Concerning One Approach to the Selection of Organizational and Engineering Solutions for Building Construction

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Abstract. The construction process is implemented by methods differing from each other in the materials, mechanisms, tools, construction equipment used, as well as the qualitative and quantitative composition of the units and teams of workers. Each of these factors, in turn, is characterized by certain engineering, technical and economic indicators. Therefore, precise optimization models play an important role when assessing and selecting rational values for the parameters of technical, organizational and engineering solutions. Different methods and models can be used including direct enumeration of alternatives when choosing the optimal (rational) values of the parameters characterizing technical, organizational and engineering solutions. Models of this kind are extensively described in the literature and are widely used in practice. Such optimization problems are solved using a variety of methods of linear, nonlinear, stochastic programming. One of these methods is described in this paper.

1. Introduction

Organizational and engineering solutions selected for the construction of buildings determine the nature and scale of the construction process optimization problems [1,2,3,4,5].

Studies have shown that many methods of linear, nonlinear, stochastic programming allow selecting the best method of construction and installation works. First of all, the most difficult is the method of building structure installation [6,11,12,13,14,15].

The construction of buildings and structures is a complex production process, which involves complex calculations and various kinds of tasks, but also a variety of organizational and engineering solutions (OES). Selecting the "best" organizational and engineering solutions, beneficial from the economical point of view for the construction of buildings and structures, is one of the most important tasks in the Russian Federation. An important part of construction and installation works is a comprehensive study of various work methods. This provides the source material for the research and further selection of the most suitable method.

2. Materials and methods

Solving this problem requires determining an optimality criterion and setting boundary conditions. The optimization problem corresponding to the assessment and selection of the best engineering solutions can be represented in the following form [1,7,8,9,10].
A set of X values shall be determined, where the objective function corresponding to the adopted optimality criterion reaches its minimum, and the boundary conditions are met.

A certain area of optimal and effective solutions is identified from the analysis of compared alternatives. The essence of the algorithm of finding the most effective OES is to divide the entire selection set into stages that can be analyzed in detail, as well as to establish connections between them to be compared later. Below is a block diagram for the algorithm of finding the optimal OES (Figure 1). Figure 1 shows that the system allows selecting from many alternatives.

![Block diagram](image)

**Figure 1.** Block diagram for the algorithm of finding the optimal OES.

It is necessary to highlight the main areas containing specific approaches, which solve the problem of rational construction works method selection [6].

The first area of choice is when problem-solving is performed analytically by selecting the most convenient solution in specific boundary conditions.

The second area can be clearly defined when the best OES is selected for the given conditions by analyzing various other OESs without any definitely structured algorithm relying on previous experience and knowledge.

While the third area, with the development of modern computers and technology, as well as automated systems such as BIM CAD, clearly shows that the choice of OES goes beyond the mathematics and management experience, and requires setting boundary conditions at the design stage as well. The mathematical model of the construction process for a building or a part of it allows to
precisely analyze the main physical, economic and organizational characteristics, as well as to predict the model behavior when these parameters deviate.

These OES selection areas are described by specific methods and techniques for selecting the best solution.

Of course, studies similar to this have been carried out earlier, but most of them covered only the second area, namely — the selection based on the comparison.

An analytical approach to the problem of choosing a rational organizational and technological solution for building construction deserves consideration as well, because it is more detailed than the second one, can use acceptance models, and does not require deep BIM knowledge. Research is conducted by most specialists in this area namely.

3. Results
This area includes a method that is considered effective. It is based on the opinion of experts, as well as on their methods of assessment. Such an approach not only encourages to compare various methods and production technologies taking into account all factors but also to select the most effective OES while sorting through all of the available ones. In this case, any construction process is analyzed in terms of whether a particular goal is achieved, which is ultimately a system of separate tasks that differ by dependencies between these tasks.

The method of expert assessment, which is based on the intuitive and logical analysis performed by experts with a qualitative and quantitative assessment of judgments and formal processing of the results. The complex use of intuition, logical thinking and quantitative assessments with formal processing allows obtaining satisfactory solutions to many theoretical and practical problems.

All problems solved by the method of expert assessment can be divided into two types: tasks having sufficient information potential, and tasks having insufficient information potential for being solved with complete confidence in the reliability of the obtained results without using special procedures. The current research covers the solution of problems belonging to the first type. Solving these problems using the expert assessment method has certain complexities related to effective implementation of information arrays by correctly selecting the experts, creating rational expert interview procedures and using optimal methods for expert interview results processing.

It should be clarified that for each of the areas, methods shall be created, as well as a set of criteria, to evaluate the obtained result.

Finally, the factor effect on the selected main criterion is determined. After that, the effect on the course of work is determined. Then the method of work execution is selected meeting the boundary conditions and taking into account additional factors.

The rational decision alternatives can be selected using a multi-functional generalized criterion for the decision success. However, this criterion is virtually not applicable when rational alternatives for organizational and technological solutions shall be chosen, since it is applied only in cases where all the assessed indicators are equivalent.

Most normalization principles are based on the maximum approximation of the normalized values to the so-called ideal vector.

Assessment of OES parameters and their relationship.

The following requirements are imposed on the parameters:
- focus on achieving a given goal;
- consistency with regulations and the economic situation;
- compliance with the modern scientific and technical level of production and experience;
- prevention, and in case of occurrence — means to overcome the negative consequences of risky actions.

When the assessment criteria are chosen incorrectly, only a semblance of the correct solution can be seen. The criteria are selected by logical reasoning and intuition.

To be able to compare the alternatives and select the best one it is necessary to determine the indicators first. These indicators are usually called selection criteria (Table 1).
Table 1. Criteria classification.

| Criteria Classification         | Description                                                                                                                                 |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Work price                    | Depends on weight, length, type of columns, availability of mounting elements, availability of pre-mounted elements, crane type, work schedule. |
| Work performance rate         | Depends on the worker qualifications, mechanization level, the number of workers, the availability and quality of working plan for this type of work. |
| Operating costs               | Including warehousing, site preparation, preparatory works.                                                                                   |
| Ergonomics                    | Depends on the availability of all the necessary tools during the works, as well as the percent of workers equipped with these tools, the level of utilization of modern technologies, working plan availability, qualifications of workers. |
| Required time                 | The required amount of time to carry out this type of work, which can be obtained from time tracking.                                          |
| Work quality                  | To assess the quality after the works are completed and sign the act of hidden works (for example, anti-corrosion treatment), defect examination and geodetic surveys are carried out to determine deviations from the design position, as well as to find any damaged made during work. |
| Construction site limitations | This criterion describes the availability of sufficient space to use a particular installation method. In a cramped urban environment, the installation "from wheels" is not possible, therefore storage may be required. |
| Work method                   | Under different conditions and equipment available at the site, various work execution methods can be used.                                    |

Depending on the abovementioned and other criteria, which are taken into account during rational OES selection, a solution is selected that satisfies the main or the most critical factor, disregarding all others [16].

The time required to install one two-leg steel column was tracked. The column was selected based on the column bearing capacity calculation.

Experimental studies via time tracking allowed to determine the time parameters of assembly operations. 9 important criteria were selected for time tracking that could affect the total work duration. The time of these work types was tracked including the time spent on the preparatory and final parts, as well as for the routine break. Time tracking data are provided in Table 2.
Table 2. Timing results.

| S/N | Operation or process name            | Start  | End   | $T_{\text{min}}$ | $T_{\text{hour}}$ | Including $T_{n-3}$ | $T_n$ |
|-----|--------------------------------------|--------|-------|------------------|------------------|---------------------|------|
| 1   | Checking anchor bolts                | 08.00  | 08.18 | 18               | 0.3              | 13                  | 0.09 |
| 2   | Installation axes marking            | 08.19  | 08.43 | 24               | 0.4              | 21                  | 0.11 |
| 3   | Securing suspended supports and wooden beams | 08.44  | 09.27 | 43               | 0.72             | 37                  | 0.07 |
| 4   | Column slinging                      | 09.28  | 09.47 | 19               | 0.32             | 7                   | 0.21 |
| 5   | Column positioning on anchor bolts   | 09.48  | 10.25 | 37               | 0.62             | 53                  | 0.53 |
| 6   | Attachment using anchors              | 10.26  | 10.49 | 23               | 0.38             | 10                  | 0.10 |
| 7   | Positioning the column shoe on slabs | 10.50  | 11.22 | 32               | 0.58             | 26                  | 0.10 |
| 8   | Column bracing                       | 11.23  | 11.46 | 23               | 0.38             | 17                  | 0.10 |
| 9   | Installation of scaffolds in the abutment points | 11.47  | 12.34 | 47               | 0.78             | 43                  | 0.3  |
|     | Total                                |        |       | 4.43             | 3.95             | 1.52                |      |

To analyze the distribution of the column installation process duration values, the theoretical distribution parameters have been calculated (see Table 3).

Table 3. Parameters for calculating empirical characteristics.

| Period $D_i$ | Center of period $d_j$ | Absolute frequency, $m_i$ | Relative frequency, $m_i/m$ | $d_i \times m_i$ | $(d_i \times D_i)^2$ | $(d_i \times D_i)^2 \times m_i$ |
|--------------|------------------------|---------------------------|--------------------------|------------------|---------------------|-------------------------------|
| 4.0–4.2      | 4.1                    | -                         | -                        | -                | -0.4                | 0.160                         |
| 4.2–4.4      | 4.3                    | 27                        | 0.25                     | 116.1            | -0.2                | 0.040                         |
| 4.4–4.6      | 4.5                    | 81                        | 0.75                     | 364.5            | 0                   | 0                              |
| 4.6–4.8      | 4.7                    | -                         | -                        | -                | -0.4                | 0.160                         |

The variance was estimated using the formula (1):

$$\sigma^2 = \frac{\sum (d_j \times d_i)^2 \times m_i}{n}, \tag{1}$$

where $d_j = 4.3$ — average time period value, $n$ — number of sections.
The mean square deviation totals $\sigma = 0.346$. 
The results of actual time tracking by the example column installation have shown that 75 percent times the works took 4.4–4.6 hours. Thus, we assume that this deviation is insignificant.

After a meaningful analysis, the factors are selected influencing the resulting indicator of the column installation process duration.

The following factors have been found to affect the resulting indicator:
- X1 - Anchor bolts checking
- X2 - Installation axes marking
- X3 - Securing suspended supports and wooden beams
- X4 - Column slinging
- X5 - Column positioning on anchor bolts
- X6 - Positioning the column shoe on slabs
- X7 - Column bracing
- X8 - Installation of scaffolds in the abutment points

After finding these parameters, correlation analysis can be performed to determine the closest relationships between the processes (Table 4).

|       | X1  | X2   | X3  | X4  | X5  | X6   | X7   | X8   |
|-------|-----|------|-----|-----|-----|------|------|------|
| z     |     |      |     |     |     |      |      |      |
| X1    | 0.17| 1.00 | -0.10| 1.00|     |      |      |      |
| X2    | 0.21| -0.10| 0.53 | 0.13| 1.00|      |      |      |
| X3    | 0.37| 0.35 | 0.13 | 0.71| 1.00|      |      |      |
| X4    | 0.37| 0.35 | 0.13 | 0.71| 1.00|      |      |      |
| X5    | -0.07| 0.23 | -0.38| 1.00|      |      |      |      |
| X6    | 0.30| 0.13 | -0.14| 0.34| 0.37| 1.00 |      |      |
| X7    | -0.15| 0.01 | 0.29 | 0.26| -0.15| -0.24| 1.00 |      |
| X8    | 0.64| 0.21 | 0.16 | -0.14| 0.19| 0.11 | 0.06 | 1.00 |

Analysis of Table 4 shows that the closest relationship is observed between z and such factors as X3, X5, X6, X8. At the same time, a weak relationship is observed for X2, X4, X7. Accordingly, weak relationships are excluded from the model.

The combination of the above factors is used for multivariate analysis, which allows assessing the significance of these factors and determining how much technology efficiency can be improved in the future.

The time tracking data showed that the complete column installation cycle for this facility takes from 4.4–4.6 hours/column according to the standards given in SNiP. The standard time for the installation of columns of this type is 4.9 hours. Thus, the correlation coefficient = 0.91.

The concluded research showed that this type of work required less time than stated in SNiP. Thus, with the correlation coefficient = 0.91 of the value stated in SNiP, the decision is made to continue this type of works, provided that the safety of this building will be ensured by the required work quality.

This test was performed in the following steps: problem statement, after which the experiment task was set. Then the information sources were analyzed, and a list of sources was compiled that met the requirements for secondary information. The test began with the collection of data, while content analysis and criteria classification to determine the OES selection system were performed after that. Time tracking and correlation analysis were carried out to establish relationships in mathematical form between factors during installation works. The correlation coefficient was calculated to determine the deviation from the temporary specifications given in SNiP for this type of works. An information report was made on the performed activities.
4. Discussion
Based on the analysis of the existing apparatus, the method of selecting alternatives based on the criterion of proximity to the ideal point was found to best suit the current tasks for choosing the best organizational and technological solutions, which consists in forming a generalized criterion based on the deviation of the considered alternatives from the ideal one, formed from the best values of the assessed indicators. First, the best (ultimate) and worst (negative ultimate) alternatives are determined.

As already noted, the best organizational and technological solutions are proposed to be selected according to one or several generalized criteria that fully characterize the considered alternatives at all production stages. To make the assessment results as representative as possible, the generalized criteria shall be decomposed into individual assessment indicators or their groups (as indicated in the scheme and mentioned earlier). Moreover, the more assessed indicators will be considered, the more accurate and reliable organizational and engineering solutions will be.

5. Conclusions
The problems solved in this study are characterized by different dimensions of estimated indicators (labor intensity, duration, level of mechanization, cost indicators, etc.), which excludes the possibility of a direct comparison. Therefore, one of the key problems of a comprehensive assessment, when a certain selection is performed, is the normalization of assessed indicators, i.e., reducing all the assessed indicators to a comparable form.

The current analysis revealed that different methods can be used for OES selection. Currently, the most effective method is a computer simulation, since the results of this method are the simplest and most accurate. The priority direction of all selection methods is to increase the efficiency of making organizational and engineering decisions during construction.

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