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MODELS FOR THE CHOICE OF THE MOST FAVORABLE CONTRACTOR FOR CONSTRUCTION OF THE THERMAL INSULATION SYSTEMS

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Abstract. *The paper considers the multi-criterion models of the choice of the most favorable contractor for construction of the thermal insulation system at the previously constructed buildings. The paper is a contribution to the consideration of the most favorable contractor, as it is one of the very important decisions of the investor. A large number of variant solutions is proposed. Firstly, the criteria for the choice of the most favorable contractor of these works are formed. Then, a methodology for the choice of the contractor for the construction of the facade thermal insulation system is presented, that is the mathematical models for the solution of such problem are presented, with a purpose to determine the optimal solution, that is, make a choice of the most favorable contractor of these works.*

Key words: *civil engineering, thermal insulation systems, contractor choice, models, optimization.*

1. INTRODUCTION

The choice of the most favorable contractor for construction of the facade thermal insulation system on buildings is a very important decision of an investor. After the choice of the contractor, the investor signs a building contract with it, and introduces it to the business.

The problems of the choice of the favorable contractor for construction of the thermal insulation system should be considered from several aspects: defining the criteria for the choice of the contractor and limiting factors, forming of the mathematical models, solution of the posed problems and the analysis of the obtained solution.

The most of the investment projects are, as a rule, executed by hiring a number of the specialized contractors for the individual types of works. Though an investor often signs the contract for the construction of the facade thermal insulation system with one con-

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tractor, this contractor that signed the contract and assumed the construction of the whole building, in the course of construction of the facade thermal insulation system hires other specialized subcontractors.

The investor regularly faces the problem of the optimum choice of the most favorable contractor for construction of the facade thermal insulation system. The aim is to realize the facade thermal insulation system in a best way, and define the criteria of the optimal problem solution, that is choice of contractor. These criteria may be: unicriterion, bicriterion and multicriterion ones. In the choice of the contractor, mostly the bicriterion problem is met. Such criteria are most frequently: the minimum building construction costs, with real time of building construction and the attainment of the required quality.

Most frequently met in practice are the three basic variants of the problem of the choice of the most favorable contractor for construction of the facade thermal insulation system:

a) choice of a contractor for construction of the entire thermal insulation system,
b) choice of one contractor of each phase (activity) of thermal insulation system construction, and
c) choice of multiple contractors or assigning of one or more phases (activities) of the thermal insulation system works to the same contractor.

If the main contractor hires its subcontractors, the a) problem boils down to b) or c) problem, which a very common case in the complex investment buildings. The c) problem is an common case, and the b) problem may be derived from it.

2. CHOICE OF THE MOST FAVORABLE CONTRACTOR FOR CONSTRUCTION OF THE THERMAL INSULATION SYSTEM ON THE ENTIRE BUILDING

The problem of the choice of the most favorable contractor for construction of the thermal insulation system on the entire building, is a multi attribute decision problem, that is a multicriterion decision. When solving the multi attribute decision problem, a decision matrix is formed from the definition of the initial data, and by this the appropriate mathematical model. Then, it is necessary to choose on or more methods for solution and analysis of the solution, which comprises a possible alteration of some of the parameters and repeated solution of the problem.

The choice of one, among a large number of potential contractors for construction of the thermal insulation systems o the entire building, is reduced to the multi attribute decision problem. The potential contractor may be:

- Potential individual contractor or
- group of multiple contractors.

When a group of multiple contractors is observed, then the construction of the entire thermal insulation system on the building is assigned to a certain group. In this process no division of work to the individual contractors within the group takes place, for, in this case, the sequence of the execution of the individual contractors within a group would have to be taken into account. In this way, we would shift to the problem of the choice of multiple contractors, which will be discussed later.

The potential contractors are the alternatives of the multi attribute decision model. At that, the same contractor may offer one or more variants of the construction of the

thermal insulation system of the building. Of course, each of the offered variants for the construction of the thermal insulation system on the object has the certain specifics in relation to the other variants in terms of the criteria for the choice of the contractor. For each variant, the values of each criterion are determined separately, is it is the case with various contractors. Apart from the characteristics of the construction project, the certain references of the potential contractors may also be the criteria for the contractor choice. Therefore, eventually, there are two types of criteria and those are:

- characteristics of the construction project
- references of the potential contractors.

The characteristics of the construction project comprise:

- Duration of construction works
- Total costs of the thermal insulation system construction,
- Dynamics of the financing,
- Quality of the construction, etc.

The references of the potential contractors comprise:

- Investors' indicators of the cooperation up-to-date with the potential the contractors at similar construction projects.
- Potential contractors indicators of the successfulness in construction of similar projects with other investors, etc.

The potential contractors may be valued on the basis of the defined criteria, which cant be:

- General criteria, related to the concretely considered enterprise, and
- Special criteria, related to the concretely considered project.

The applied criteria may have the quantitative values or the qualitative features. For each of the criteria, depending on its nature, the difficulty coefficient is assigned – expressing the degree of significance of certain criteria. It should be pointed out that the certain criteria require attainment of the maximum values, while the other criteria may require the attainment of the minimum values. The solution to this problem determines the most favorable contractor (or the most favorable offer, if one or more contractors gave several offers).

2.1 General criteria for evaluation of a conctractor

The general criteria for evaluation of a contractor are the general characteristics of an enterprise, which are defined by the investor.

The general criteria may be defined in the following way:

- capacity of the building company
- participation in foreign and national market,
- available machinery,
- existence of the specialized groups for execution of certain works
- possession of the required specialized facilities and their quality (for: coatings, thermal insulation material, construction scaffold, etc.) and
- successfulness of the company.

Capacity of a building company is measured according to the number of employees:
Mini companies, to 100 employees,
Small companies, 100 to 500 workers,
Medium companies, 500 to 1500 employees, and
Big companies, over 1500 employees.
The value of the criterion is expressed with the total number of the employees in the company.

Participation in the foreign market is a criterion referring to the previous successfulness of the company, and it is comprised that the job was obtained at an international tender. Evaluation of this criterion is done according to the number and the type of the objects that were constructed abroad.

Available machinery for construction of the investment object is a very important criterion. The value of this criterion is determined according to the type, number, power and capacity of the machinery of the considered company.

Existence of the specialized teams for execution of certain works, is a comparative advantage of a company, because it is not dependant on the subcontractors. Evaluation of this criterion is done by existence of the specialized teams for execution of the certain number of activities with their own means, or with the subcontractor.

Possession of the required specialized facilities, is a huge advantage for the contractor. It makes the potential contractor independent of another company which would participate as a subcontractor. Evaluation of this criterion is done according to the capacity of the required facilities for the execution of the considered investment object.

Successfulness of a company serves for the evaluation of the entire company. The evaluation of the material and financial status, strategy and business policy, and company development perspectives. The evaluation of this criterion is given on the basis of the status of the company's debt, profitability, solvency etc.

2.2 Special criteria for evaluation of a contractor

The general criteria defined the characteristics of a company, while the special criteria define the characteristics of the concrete investment object and the thermal insulation system. Those are: the efficiency of the thermal insulation system, cost of construction of the thermal insulation system, deadline of construction of the thermal insulation system, the contractor references from the similar assignments, distance from the production facilities to the construction site and whether the company has the resources for construction of the thermal insulation system.

The efficiency of the thermal insulation system, is the priority criterion. The quality construction provides the maximum thermo-energetic efficiency of the thermal insulation system and reduction of the energy losses to the minimum. This element cannot be quantitatively expressed through the offer. The economic effects of the quality construction, as a criterion, may be financially considered during the building exploitation. This could be one of the important elements of the techno-economic analysis of the building process of each production, business or residential facility.

The cost of building construction is the basic element of offer for the construction of the thermal insulation system on the investment object. The value of this criterion is expressed in dinars, dollars, euros...

Deadline of construction is another important element of the offer. While evaluating this criterion, it is necessary to take into account the quality of the construction works and the necessary testing during construction, as well as after the construction of the thermal insulation system. The evaluation of this criterion is expressed by the number of days spent in the construction of the system.

The contractor references from the similar assignments is an important criterion in the choice of the most favorable contractor of the thermal insulation system for the building construction. A company which already conducted the same or the similar construction works, possess the required experience. The experience is necessary when constructing a thermal insulation system on the building structures, and it is reflected in the knowledge of possible problems which may arise in the building construction phase. The references of the contractors for the same or similar construction tasks reassures an investor that the contractor will successfully accomplish the task. The value of this criterion is expressed by the number of previously constructed thermal insulation system on buildings (same or similar).

Distance from the production facilities to the construction site significantly affects the organization of the thermal insulation system construction. The less the distance between the production facility to the construction site, the more favorable the choice is. The proximity of the production facility provides construction without big or without any stockpile at the construction site, as well as the minimum transport consists of the prefabricated product from the production facilities. All this, significantly reduces the costs of thermal insulation system construction. The value of this criterion is expressed by the distance from the production facility to the construction site, in meters.

Resources for construction of the building (labor force, equipment, machinery) are very significant for successful execution of the works, and at that the available resources should be considered, not the total resources of a company. The value of this criterion is expressed in the number of the individual resources.

2.3 Choice of a contractor

Upon the collection of the offers, the most favorable tenderer (one tenderer may give one or more bids). The investor of the works, according to its needs, evaluates the criteria. For the successful analysis of the problem, the criteria may have the appropriate difficulty coefficients added. When choosing the most favorable contractor of the thermal insulation system on the investment structure, most often the following criteria are employed:

- The most important criteria:
  - quality of the construction works,
  - total costs of the installation of the thermal insulation systems on the structure, and
  - terms of payment;
- Following are the significant criteria:
  - duration of the guarantee period, and
  - duration of the thermal insulation system construction;
- Of least importance is the up to date business cooperation.

As it is said, the criteria are determined by the investor itself, according to the nature of structure, its needs and requirements. On the basis of the adopted criteria and their im-

portance, the most favorable solution in the choice of the contractor for the construction of the thermal insulation system on the investment structure is determined by one of the known methods. This problem is a task of the multi attribute decision making.

3. CHOICE OF SEVERAL CONTRACTORS FOR THE THERMAL INSULATION SYSTEM CONSTRUCTION

As opposed to the previous problem, the choice of several contractors for the thermal insulation system construction is a problem of multiple objective decision making. If each of the contractors performs only one phase (activity) of the thermal insulation system construction, then the single criterion model of the problem of the choice of contractors is reduced to the assignment task [1]. This task comprises the problem of the choice of the project contractor with the independent phases (groups of activities). By the function of the criteria, the efficiency of the executed arrangement of the contractors. The function of the criterion is minimized or maximized, depending on the nature of the criterion in the presented problem. This model may be modified, so that one or more contractors at the investment structure may perform several phases (activities). Whether the problem will be observed as a unicriterion, bicriterion or multi criterion problem, depends on the nature of the considered problem and the objectives that should be attained by the solution of this problem.

The general mathematical model of the multicriterion decision making of the minimization of the duration of the activity with the longest period of duration (equation 1) and the minimization of the total construction costs of the thermal insulation system on the investment structure (equation 2) is formulated as the bicriteron non-linear problem of the 0-1 programming:

$$\min \{\mathbf{Tp(x)} = \max_{\{x_{ik}=1\}} \mathbf{t_{ik}}, \quad \mathbf{i \in l_k}, \mathbf{k \in K}\} \tag{1}$$

$$\min (\mathbf{Cp(x)} = \sum_{\mathbf{i \in l_k}} \sum_{\mathbf{k \in K}} \mathbf{c_{ik}\, x_{ik}}) \tag{2}$$

with the system of limitations:

$$\sum_{\mathbf{k \in K}} \mathbf{x_{ik}} = 1, \quad \mathbf{i \in l_k} \tag{3}$$

$$\mathbf{x_{ik} \in \{1,0\}\ i \in l_k,\ k \in K} \tag{4}$$

$$\bigcup_{\mathbf{k \in K}} \mathbf{l_k} = \mathbf{l} \tag{5}$$

where:

- $\mathbf{m}, \mathbf{i}, \mathbf{l}$ - is the small number of activities, indices and set of activities, $\mathbf{i \in l} = \{1,2, \dots ,m\}$;
- $\mathbf{n}, \mathbf{k}, \mathbf{K}$ - number of possible contractors, indices and set of contractor indices, $\mathbf{k \in K} = \{1,2, \dots ,\mathbf{n}\}$;
- $\mathbf{l_k \subseteq l}$ - set of indices for activities for whose execution the **k** contractor is specialized, $\mathbf{k \in K}$;
- $\mathbf{t_i}$ - duration of **i-th** activity, $\mathbf{i \in l}$;

$\mathbf{c_{ik}}$ - costs of **i**-th activity when it is executed by the **k**-th contractor, $\mathbf{i \in l}$, $\mathbf{k \in K}$;

$\mathbf{x_{ik}}$ - decision unknowns with values:
1 – if the **i**-th activity is assigned to the **k**-th contractor, or
0 - if **i**-th activity is not assigned to **k**-th contractor, $\mathbf{i \in l}$, $\mathbf{k \in K}$;

The limiting equation (3) defines that each activity may be executed by only one contractor, which is specialized for that kind of activities, and that each activity may be executed only once. The equation (4) indicates the nature of the unknowns. The equation (5) defines the problem in such a manner that it has a solution if and only if for each activity at least one contractor competes. The non-linearity of the equation (3) defines the non-linearity of the whole model (equation 1 to 5).

In the general sense, by the application of the multi objective decision model solving methodology the, there is a set **Q** with the finite number (**h**) of the efficient solutions, marked as the **q**- solutions:

$$\mathbf{(Tp^{(q)}, Cp^{(q)}, x_{ik}^{(q)}, t_{ik}^{(q)}, i \in l_k, k \in K), \quad q \in Q=\{1,2, \ldots ,h\}} \tag{6}$$

In the decision making phase, one solution will be used. The total duration of the project is determined by the time of the duration of the activity of the critical path, while the non-critical activities have the corresponding times of the latest beginnings:

$$\mathbf{Tp^{(q)} - t_{ik}^{(q)}, \quad q \in Q, i \in l_k, k \in K}. \tag{7}$$

For the choice of one contractor for each phase (activity) of the project execution, the previous model (form 1 to 7) must be expanded by a subset of limitations, introducing the conditions that each contractor may be assigned only one phase (activity) of the project, from the set of activities for which the said contractor is specialized for:

$$\sum_{\mathbf{i \in l_k}} \mathbf{x_{ik} \leq 1}, \quad \mathbf{k \in K}. \tag{8}$$

In the concrete case of assigning the execution of certain phases (activities) of the project, may be connected to the series of other particularities. There might be cases when the times of execution of certain phases (activities) are not defined in advance, but the concrete potential contractors define the duration periods of those phases (activities).

A particularly interesting possibility is the one of the crediting the project execution, by the contractor. This crediting may be in the form of the postponed payment of the executed works. It most of the cases means the more favorable terms, though, nominally, those cost may be higher due to the postponed payment of the executed works. The problem of the choice of the most favorable contractor of the thermal insulation system construction on the investment structure may be more complex if the additional elements are introduced as the choice criteria, such as could be: long term business cooperation with one of the potential contractors, or giving advantage to some potential contractors for some other reasons. In this case, the general variant of the contractor choice is formed, by the introduction of the new parameters:

$\mathbf{l_{0k} \subseteq l_k}$, $\mathbf{K_0 \subset K}$ - Set of **i**-th phases (activities) which are obligatory assigned to the **k**-th contractor and the set of **k**-th contractors with such characteristics, $\mathbf{i \in l_{0k}}$, $\mathbf{k \in K_0}$;

$\mathbf{K_1 \subseteq \{K \therefore K_0\}}$, $\mathbf{K_2}$ - Set of **k**-th contractors which have the maximum number of phases (activities) per project limited, $\mathbf{k \in K_1}$, and the contractors without such characteristics, $\mathbf{k \in K_2}$, $\mathbf{K_2 = K \therefore K_1}$;

$\mathbf{m_k}$ - The highest number of phases (activities) which a **k**-th contractor can be assigned to execute, $\mathbf{k \in K_1}$;

r, s, S - Possible number of variants of payment to the contractors, indices and set of indices of the variants of payment, $\mathbf{s \in S = \{1,2, \ldots ,r\}}$;

$\mathbf{S_{ik} \subseteq S}$ - Set of indices of payment variants for the i-th phase (activity) if it is executed by the **k**-th contractor, $\mathbf{i \subseteq l_k}$, $\mathbf{k \subseteq K}$;

t - Time unit of the project phase (activity) execution duration, most frequently this unit is: hour, day, week or month;

$\mathbf{t_{iks}}$ - Duration of the **i**-th phase (activity), when this phase (activity) is executed by the **k**-th contractor with **s**-th manner of payment, $\mathbf{i \in l_k}$, $\mathbf{k \in K}$, $\mathbf{s \in S_{ik}}$;

$\mathbf{x_{iks}}$ - Variables with assigned values:
1 - when i-th phase (activity) is assigned to the k-th contractor which has s-th variant of payment, or
0 - in the opposite case, $\mathbf{i \in l_k}$, $\mathbf{k \in K}$, $\mathbf{s \in S_{ik}}$;

$\mathbf{c_{iks}}$ - Monthly costs of the **i**-th phase (activity), when this phase (activity) is executed by the **k**-th contractor with the **s**-th variant of payment [EUR/month], $\mathbf{i \in l_k}$, $\mathbf{k \in K}$, $\mathbf{s \in S_{ik}}$;

T - Duration of the project execution [month];

$\mathbf{c_{ikst}}$ - Monthly costs of the **i**-th phase (activity), when this phase (activity) is executed by the **k**-th contractor with the **s**-th variant of payment in the **t**-th month [EUR/month], $\mathbf{i \in l_k}$, $\mathbf{k \in K}$, $\mathbf{s \in S_{ik}}$, $\mathbf{t} = 1, 2, \ldots, \mathbf{T}$;

$$\mathbf{c_{ikst}} = \begin{cases} \mathbf{c_{iks}}\ \mathbf{t_{iks}}, & \text{if } \mathbf{t} = \mathbf{t_{iks}}^{\mathbf{beginning}}, \quad \text{if } \mathbf{s} = 1,\ \mathbf{x_{ik1}} = 1 \\ \mathbf{c_{iks}}, & \text{if } \mathbf{t_{iks}}^{\mathbf{beginning}} \le \mathbf{t} \le \mathbf{t_{iks}}^{\mathbf{termination}}, \quad \text{if } \mathbf{s} = 2,\ \mathbf{x_{ik2}} = 1 \\ \mathbf{c_{iks}}\ \mathbf{t_{iks}}, & \text{if } \mathbf{t} = \mathbf{t_{iks}}^{\mathbf{termination}}, \quad \text{if } \mathbf{s} = 3,\ \mathbf{x_{ik3}} = 1 \end{cases}$$

where:
$\mathbf{t_{iks}}^{\mathbf{beginning}}$ - beginning of the **i**-th activity,
$\mathbf{t_{iks}}^{\mathbf{termination}}$ - termination of the **i**-th activity,
$\mathbf{s} = 1$ - total costs of the initial month of the phase (activities) execution,
$\mathbf{s} = 2$ - monthly costs in each month of the activity execution,
$\mathbf{s} = 3$ - total costs of the final month of the phase (activity) execution.

According to the previously given examples, a general postulate of the multicriterion mathematical model for the choice of the most favorable contractor of the thermal insulation system with the independent phases may be formed:

$$\mathbf{min} \{\mathbf{Tp} = \underset{\{\mathbf{x_{iks=1}}\}}{\mathbf{max}}\ \mathbf{t_{iks}}, \mathbf{i \in l_k}, \mathbf{k \in K}, \mathbf{s \in S_{ik}}\} \tag{9}$$

$$\textbf{(min) } Cp = \sum_{i\in l_k} \sum_{k\in K} \sum_{s\in S_{ik}} \sum_{t\in T} c_{ikst}\, x_{iks} \tag{10}$$

Criterion (9) minimizes project duration, while criterion (10) minimizes project costs.

$$\textbf{(min) } C_t = \sum_{i\in l_k} \sum_{k\in K} \sum_{s\in S_{ik}} c_{ikst}\, x_{iks} \text{ for some months } t\in T, \tag{11}$$

$$\textbf{(opt) } \underline{C}_k = \sum_{i\in l_k} \sum_{s\in S_{ik}} \sum_{t\in T} c_{ikst}\, x_{iks} \text{ for some contractors } k\in K, \tag{12}$$

The equation (11) considers the monthly costs of the project, and the equation (12) comprises the costs of the individual contractors. A minimization of payment of the individual contractors and the maximization of the construction works value assigned to the certain contractors may be performed.

The formed general multicriterion mathematical model for the choice of the most favorable contractor with the independent phases (9,10,11 and 12) has the following system of limitations:

$$\sum_{k\in K} \sum_{s\in S_{ik}} x_{iks} = 1, \quad i\in I \tag{13}$$

$$x_{iks} = 1, \quad k\in K_0, \quad i\in l_{0k}, \quad s\in S_{ik}, \tag{14}$$

$$\sum_{i\in l_k} \sum_{s\in S_{ik}} x_{iks} \le m_k, \quad k\in K_1, \tag{15}$$

$$\sum_{i\in l_k} \sum_{k\in K} \sum_{s\in S_{ik}} c_{ikst}\, x_{iks} \le C_{ot}, \quad \text{for some month } t\in T, \tag{16}$$

$$\sum_{i\in l_k} \sum_{s\in S_{ik}} \sum_{t\in T} c_{ikst}\, x_{iks} \le \underline{C}_{ok}, \quad \text{for some contractors } k\in K, \tag{17}$$

$$\sum_{i\in l_k} \sum_{s\in S_{ik}} \sum_{t\in T} c_{ikst}\, x_{iks} \ge \underline{c}_{ok}, \quad \text{for some contractors } k\in K, \tag{18}$$

$$x_{iks} \in \{1,0\}, \quad i\in l_k, \; k\in K, \; s\in S_{ik}. \tag{19}$$

The limitation (13) defines that each phase (activity) of the project must be executed. The limitation (14) provides that the required phases (activities) are assigned to certain contractors. Limitation (15) maximizes the number of phases (activities) which are assigned to certain contractors. The limitation (16) limits the costs of the project for the given months (values of C_{ot}), while (17) limits the total costs of the individual contractors (values of $\underline{C}_{ok}$) . The limitation (18) provides the contractors the least cost realization of the value $\underline{C}_{ok}$, and the nature of the variables is defined by the limitation (19).

4. CONCLUSION

The paper presents the application of the multicriterion decision making model. The general postulates of each group of problems are given, and the general and concrete mathematical models are formed, and the methods for finding the efficient solutions in

the choice of the most favorable contractor of the thermal insulation system at the investment structure. In solving the multi attribute decision making, it is obvious that by the definition of the initial data the matrix of decision making is formed, and in this way the appropriate mathematical model. Then the choice of one or more methods for solution are chosen, and the solutions are determined and analyzed. A possible repeated solving of the problems is done with the corresponding alterations of some of the parameters in the mathematical model.

The research from the various fields of the organized business planning and the realization of the corresponding tasks confirms that in most cases, it is required to consider several criteria for the evaluation of the solution efficiency simultaneously. The number of criteria depends on the type of the problem being solved.

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MODELI IZBORA NAJPOVOLJNIJEG IZVOĐAČA ZA POSTAVLJANJE TERMOIZOLACIONOG SISTEMA

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U radu se razmatraju Višekriterijumski modeli izbora najpovoljnijeg izvođača za postavljanje fasadnog termoizolacionog sistema na ranije izgrađenim objektima. Rad predstavlja prilog razmatranju najpovoljnijeg izvođača, kao jednoj od veoma važnih odluka investitora. Dat je veći broj varijantnih mogućnosti. Najpre se formiraju kriterijumi za izbor najpovoljnijeg izvođača ovih radova. Zatim se predstavlja metodologija izbora izvođača za postavljanje fasadnog termoizolacionog sistema, odnosno prezentuju matematički modeli za rešavanje ovako postavljenog problema sa ciljem da se odredi optimalno rešenje, odnosno izvrši izbor najpovoljnijeg izvođača radova na ovim poslovima.

Key words: *građevinarstvo, termoizolacioni sistemi, izbor izvođača, modeli, optimizacija.*