

# Selection model of work technology based on multi-criteria evaluations

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**Abstract.** A model for the selection of options for the production of work in a construction project is considered, when each option is characterized by a set of criteria. The number of analyzed options is being reduced based on the construction of the Pareto-optimal solution set. The remaining options are used to solve the problem based on the network model, in which the solution will be a subcritical path that meets budgetary constraints. At the same time, the proposed comprehensive indicator characterizing the preferences of the customer makes it possible to determine alternative options for performing work in the energy project in such a way that the amount of costs allocated to implement the set of work under consideration is minimal. Another statement of the problem is also considered when it is necessary to determine a strategy for the implementation of an energy project that, given a planned budget constraint, maximizes the growth of a comprehensive indicator that characterizes customer preferences in this project. The solution of the tasks is given under the assumption of the convexity of the cost function.

## 1 Introduction

In modern conditions, with the introduction of new technologies, many varieties of methods for performing work in construction are most clearly manifested, i.e. the variability of work in construction that has existed to date has increased significantly. It should be noted that the modifications are determined not only by the number of technological methods for performing the work, but also by the managerial decisions that ensure the implementation of this work. In view of the multivariability of the construction work, the proposed solutions (sent by regulatory acts and documents) should be selected from the best offers, which stipulate the high quality of work at the optimal cost.

Undoubtedly, such a complex work involves a difficult task even at the stage of selecting a specialized contracting institution that will take on the preparatory functions preceding the construction of a certain object. In addition, it becomes necessary to carry out activities aimed at the preliminary preparation of these institutions for work on the implementation of the proposed project. In modern conditions, with the advent of a large number of new materials, the range of possible options for the production of works has become much wider. Moreover, each of the works is evaluated according to a certain set of

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criteria that the project manager sets. In the construction industry, the following parameters can be used as evaluation parameters: time to complete the work, its cost, manufacturability, quality, durability, level of mechanization (cost of fixed assets used, divided by the number of employees), number of workers, use of auxiliary equipment, maintainability (can be estimated, as an auxiliary time needed to prepare to proceed with direct repair), etc.

Of the entire list of indicators, the greatest number of questions is caused by the indicator of “technological effectiveness” [1, 2]. In general, manufacturability is one of the characteristics of a product that expresses the convenience of its production, maintainability, and performance. At its core, this indicator is complex and often represents a combination of quantitatively and qualitatively defined characteristics. Some indicators, such as: cost, material consumption, labor intensity, duration of preparation, duration of preparatory work to prepare for the direct implementation of this work, and other parameters of both relational and absolute order.

In addition to the above, the manufacturability of the work is determined by some parameters that reflect the subjective sensations of a person that cannot be determined by rigorous mathematical methods. Only a person - or a team of specialists - possessing the necessary knowledge, skills, etc., can determine which of the projects is more convenient for people to live, for example, when implementing a complex development of a microdistrict. Thus, an expert opinion of a specialist (or group of experts) regarding the manufacturability of an ongoing project is necessary.

Thus, manufacturability is a kind of complex indicator that can be decomposed into components. Therefore, it cannot be applied directly in the calculation of the integral assessment characterizing a specific method of construction work [3, 4], but at the same time, the most significant components of this indicator should be included in the calculation.

## 2 Materials and methods

Consider a construction project consisting of  $k$  works, the implementation of which is carried out sequentially. Each of the works is characterized by a set of  $m$  quantitative indicators. In the case when the indicators contain verbally specified data, it is necessary to digitize them using expert survey procedures.

Each of these  $k$  jobs can be done in several ways. Given the modern possibilities of construction production, it should be recognized that the number of options for implementation can be significant; therefore, algorithmic support for the process of choosing options for performing construction work is necessary [5, 6].

Without violating the generality of reasoning, we assume that the number of possible ways to perform each of the work is the same and equal  $n$ .

Each of the works is characterized by the following set of indicators:

- lead time;
- cost;
- execution time;
- material consumption;
- the duration of the preparatory work to prepare for the direct implementation of this work;
- quality;
- durability;
- level of mechanization (cost of fixed assets used, divided by the number of employees);
- number of workers;

- use of auxiliary equipment;
- maintainability (can be estimated as the auxiliary time required to prepare to proceed with direct repair).

Naturally, for the decision maker, it is most desirable to take into account the entire spectrum of parameters, which requires the construction of a certain procedure for ranking options for the execution of work. But in this case, it is necessary to take into account the fact that the main management factor that allows influencing decisions is financing. Therefore, we will characterize each work carried out according to a specific option with the amount of costs  $c_{ik}$ , ( $i=1,2,\dots,k$ ;  $i=1,2,\dots,n$ ) allocated to ensure this option, highlighting this characteristic separately, and the integral characteristic, built on the basis of the above ten factors  $z_{ik}$ .

The problem arises of determining options for the implementation of work that would ensure the highest integral characteristic within the existing budget.

We will solve this problem in stages: at the first stage, we will try to determine the integral characteristics for all works and all options with the construction of a Pareto-optimal set of solutions. And at the second stage, we consider the algorithm for solving the problem for the case of determining the most profitable options for carrying out work within the existing budget.

### 3 Results

To determine the integral characteristics of the work that needs to be performed, we represent a certain set of points in the  $m$ -dimensional space in the form of rational options we select. Based on this provision, it is necessary to justify the method of determining system assessments for the many works that must be performed during the implementation of the project. To do this, it is necessary to introduce the provision that work efficiency will be directly dependent on the number of options considered - the less variability, the more efficiently the task is performed and vice versa [7].

There is no doubt that at the initial stage of the development of the algorithm, the use of the Pareto-optimal set as in will be effective. However, the main obstacle to using the algorithm proposed in is what we tried to avoid - the sufficient power of the set of strategies presented to the decision maker.

Thus, the task posed by us is not solved in full due to the variability of the process. Therefore, it becomes necessary to determine a certain lower boundary beyond which the indicator  $x_j^*$  is not considered. This lower boundary of the  $m$ -dimensional space defines a cone-shaped conglomerate of solutions, and from here the expert can consider the necessary solutions from a geometric point of view placed inside the  $m$ -dimensional parallelepiped. All points that are not included in the box are not considered unpromising. We know that the best indicator is one. The lowest threshold point will be one of the vertices of the given box, defined as  $\{x_1^*, x_2^*, \dots, x_m^*\}$ . Therefore, the best point defined as a unit will be on the opposite side with indicators  $\{x_1 = 1, x_2 = 1, \dots, x_m = 1\}$ .

In order to determine the optimal options, we transfer the coordinate system to the lowest point  $\{x_1^*, x_2^*, \dots, x_m^*\}$ . To carry out this operation, perform the following action

$$y_{i1} = x_{i1} - x_1^*, y_{i2} = x_{i2} - x_2^*, \dots, y_{im} = x_{im} - x_m^*, \quad i = \overline{1, n} \quad (1)$$

The criterion for the selection of competitive options is the condition for the positivity of all values in the new coordinate system, that is, all inequalities of the form

$$y_{i1} > 0, y_{i2} > 0, \dots, y_{im} > 0, \quad i = \overline{1, n} \quad (2)$$

For further solution in the transformed coordinate system, we find the average values for all indicators. For this purpose, we use the formulas

$$\overline{y_1} = \frac{\sum_{i=1}^n y_{i1}}{n}, \overline{y_2} = \frac{\sum_{i=1}^n y_{i2}}{n}, \dots, \overline{y_m} = \frac{\sum_{i=1}^n y_{im}}{n} \quad (3)$$

Thus, as a result of the transformation of the coordinate system, we have the localization of all competitive options in the first "quadrant" of the new coordinate system whose axes will correspond to the boundary values of the indicators. In this coordinate system, a point is found that corresponds to the average values of the initial indicators. Obviously, the farther the point characterizing the variant from the beginning of the transformed coordinate system, the better. There is an assumption that we take as the weighting coefficients the values characterizing the coordinates of this midpoint, that is, the weighting coefficients should be proportional to its coordinate values.

Given the conditions for normalizing weighting factors, the required ratios can be presented in the form

$$q_1 = \frac{\overline{y_1}}{\sum_{j=1}^m \overline{y_j}}, \quad q_2 = \frac{\overline{y_2}}{\sum_{j=1}^m \overline{y_j}}, \quad \dots, \quad q_m = \frac{\overline{y_m}}{\sum_{j=1}^m \overline{y_j}} \quad (4)$$

The geometric meaning of the obtained values lies in the fact that they are the squares of the directing cosines, the vector connecting the beginning of the transformed coordinate system with a point characterizing the average values of the analyzed indicators.

Based on the transformations, we conclude that among the analyzed points, those whose coordinate values (at least one of the declared coordinates) are below the average position should be discarded, i.e. values are below average. Then, two ways open before us: to carry out further transformations or go to the original coordinate system and perform calculations based on the additive model.

According to the first option, the conversion can be improved by discarding unnecessary options, for which you should put the beginning of the new coordinate system at a midpoint. According to the second option (when using the additive model) we use the calculated values of the weight coefficients (4), we use the additive model

$$z_i = \sum_{j=1}^m q_j x_{ij}, \quad i = 1, 2, \dots, n \quad (5)$$

As a result of the calculations, the expert will determine the best option as a strictly defined point of  $m$ - dimensional.

Thus, an expert can easily determine the best option.

Nevertheless, the number of promising options will be reduced, but still for each work there will be at least two options for the possible implementation of the work. The problem arises of choosing a possible method of production of each type of work in order to meet certain conditions.

## 4 Discussions

Consider the case of pre-production for the implementation of a construction project consisting of  $k$  works performed sequentially. Each of the works can be performed according to one of the possible modifications, which are characterized by the cost of implementation  $c_{ij}$  ( $i=1,2,\dots,k$ ;  $j=1,2,\dots,n$ ) and integral parameter  $z_{ij}$  ( $i=1,2,\dots,k$ ;  $j=1,2,\dots,n$ ), the methodology for which is given above. In this case, each possible value of the integral parameter  $z_{ij}$  will correspond to a certain amount of costs specified by the value  $c_{ij}$ .

From this we can conclude that you can use more than one problem statement.

In order to provide a general description of the formulation of the optimization problem, we define a certain binary variable  $x_{ij}$ . It will have two meanings - one and zero. In the first case, the  $i$ -th work is performed according to option  $j$ ; in the second - if execution occurs in any other way.

The assumptions described allow us to go on to the description of the tasks.

Task 1. The proposed comprehensive indicator characterizing the preferences of the customer will allow us to determine possible options for their implementation in such a way that the amount of costs allocated for these purposes is minimized. In a formalized representation, this problem can be represented as follows

$$\begin{aligned} \sum_{i=1}^k \sum_{j=1}^n c_{ij} x_{ij} &\rightarrow \min, \\ \sum_{i=1}^k \sum_{j=1}^n z_{ij} x_{ij} &\leq Z_0, \quad \sum_{j=1}^n x_{ij} = 1, \quad i = 1, 2, \dots, k \end{aligned} \quad (6)$$

where  $Z_0$  – the value of the total value of the integral indicator of the implementation of the construction project, set directly and determining the requirements of the customer.

The semantic meaning of the last restrictions, and their number will be equal to the number of work performed in the project, means in (6) that each task posed during the project will have a strictly defined way of doing this work.

Task 2. It is necessary to determine a project implementation strategy that, given a given budgetary constraint, maximizes the growth of an integrated indicator characterizing customer preferences in this project

$$\begin{aligned} \sum_{i=1}^k \sum_{j=1}^n z_{ij} x_{ij} &\rightarrow \max, \\ \sum_{i=1}^k \sum_{j=1}^n c_{ij} x_{ij} &\leq B, \quad \sum_{j=1}^n x_{ij} = 1, \quad i = 1, 2, \dots, k \end{aligned} \quad (7)$$

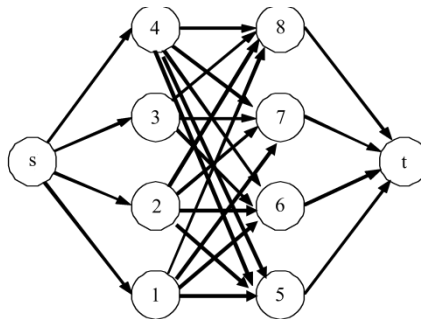
Here  $B$  – is the amount of resource that the company possesses to achieve the task.

It is easy to notice that the obtained problems (6), (7) can be solved by methods that solve combinatorial programming problems. The researcher can use such well-developed methods as dichotomous and dynamic programming, the branch and bound method. However, all the proposed methods are complex enough to obtain specific calculation results. It follows that we can try to build a heuristic algorithm to achieve the goal, and as a way to solve the problem we will use graphs, a well-developed and described method to achieve the goal in this paper.

We will construct a graph describing all possible alternatives for performing work. The vertices describe the event, that is, the end of the previous work and the beginning of the next. And the arcs will characterize the work performed by a certain modification. An event that describes the start of the first work in the project will not have previous events and

therefore it will not include any arcs. Similarly, with the final event of the project: no arc will exit from it. The number of vertices in the intermediate layers will be determined by the number of possible varieties of the work in question.

Thus, in the constructed network, each path will characterize a certain strategy for performing work in the project. For example, the path  $[s - 3, 3 - 5, 5 - t]$  corresponds to the organizational and technological solution, when the first work is performed according to the third option, and the second work according to the fifth.



**Fig. 1.** Network model for two jobs, each of which can be performed in four ways ( $k=2$ ;  $n=4$ ).

In this case, the converse statement will also be fulfilled: for any combination of work methods in the project under consideration, a certain path will exist in the constructed network from the initial vertex to the final.

Any arc of such a graph will be characterized by two numbers: the value of the integral indicator characterizing customer preferences  $z_{ij}$  and the cost value  $c_{ij}$  necessary to implement this alternative. The total length of the selected path will characterize the trajectory describing the implementation strategy of the ongoing construction project, and will be characterized by the value of the integral indicator  $Z$ , as well as the value of the costs  $C$ , allocated to implement this strategy, determined from the expressions

$$Z = \sum_{i=1, j \in M}^k z_{ij}, \quad C = \sum_{i=1, j \in M}^k c_{ij} \quad (8)$$

where  $M$  – many selected ways to complete the project.

The task set will differ from the traditional “knapsack” task in that we need to complete all the many tasks that are part of the project. Only a variation in the quality of work performed and the cost of their implementation within the allocated budget is possible.

Presented in Fig. 1 the graph 1 will contain the whole set of possible solutions, but even with a small dimension of the problem, the number of solutions can be significant, as shown in Fig. 1. This graph will contain two trivial solutions: the upper envelope of the graph (in Fig. 1 this option is represented by  $(s - 4; 4 - 8; 8 - t)$ , will correspond to the strategy for performing work on the most attractive and most expensive option; the lower envelope ( in Fig. 1, this option is presented by  $(s - 1; 1 - 5; 5 - t)$  describing the option when all work is performed according to the simplest technology, but the costs will be the lowest. As a rule, such decisions are not of interest to the customer: the most expensive strategy for the implementation of the project on the conditions of a shortage of funds, and the cheapest - due to unsatisfactory solution of the main issues in the project.

This leads to the need to determine on a given graph the set of subcritical paths, the characteristics of which will satisfy the customer’s requirements, that is, the value of the integral score  $Z$  and the total cost of  $C$ . That is, the subcritical path should have an integral

estimate not lower than the given one, and the amount of costs required to implement this alternative should satisfy the initial budget constraint.

It is quite clear that, given the real state of things, it is unlikely that it will be possible to achieve maximum values of the integral indicator within the allocated budget. That is why the subcritical path that satisfies the set limits will be approximately in the middle of the constructed model.

Effective algorithms for solving the problem have not yet been found because it is very, very difficult to identify paths of a certain length in an arbitrary graph.

But taking into account the peculiarities of the tasks being solved, which does not require absolute accuracy, we can try to propose a heuristic solution algorithm based on the Danzig rule used to solve the "knapsack" problem.

In this case, as an effect, the value of the integral indicator is used in the implementation of a specific type of work, and as costs, the amount of financing of this alternative. Thus, for each type of work  $i$ , performed according to a specific variant  $j$ , we can introduce the efficiency indicator  $E_{f_{ij}}$  of the chosen strategy

$$E_{f_{ij}} = Z_{ij}/C_{ij} \quad (9)$$

In this case, we have the following way to solve the problem:

1 step. For each arc of the graph, the efficiency is determined. Thus, the value of each of the scenarios is calculated.

2 step. The path of maximum efficiency is found by the known algorithm.

$k$ -th step. It provides actions for finding the optimal solution by selecting the best value in the field of the obtained value.

However, the obtained method for solving the problem of forming a project implementation strategy can be simplified based on the use of convexity properties.

Consider the case when the cost function that describes the change in the cost of work from the way they are performed will have the property of convexity. This property is often referred to as a case of decreasing efficiency when zoomed out. This means that each subsequent improvement in the integral parameter of work will be accompanied by a large level of funding. This property allows us to solve problems (6) and (7) quite simply. Consider an algorithm for solving such a problem in more detail.

First of all, attention should be paid to the fact that the dependence of costs on the implementation strategy of the work, as a rule, is obtained in a discrete form. Based on these data, a convex piecewise linear function can be constructed, which is convenient to set in tabular form. The cells of the table provide data on the integral indicator that can be achieved if the work in question is performed according to the considered alternative. In this case, the costs are recorded in the numerator, the values of the integral indicator in the denominator.

The algorithm for choosing a project implementation strategy is as follows:

1 step. From the remaining cells of the cost table, a cell with the maximum efficiency of resource use, that is, the maximum fraction standing in this cell, is selected. Since this operation means that for the work under consideration, a version of its execution has been selected and, therefore, this table cell should be excluded from the further solution. In the case when several cells will have the same efficiency, then a cell is selected that provides a larger increase in the integral characteristic. The data obtained are entered in the table, and it is necessary to do this taking into account the costs, which will determine the optimal solution to the problem.

2 step. The obtained value of the increment of the integral characteristic of the project is compared with the necessary value, which must be achieved. If the goal of the calculation is achieved, then the algorithm ends. Otherwise, the task is again in the first step.

Thus, in the second step, you can determine the solution of the task, for which the table data that is the most recent is highlighted, the column number determines the work to be done, and the line number is the way to do this work. In this case, it is necessary to control the amount of costs allocated to increase the integral characteristics of the work.

## 5 Conclusion

Thus, the article presents an algorithm for determining the Pareto-optimal set of potential ways of implementing the components of the project in the form of a sequence of construction and installation works and obtaining the integral characteristics of such a choice. The complex assessments obtained in this way for possible work scenarios are subsequently used for cases of project implementation with a convex cost function to select the optimal implementation option for this project. And having received the desired, we have the opportunity to implement the project with a significant simplification of decision making.

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