Bases of Elements of Multi-Criteria Analysis of Quality of Design Decisions

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Abstract. Economic and mathematical models are focused on obtaining optimal solutions to particular problems in the field of transport construction (formation of organizational structures, provision of materials for construction, creation of specialized units, development of production standards, development of work schedules, etc.). None of the considered methods can claim universality in substantiating decisions, since the decision-making process itself has a complex hierarchical structure: part of the decisions is made “at the highest level”, the other part of decisions is transferred to the “lower” levels. No governing body is capable of making all decisions. Therefore, economic and mathematical models can also be recommended both in the field of macroeconomics (to the highest level of transport construction management) and in the field of microeconomics (construction organizations, enterprises, production units). In this regard, it is important to correctly assess the “niche” of the construction management system, in which one or another model should have a place. Obviously, most of them can be recommended to organizations and enterprises of the “middle” and “lower” levels in which the technological processes of the construction of transport facilities are implemented, although their application at the highest level is also possible (for example, cluster analysis models, linear programming, network models, etc.).

1. Introduction
It is advisable to protect yourself from the “absolutization” of mathematical models in the justification and decision-making. The well-known mathematician B.O. Kupmen defines it as “… a professional disease of people so enthusiastic about modern computer technology that they believe in the possibility of easily finding an answer to a mathematical problem, which they can neither formulate nor solve, hoping only for expensive computer”.

Mathematical methods cannot be opposed to other decision-making methods, including intuitive ones. A. Hall defines intuition as “… instant understanding or awareness of something without any conscious thought, sudden premonition of the desired solution without the intervention of logic, conceptualization and other forms of mental activity”. R. L. Keeney complements this concept with the phrase “intuition is a combination of great practical experience and a high culture of thinking”. It is appropriate to recall that many ingenious discoveries appeared intuitively, and then were confirmed in the course of complex scientific research [1-5].

However, no matter how the decision is substantiated, there is always a problem of the criterion of efficiency of the decision in the process of its adoption. In the management science, the selection
(justification) of a criterion is recognized as one of the main problems. Therefore, it is necessary to understand the essence of this concept, to understand the basic rules and recommendations for its formulation and practical application.

2. Efficiency criteria and restrictions

The criterion of efficiency is usually understood as an indicator, sign, measure with which the best of the alternatives, the best of the ways to achieve the goal are selected. It follows that the criterion does not exist by itself without regard to the goal. Therefore, before developing a system of criteria, it is necessary to decide on a system of goals.

Along with the criterion, there is the concept of “restriction”, which is close in its purpose to the criterion and complements it. The methodological approach of justification for the formation of a system of criteria and restrictions is presented in the diagram (figure 1).

![Diagram of forming a system of criteria and restrictions](image)

Figure 1. The diagram of forming a system of criteria and restrictions

Depending on the nature of the goal (goals) and the conditions for their achieving, indicators are selected for comparing alternatives (performance indicators) $I_1, I_2, \ldots, I_n$. They are usually divided into three groups:

1) indicators reflecting expected results (pace of work and terms of commissioning; scope of construction and installation works, etc.);
2) estimated costs (construction cost; need for material, technical and labor resources);
3) time to complete the task.

Options comparison indicators have different significance. Therefore, the most important of them are accepted as criteria, others as restrictions.

The fundamental difference between the “criterion” and the “restriction” is that the criterion is extreme in nature and is written as: $C \rightarrow \min (\max)$, i.e. it allows choosing the best of the alternatives that has the minimum or maximum value of the selected indicator, and the restriction is written in the form of inequalities of the form:

$R \geq R_{\text{lim}}$ or $R \geq R_{\text{lim}}$, i.e. we are satisfied with any alternative in which the value of the indicator does not exceed a certain limit value (or not lower than it).

The distinction between the “criterion” and the “restriction” can be illustrated (figure 2), where the level of profitability $L_p$ is taken as an indicator of efficiency $I_i$. 
In the figure, the acceptable (directive) level of profitability is assumed to be 3%. If we take it as a restriction, the efficiency condition of the alternative options will take the form: \( L_p \geq L_{p, dir} \), i.e. any alternative will be acceptable if its profitability level is not lower than 3%. In particular, in Figure 2a, all options except the fourth will be effective.

In Figure 2b, the \( L_p \) indicator is a criterion, the efficiency condition is expressed by the inequality \( L_p \rightarrow \max \). Therefore, option 3 will be effective (in this case - optimal).

The considered example shows that restrictions are used to identify many competitive options, and the criterion acts as a tool for choosing the best of them. The criterion can be simple (i.e. to consist of one indicator) or complex (of several simple indicators).

Not every indicator can be accepted as a criterion, but only those that meet certain requirements:

1) The criterion should reflect in a general form all types of expenses. Since the components of the criterion often have different meters (dollars, tons per day, etc.), a complex meter that does not contradict them should be selected for its formation;

2) The criterion should provide the decision maker with a clear idea of the degree of achievement of the goal for each of the compared options;

3) The criterion should allow the possibility of comparing the effect obtained from the implementation of the decision with the required expenses;

4) The criterion must be effective (workable), i.e. the decision maker must understand the physical meaning of the criterion. Otherwise, it will be difficult for him to defend the decision during approval by the senior boss. A sign of efficiency is also the simplicity of calculating the criterion for each of the compared decisions;

5) The criterion must have the property of non-redundancy. In the generalized criterion, duplication of the same indicator is unacceptable, since this leads to unreasonably overestimating the role of this indicator in relation to other indicators (usually duplication of the indicators “cost of work” and “time to complete the task” is allowed).

Taking into account these requirements, we will consider the rules for the formation of criteria from previously adopted indicators for comparing options.

Criteria can be built according to three principal options.

1. One of the indicators is taken as a criterion, which has a clear dominance over other indicators (for example, task completion time or project cost). Such a criterion is called simple.

2. A criterion is formed by two or more indicators through their convolution into a composite criterion. The latter, as a rule, has the form of a function where the relative significance of indicators is not taken into account (they are accepted as equally valuable). An example of such a criterion is the pace of work \( V \), which is the ratio of the scope of work \( Q \) to the time of their completion \( T \):

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**Figure 2.** Illustration of the concepts of “criterion” and “restriction”
\[ V = \frac{Q}{T}. \]  

3. The criterion is formed from \( n \) particular criteria \( C_i \), the relative significance of which can vary. For this, a generalized criterion \( C_0 \) is used:

\[ C_0 = \sum_{i=1}^{n} \alpha_i C_i \rightarrow \text{min(max)}, \]  

where \( \alpha_i \) — weight of each \( i \)-th criterion \( C_i \).

When forming a generalized criterion, two problems must be solved:
- it is necessary to determine the significance (weight) of each particular criterion, i.e. set the value \( \alpha_i \).
- it is necessary to overcome the “dimension problem” of particular criteria, i.e. fulfill the first requirement to criterion.

3. Results and discussions
The significance of particular criteria can be established in two ways:

The expert method (or an expert survey method), the essence of which is described in the mathematical literature. It can be briefly described as the following: a group of experts is interviewed, each of which gives its own assessment of the significance of each particular criterion. Then, the obtained data are processed by the methods of mathematical statistics, and a certain average (or compromise) value \( \alpha_i \) is found;

The method of “relative preferences”, which is a special case of the expert method (this is the method of one expert - the decision maker). Its essence is the following actions.

The decision maker, individually or with the help of colleagues, arranges each of the particular criteria in a row in descending order of their significance.

For example, if four particular criteria are used and they are arranged in the order: \( C_1 > C_2 = C_3 > C_4 \), this means that \( C_1 \) is more important than \( C_2 \), \( C_2 \) is equivalent to \( C_3 \), and \( C_3 \) is more important than \( C_4 \). Such a record is called an “order relation”.

If \( C_1 \) is more important than \( C_1 \) (\( C_1 > C_2 \)), then the criterion \( C_1 \) is assigned a coefficient of significance \( \beta_{12} = 3 \).

If \( C_1 \) is equivalent to \( C_2 \) (\( C_1 = C_2 \)), then \( \beta_{12} = 2 \).

If \( C_1 \) is less important than \( C_2 \) (\( C_1 \leq C_2 \)), then \( \beta_{12} = 1 \).

To calculate \( \alpha_i \), a scoring square matrix is constructed, in which the partial criteria \( C_i \) are arranged in rows and columns (table 1).

In each row, at the intersection of a row and a column, values of \( \beta_{ij} \) are assigned that correspond to the order of preference of the row criterion over the column criterion. As a result, for each \( i \)-th row, one can get the sum of the significance coefficients for the criterion \( C_i \) \( \left( \sum_{j=1}^{n} \beta_{ij} \right) \). Summing up these results by columns, we get

\[ A = \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij}. \]
Table 1. Scoring matrix for calculating the coefficients $\alpha_i$

| Criteria | $C_1$ | $C_2$ | ... | $C_n$ | $\sum_{i=1}^{n} \beta_{ij}$ | $\alpha_i$ |
|----------|-------|-------|-----|-------|----------------------------|------------|
| $C_1$    | $\beta_{12}$ | $\beta_{1n}$ | $\sum_{i=1}^{n} \beta_{1j}$ | $\alpha_1$ |
| $C_2$    | $\beta_{21}$ | $\beta_{2n}$ | $\sum_{i=1}^{n} \beta_{2j}$ | $\alpha_2$ |
| ...      | ...    | ...    | ... | ...  | ...                        | ...        |
| $C_n$    | $\beta_{n1}$ | $\beta_{n2}$ | $\sum_{i=1}^{n} \beta_{nj}$ | $\alpha_n$ |

\[ \sum \beta_{ij} = \sum_{i=1}^{n} \alpha_i = 1.0 \]

The coefficient of significance of the criterion $C_i$ will be equal to:

\[ \alpha_i = \frac{\sum_{i=1}^{n} \beta_{ij}}{A}. \] (4)

Let us consider the results of calculating the significance coefficients of the criteria, if a relationship of their order is established: $C_1 > C_2 > C_3 = C_4$. We build the scoring matrix (table 2).

Table 2. Scoring matrix

| Criteria | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $\sum_{i=1}^{n} \beta_{ij}$ | $\alpha_i$ |
|----------|-------|-------|-------|-------|----------------------------|------------|
| $C_1$    | 3     | 3     | 3     | 9     | 0.375                      |
| $C_2$    | 1     | 3     | 3     | 7     | 0.292                      |
| $C_3$    | 1     | 1     | 2     | 4     | 0.167                      |
| $C_4$    | 1     | 1     | 2     | 4     | 0.167                      |

\[ A = 24 \]
\[ \sum \alpha_i = 1.00 \]

In cell $C_1 - C_2$, we will write the number 3, because $C_1 > C_2$. Since $C_1$ will be more important than all other criteria in the row (transitivity property, if $C_1 > C_2$ and $C_2 > C_3$, then $C_1 > C_3$, i.e. set of ordered pairs of elements of this set), then the number 3 should be written in the two remaining cells of the first row. Thus, the sum of the numbers of the first row will be 9. Similarly, fill in all the other cells of the scoring matrix (in cell $C_4 - C_1$, there will be the number 1, because $C_4 < C_1$; in a cell $C_4 - C_3$ there will be the number 2, since $C_4 = C_3$).
Summing up the numbers in the column \( \sum_{j=1}^{n} \beta_{ij} \), we get \( A = 24 \).

Hence, \( \alpha_1 = 9/24 = 0.375 \); \( \alpha_2 = 7/24 = 0.291 \); \( \alpha_3 = \alpha_4 = 0.167 \).

The condition \( \sum \alpha_i = 1.00 \) is satisfied.

To solve the problem of “dimension” in equation (2), not the absolute values of \( C_i \) are used, but their normalized values calculated by the formula:

\[
C^n_i = \frac{C_{ia}}{C^\text{lim}_i},
\]

where \( C_{ia} \) and \( C^\text{lim}_i \) - the actual and limit (or normative) values of the criterion, respectively. Using formula (5), different-dimensional criteria are reduced to one-dimensional (in fractions of a unit).

In practice, there are often situations where not all criteria have the same way of optimization (i.e. all tend to either minimum or maximum). For example, expenses, losses, deadlines for putting objects into operation tend to a minimum, and profit, pace of work, profitability and others – to a maximum). In this case, equation (2) is divided into two parts: minimized criteria are collected in one part, and maximized criteria in the other. If we denote the first group by \( C_i \) (\( i = 1, 2, \ldots, m \)), and the second through \( C_j \) (\( j = 1, 2, \ldots, l \)), then formula (5) takes the form:

\[
C_o = \sum_{i=1}^{m} \alpha_i C^n_i + \sum_{j=1}^{l} \alpha_j \frac{1}{C^n_j} \rightarrow \min,
\]

when \( m + l = n \).

Thus, the essence of the concepts of “criteria” and “restrictions”, as well as the rules for the formation of particular and generalized criteria, were examined. In the theory of decision making, there is the concept of “decision efficiency”, which in essence is a concept of its quality.

The encyclopedic definition of “efficiency” of any system comes down to its effectiveness, the degree of achieving the goals. In this context, the efficiency of the decision should be considered as an indicator characterizing the quality of the decision, the degree of use of financial, material and labor resources. The measure of efficiency is the criterion of efficiency [6-11,12-17].

4. Conclusions
By definition, efficiency does not exist regardless of the goals for which, in fact, a decision is made, as well as the conditions for the implementation of these goals. If we change the goals and (or) construction conditions, then a previously effective solution may be ineffective. For example, the transition to a market economy from the planned economy of the USSR led to the fact that the old standard construction decisions were ineffective, since they did not adequately reflect new goals (the main of which is making a profit) and the conditions of competition, investment in construction etc.

Similarly, efficiency does not exist separately from the efficiency criterion. If, by definition, efficiency is an indicator of the degree of achievement of goals, then the criterion is a measure of the assessment of this degree. For example, a solution that is optimal according to the criterion of cost of production may be unacceptable by the criterion of its demand in the market (nobody needs cheap, but unclaimed products).
The efficiency of the decision is divided into expected (predicted) and actually achieved. The first is assessed at the stage of development of projects (investment projects) of the construction organization, the second - after it is finished upon completion of tasks [10-17].

Goals have a different nature. When making decisions on the construction of transport facilities, economic, industrial (technological), social, environmental and other goals are pursued. Therefore, the efficiency of decisions can be divided into economic, operational, industrial, social, and environmental.

The operational (or general) efficiency $E_o$ is generally understood as the ratio of the scope of actually performed (or predicted) work $Q_a$ to the planned (directive) indicators $Q_{dir}$:

$$E_o = Q_a / Q_{dir}.$$  (7)

The economic efficiency of the decision $E_e$ is assessed by the ratio of the economic effect (profit, profitability of production) $P$ to the costs $Z$, due to which this effect was achieved:

$$E = P/Z.$$  (8)

All other types of efficiency are calculated similarly using dependencies of the type (7) or (8). At the same time, the appropriate indicator of the effect in monetary or physical terms should be set in the numerator.

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