

\[ S = \sum_{i=1}^{n} w_i \cdot x_i, \quad i \in (1, n) \]  

where: 
- \( S \) – suitability, 
- \( w_i \) – weight of a criterion, 
- \( x_i \) – value of a parameter, 
- \( i \) – a criterion, 
- \( n \) – number of criteria.

The formula for an analysis which additionally contains ‘barrier’ criteria is as follows:

\[ S = \sum_{i=1}^{n} w_i \cdot x_i \prod_{j} c_j \]  

where: the additional symbol \( c_j \) denotes the j-th constraint.

Criteria adopted for the analysis pertain to the need of a given location to fulfill pre-defined conditions. When applying the hard method, criteria are defined as barriers (e.g. no further than 200 m from water, an area with the terrain slope of no more than 30°). Then, the suitability map is a zero-one construct (suitable location – 1, useless location – 0). The final suitability map is a simple product of individual suitability maps (except for the conjunction in formula 2). In some cases, criteria can be defined in a softer manner (e.g. the further from a road, the better; the flatter the land relief, the better). Then, it would be impossible to make direct comparisons, for example between the distance to water and the land slope angle in a given location. Hence, certain standardization of criteria defined as above is in order. It is accomplished according to the formula 3:
\[ x_i = \frac{R_i - R_{\text{min}}}{R_{\text{max}} - R_{\text{min}}} \cdot d \]  

where:  
- \( x_i \) – a parameter corresponding to a given condition after standardization,  
- \( R_i \) – value of the parameter before standardization,  
- \( R_{\text{min}}, R_{\text{max}} \) – minimum and maximum value of the parameter of a criterion,  
- \( d \) – standardization interval.

Standardization is carried out within the boundaries of the adopted interval, e.g. 0-100. Then, the maximum suitability is 100, while the minimum one is 0. Having completed standardization, each point of the analysis has an assigned value of suitability in a range equal from 0 to 100.

### 3.2. Analytic Hierarchy Process (AHP)

Allows one to take into consideration various criteria which are decisive for reaching a set goal [10]. The principal assumption is that the goal is attainable through the fulfillment of partial goals leading to the overall objective. All variant solutions submitted to analysis satisfy the expectations, but to various degrees. The extent to which the main purpose is fulfilled by a given decision variant depends on the degree of fulfillment of main criteria and adequately grouped partial criteria. Decomposition of a problem facilitates an analysis and is in fact the essence of AHP. The solution of a problem is achieved through three stages (steps), which make an integrated and logical sequence:

1. development of a hierarchy model (determination of criteria),  
2. assessment of the criteria on a 9-point scoring scale,  
3. evaluation and ranking of the variants by assigning to them priorities (main weights), while also taking into consideration the vectors of partial criteria.

A hierarchy model composed of 4 levels is constructed to evaluate alternative options. During the analytical process, all criteria on a given level are pairwise compared against the goal for their importance. The assessment is made on a scale provided in literature [11] and the values derived from comparisons are entered into a comparison matrix A. The number of compared pairs which make up the matrix depends on the number of defined criteria. The matrix is filled with the values determined during the evaluation of the criteria. The diagonal of the matrix is composed of the values equal one, because it comprises comparisons of each criterion to itself (\( a_{ij} = 1 \) for \( i=j \)) while components \( a_{ij} \) are the reverse of \( a_{ji} \). Logically, all \( a_{ij} > 0 \). Literature gives computational formulas for the subsequent steps, which lead to calculating the value of the priority indicator.

The final stage in analyzing alternative options with the AHP method is the identification of the option which satisfies the set criteria to the highest degree. For this purpose, calculations are made which show to what degree individual criteria are satisfied by the analyzed variants. Values of the priority vector for each criterion and each alternative against the analyzed criteria are examined as sums of their products:

\[ w_i^A = \sum w_i^{k} w_i^w \]  

where:  
- \( w_i^k \) - priority vector for main criteria,  
- \( w_i^w \) - priority vector for variants

### 3.3. The Indicator Method

Based on matrices, in which particular impacts are described with the help of weights defining their importance. The number in the top, left-hand corner of each cell refers to the direct impact, whereas the one in the bottom, right-hand corner describes the indirect impact of each of the elements submitted to analysis. The number in the middle is the sum of effects multiplied by their weights. The sum of individual effects is a partial assessment value. Both assessments of effects of the project’s impact and estimates of weights require opinions of experts. When preparing questionnaires, negative effects of a planned construction project should be included as well. Actually, the indicator method is particularly helpful when negative impacts need to be analyzed, too, as they will emerge in a table as negative values of criteria [12]. Table 1 shows an example.
Table 1. An example of matrix for calculations by the indicator method.

| No | Criterion | Variant 1 of the investment | Variant 2 of the investment | Variant 3 of the investment | Weight of criterion |
|----|-----------|-----------------------------|-----------------------------|-----------------------------|-------------------|
| 1  | A1        | $P_{11}$                   | $P_{12}$                   | $P_{13}$                   | $W_1$             |
|    |           | $Q_{11}$                   | $Q_{12}$                   | $Q_{13}$                   |                   |
|    |           | $R_{11}$                   | $R_{12}$                   | $R_{13}$                   |                   |
| 2  | A2        | $P_{21}$                   | $P_{22}$                   | $P_{23}$                   | $W_2$             |
|    |           | $Q_{21}$                   | $Q_{22}$                   | $Q_{23}$                   |                   |
|    |           | $R_{21}$                   | $R_{22}$                   | $R_{23}$                   |                   |

Evaluation of a partial impact on the environment of the $i$-th criterion in the $j$-th variant:

$$Q_{ij} = (P_{ij} + R_{ij}) \cdot W_i$$  \hspace{1cm} (5)

where:
- $P_{ij}$ - direct effect of the subsequent variant in the context of criterion A
- $R_{ij}$ - indirect effect of the subsequent variant in the context of criterion A
- $W_i$ - weight of criterion A

Computations performed according to the indicator method can be enhanced by graphical interpretation, where the shape of a diagram can help the analyst to conclude which of the criteria have the strongest influence on the final results of the calculation.

3.4. The Multi Attribute Utility Theory (MUAT)

Method is a science-based, most advanced, multi-attribute utility theory originating from the theory of games [13]. It relies on two assumptions. First, input data about the natural environment in a planned location of the building project under consideration are always incomplete. Second, there is a bias in making an assessment because some events are likely to be hidden, while others are uncertain to happen at all or their occurrence is difficult to predict.

The first step in an analysis games [13, 14] made according to this method is to identify measurable parameters characterizing the natural environment in a planned location, e.g. noise level, concentration of exhaust fumes or pollutants in surface water bodies. Characteristics which lend themselves to a quantitative evaluation of the environment are selected. There can be various measures or states corresponding to each type of impact and they can be computed with the help of prognoses or models, constructed on the basis of long-term monitoring studies. The second step involves expressing the utility function $U(x)$ in a scale of 0–1, where 0 stands for the lowest utility, and 1 corresponds to the highest utility. Utility function curves are shown in fig. 1. Once the utility function $U(x)$ curve has been determined for every attribute under consideration, the results can be aggregated by assigning weights or scaling values to each parameter. Scaling values are a reflection of relative values arising from the perception of attributes by decision makers.

The total utility or composite quality index $CQ$ for the analyzed environment can be derived from the formula (11):

$$CQ = U(x) = \sum_{i=1}^{n} K_i \cdot U_i(x_i)$$  \hspace{1cm} (6)

where:
- $K_i$ – the scaling coefficient of the attribute describing the $i$-th element of the analyzed natural environment,
- $U_i(x_i)$ – the utility function of the $i$-th attribute (parameter) of the analyzed natural environment.

There are many pros to the above method, for example it provides numerical values describing particular characteristics of the environment. A possible disadvantage is the relatively poor readability of the method’s outcome, which depends on the detailedness of the analysis. This method is mostly used for evaluating alternative locations of a project.
3.5. Other methods

Apart from multi-criteria methods, there are approaches based on other assumptions. Checklists are an example. A checklist method can be useful in making an assessment of impacts on the environment exerted by engineering projects, both on a macro-scale and applied to selected parameters. This method allows the user to present values of impacts on a normalized scale, which helps one to determine differences in the natural environment prior to and after completing a construction project, for location variants and alternative construction technologies [14]. Three types of checklists are distinguished:

- checklists without estimations, describing impacts which are possible to appear,
- descriptive checklists with weighting – they describe possible impacts alongside their assessment on the adopted descriptive scale,
- weighted checklists, a method that comprises both a description and environmental parameters with relative weights determined by a team of experts.

For each of the analyzed environmental parameters, a function of values on a 0 to 1 scale is constructed. The function of values enables the analyst to convert the measurable value of j-th parameter to a measurable value within the range <0-1>. Value 0 means an undesirable value and value 1 stands for the highest quality of the environment after the execution of a building project under consideration.

An example of checklist for environmental studies is shown in table 2.

**Table 2.** An example of a table with a checklist.

| Questions that should be considered: | Short description Yes/No | Can this factor lead to environmental impacts? Yes/No - Why? |
|--------------------------------------|--------------------------|-------------------------------------------------|
| 1. Can the planned building structure cause physical changes in the topography? | | |
| 2. Will the planned building structure affect the use of adjacent land parcels? | | |
| 3. Does the analyzed plan envisage the use, storage, transport of substances which can be harmful to the environment? Can this fact produce a significant influence on nature? | | |

An example of yet another approach is the Histogram Method, which describes concisely particular impacts, and is a variant of a matrix approach, however with a very limited scope of the subject matter. The histogram method is a brief presentation of data related to a planned construction project.

**Table 3.** A table with data for a histogram.

| Kind of impact | Nature of the influence |
|----------------|-------------------------|
| Noise and vibration | Negligible Average Significant Short-lived Long-lived Positive Negative |
| Air pollution | |
| Landscape | |
| Pollution of ground water | |

An example is given in Table 3. The list of impacts can be quite freely modified, depending on the needs dictated by the analysis per se and the type of a planned civil; engineering project. The method can be applied in a situation when there is only one solution (there are no alternatives) during the preliminary stages of making an assessment.

Map Methods are applied whenever it is helpful to present individual factors on maps (Fig.1), taking into consideration alternative solutions.
This method is most helpful in presenting results of analyses during consultations with local communities. However, making such maps requires base-maps [15].

4. Summary and conclusions

In the construction and development business, we must undertake and perform a series of activities related to the management of engineering projects. While faced with a variety of decisions, at any stage of a building process, we can be aided by the methods discussed above. In many cases, mathematical support methods will facilitate an analysis of a complicated situation. In other cases, descriptive methods, with so-called checklists or graphical presentation of a situation, may prove more useful. Table 6 shows their practical applications.

| Table. 4 Specification of recommended application of the selected methods. |
|-------------------------------------------------|
| Check-list | Histograms | Map methods | MUAT | MCE | AHP | Indicator method |
| Location criteria | + | - | ++ | ++ | ++ | ++ | + |
| Technological criteria | - | ++ | - | + | + | + | + |
| Organizational criteria | - | ++ | - | - | + | + | + |
| Environmental protection facilities | ++ | - | + | + | + | ++ | + |
| Nature compensation | + | - | + | - | ++ | + | - |

We can notice that some of the presented methods are more universal (MCE and AHP), while others are more limited in their usability (checklists, histograms).

All methods have advantages and disadvantages, and in reality their application depends on the skills and preferences of decision makers. Noteworthy, the information contained in the Table 4 is more of an approximation, while a decision which method to apply in practice is in fact made by the user.
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