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THE CHOICE OF THE CONTRACTOR IN FOREST ENGINEERING

The paper considers the choice of the most favourable contractor for construction of the investment structures in forest engineering. The choice of the contractor is a very important decision for the company assigned with the forest management, which is an investor, because the company's business always entails very limited financial resources, so the choice is paid special attention, and the path to the optimal solution is analyzed in detail.

The issue of the choice of contractor is solved by the application of the multicriterion optimization. The investor defines the general and special contractor evaluation criteria and the limiting factors of the choice and then the mathematical model is formed and the problem is solved with the analysis of the obtained solution.

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Вибір підрядника для лісоінженерного будівництва

Розглянуто вибір оптимального підрядника для будівництва лісоінженерних споруд, що є найважливішим рішенням для інвестиційної компанії. Цьому приділяється особлива увага тому, що інвестиційні компанії, як правило, обмежені в фінансових ресурсах.

Проблема вибору підрядника вирішується шляхом багатокритеріальної оптимізації. Інвестор визначає загальні і спеціальні критерії оцінки підрядника та обмеження оптимізації, потім формує математичну модель і вирішує проблему шляхом аналізу одержаного результату.

1. Introduction

In the environment of the transitional economy, the companies in the forest engineering in Serbia, are shifting from the directed planning and command economy, to the indicative and planning and market economy. One of the aspects of the transition process in the forest engineering is the privatization of all the business, so called "services in forest engineering" referring to the felling of the trees and production of timber products, transport of timber and design and construction of the investment structures. The construction of the investment structure in forest engineering is preceded by the choice of the contractor building the primary and secondary forest roads, bridges, culverts and other structures in the forest. Even though the said investment structures have the prominent social and economic importance, for which they should be supported by the state, the companies in the forest engineering are most frequently the independent investors. From the point of view of the forest engineering company as of an investor, the investment structures in forest engineering are characterized by the relatively large quantity and extent, significant labor, machinery, and financial resources engagement, limited construction deadlines, and the location is always in difficult and inaccessible terrain requiring a particular engagement in preparation of the construction site.

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A forest engineering company, as an investor, regularly faces the problem of the optimum choice of the most favourable contractor for construction of the investment structure. The problem of choice is very complex, because in building of the investment objects, there may be one or more contractors which could build the entire investment structure, one of its parts or could take part only in one phase of the construction. Apart from that, in participation in the tender, the contractors may offer one or several variant solutions, and they can hire the specialized subcontractors.

The problem of the choice of contractor is solved by using the multicriterion optimization methodology, for the criteria set in advance, such as: the minimum building construction costs, with real time of building construction and the attainment of the required quality.

2. Criteria for the choice of contractor

The criteria for choice of contractor are made by the investor. In respect to the criteria, all the offers of the contractor are evaluated and analyzed where the choice of the most favorable offer is made. The applied criteria may have the quantitative values or qualitative characteristics. To each of the criteria, depending on its nature, a difficulty coefficient is assigned which expresses the degree of importance of the certain criteria, where some of the criteria require attainment of the maximum and other, minimum values.

The offers of the potential contractors participating in the tender for the construction of the structure are the alternatives of the multicriterion decision model. The same contractor may offer one or more variants of the investment structure construction project. Each of the offered variants for the construction of the structure have certain specifics in respect to the remaining variants in terms of the criteria for the choice of the contractor and for each variant the values of each criterion are separately determined.

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

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

2.1. General criteria for the evaluation of the contractor

The general criteria for the evaluation of the contractor are the general characteristics of an enterprise, which are defined by the investor itself. The general criteria can be defined as follows.:

- Strength of the contractor enterprise,
- Its presence on the foreign market,
- Available equipment,
- Existence of the specialized teams for certain works,
- Possession of the required specialized facilities and their quality (for concrete, reinforcement, form, etc.), and
- Status of the enterprise.

Strength of the contractor enterprise is measured by the number of employees:

- Mini enterprises, up to 100 workers,
- Small enterprises, from 100 to 500 workers,
- Medium enterprises, from 500 to 1500 workers, and
- Large enterprises, over 1500 workers.

The value of the criterion is expressed by the total number of workers in the enterprise.

Presence on the foreign market, is a criterion of an earlier successfulness of the enterprise, which comprises that the job was obtained at an international auction. The evaluation of this criterion is done according to the number of appearances on the foreign market.

Available equipment for the execution of the planned works on an investment object is a very important criterion. The value of this criterion is done by the type, number, power and capacity of the equipment of the enterprise.

Existing specialized team for certain works, are an advantage of the enterprise because it is not dependable upon the subcontractors. The evaluation of this criterion is measured by the existence of the specialized teams for the execution of the certain number of activities with its own labour or the subcontractors.

Possession of the required specialized facilities, is a significant asset for a contractor. Possession of such facilities makes the potential contractor independent from other enterprise which would participate as a subcontractor. The evaluation of this criterion is done according to the capacity of the required facilities for the completion of an investment object.

Status of the enterprise is used for the evaluation of the enterprise in its entirety. The evaluation of the material and financial status, strategy and business policy, and the perspectives of the development of the enterprise. The evaluation of this criterion is done based on the: liabilities, break-even analysis, liquidating capacity, etc.

2.2. Special criteria for the evaluation of the contractor

The general criteria determined the characteristics of the enterprises, the special criteria determine the characteristics of the concrete investment object. Such as: the price of the object construction, deadline of the construction, the references of the contractors from the similar objects, distance from the working facilities to the construction site and whether the enterprise has the resources for the completion of the object.

The cost of the object construction is the basic element of the offer for the construction of an investment object. The value of this criterion is expressed in dollars or euros...

The deadline of the construction is another very important element of the offer. When evaluating this criterion, it is necessary to take into account the quality of the completed works and their testing during construction, as well as after the object has been constructed. The Evaluation of this criterion is expressed by the number of days spent in the construction of an object.

The references of the contractor from the similar objects is an important criterion while choosing the most favourable contractor of an investment object. The enterprise which built the same or similar objects has the required experience. That experience is indispensable in the construction of an object, and it is reflected in the prediction of the possible problems met in the project realization phase. The references of the contractor from the construction of the similar objects reassures the investor that the contractor will successfully complete the job. The value of this criterion is expressed by the number of previously completed objects (same and similar).

The distance from the working facilities to the construction site greatly affects the organization of the object construction. The smaller the distance between the facilities and the construction site the more favourable the solution of the production in these facilities is. That is particularly the truth for the coordination of the production in the facilities and the dynamics of the object construction. The proximity of the working facilities facilitates the construction with small, or without any stockpiles at the construction site, as well as the minimal transport costs of the prefabricated materials from the working facilities. All of that significantly affects the decrease of the costs of an investment object construction. The value of this criterion is expressed by the distance from the working facilities to the object, in metres.

The resources for the completion of the object (labour, equipment, gear) are very important for the successful completion of the object, but one should consider the available resources, and not the total resources of the enterprise. The value of this criterion is expressed by the number of certain resources.

2.3. The choice of the contractor

After the collection of the offers, one commences the selection of the most favourable one (a contractor can give one or more offers). The investor, according to its own needs, evaluates the criteria. The appropriate difficulty coefficients could be introduced in order to have the successful problem analysis. When choosing the most favourable contractor of an investment object, the following criteria are most frequently applied:

- The most important criteria:
 - Total costs of the object construction, and
 - Terms of payment;
- Then, there are important criteria:
 - Duration of the warranty period, and
 - Quality of the performed works;
- Less important: duration of the investment object construction;
- The least important is the business cooperation up-to-date.

As it has been said, the criteria are determined by the investor itself according to the nature of the object, its needs and requirements. On the basis of the adopted criteria and their importance, the most favourable solution in the choice of the contractor is determined, by the one of the known methods. This problem is the task of the multi-attributive decision making.

3. The choice of several contractors for the investment object

As opposed to the previous problem, the choice of the several contractor for the investment object is the problem of the multi-aimed decision making. If each of the contractors perform only one phase (activity) in the object construction, then the model of the choice of the contractor is the one criterion model, and is reduced to the task of assignment [1]. This task comprises as well the problem of the choice of a contractor with the independent phases (groups of activities). The efficiency of the performed disposition of the contractors is optimized by the function of the criteria. The function of the criteria is minimized or maximized, depending on the nature of the criteria in the problem. This model can be modified, so that one or more of the contractor can have the multiple phases (activities). Whether the problem will be

considered as one criterion, two criteria or multiple criteria problem, depends on the nature of problem and the goals to be achieved by the solution of this problem.

The general mathematical model of the multi-aimed decision making of the minimization of the duration of the activities with the longest time of duration (equation 1) and the minimization of the total investment object construction costs (equation 2), is formulated as the two-criteria non-linear problem of the 0-1 programming:

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

$$\min (Cp(x) = \sum_{i \in I_k} \sum_{k \in K} c_{ik} x_{ik}) \quad (2)$$

with the limiting system:

$$\sum_{k \in K} x_{ik} = 1, \quad i \in I_k, \quad (3)$$

$$x_{ik} \in \{1, 0\} \quad i \in I_k, k \in K, \quad (4)$$

$$\bigcup_{k \in K} I_k = I, \quad (5)$$

where: m, i, I – is the number of activities, indices and set of activities, $i \in I = \{1, 2, \dots, m\}$; n, k, K – is the number of the possible contractors, indices and set of the contractor indices, $k \in K = \{1, 2, \dots, n\}$; $I_k \subseteq I$ – set of the activity indices which are performed by the specialized k contractor, $k \in K$; t_i – duration of the i activity, $i \in I$; c_{ik} – costs of the i activity when it is performed by the k contractor, $i \in I, k \in K$; x_{ik} – variables for the decision making with the values:

- 1 – if the i activity is assigned to the k contractor, or
- 0 – when the i activity is not assigned to the k contractor, $i \in I, k \in K$.

By the limiting equation (3) it is defined that each activity can be executed by only one contractor which is specialized for that kind of activity, and that each activity can be executed only once. The equation (4) indicates the nature of the variables. The equation (5) defines the problem in such a way that it has a solution only if at least one contractor applies for each activity. The non-linearity of the equation (3) determines the non-linearity of the whole model (equations 1 to 5).

In the general case, in the methodology of the multi-aimed decision making problem solving, there is a set Q with the finite number (h) of the efficient solution, marked as the q solutions:

$$(Tp^{(q)}, Cp^{(q)}, x_{ik}^{(q)}, t_{ik}^{(q)}, i \in I_k, k \in K), \quad q \in Q = \{1, 2, \dots, h\}. \quad (6)$$

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 activities in the critical way, while the non-critical activities have the appropriate times of the latest beginnings:

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

For the choice of one of the contractors for each phase (activity) of the project design, the previous model (1 to 7) should have an addition of the sub-set of the limitations, with the conditions that each contractor can be assigned by only one phase (activity) of the project, from the set activities for which the contractor is specialized

$$\sum_{i \in I_k} x_{ik} \leq 1, \quad k \in K. \quad (8)$$

In the concrete case, the assigning of the execution of the certain phases (activities) of the project, can be connected to the series of other specific activities. There may be present the cases when the times of the execution of the certain phases (activities) are not defined in advance, but the concrete potential contractor define the time of the duration of those phases (activities).

Especially interesting is the possibility of crediting of the project execution by the contractors. This crediting can be in the form of delayed payment of the executed works. It most often means an advantage, though the costs could be higher due to the delayed payment of the executed works. The problem of the choice of the most favourable contractor can be even more complex if the additional elements are involved as the choice criteria. Those could be: long term business co-operation with some of the potential contractors, or favouring of some of the potential contractors for other reasons. In that case, the general variant of the choice of the contractor is formed, through the introduction of the new parameters:

- $l_{0k} \subseteq l_k$, $K_0 \subset K$ – The set of the i phases (activities) which are obligatory assigned to the k contractor and the set of the k contractors with such characteristics, $i \in l_{0k}$, $k \in K_0$;
- $K_1 \subseteq \{K : K_0\}$, K_2 – The set of the k contractors where the maximum number of phases (activities) by project is limited, $k \in K_1$, and the contractors without such characteristics, $k \in K_2$, $K_2 = K : K_1$;
- m_k – The highest possible number of phases (activities) which the k contractor can have to execute, $k \in K_1$;
- r, s, S – The possible number of the variants of payment to the contractors, indices and the set of indices of the payment variants, $s \in S = \{1, 2, \dots, r\}$;
- $S_{ik} \subseteq S$ – The set of the indices of the payment variants for the i phase (activity) if it is executed by the k contractor, $i \in l_k$, $k \in K$;
- t – The time unit of the duration of the execution of a phase (activity) in the project, most often it is: an hour, a day, a week or a month;
- t_{iks} – The duration of the i phase (activity), when this phase (activity) is executed by the k contractor with the s manner of payment, $i \in l_k$, $k \in K$, $s \in S_{ik}$;
- x_{iks} – The variables to which the following values are assigned:
 - 1 – when the i phases (activities) are assigned to the k contractor, who has the s variant of payment, or
 - 0 – in the opposite case, $i \in l_k$, $k \in K$, $s \in S_{ik}$;
- c_{iks} – The monthly costs of the i phase (activity), when that phase (activity) is executed by the k contractor with the s variant of payment [EUR/month], $i \in l_k$, $k \in K$, $s \in S_{ik}$;
- T – Duration of the project execution [month];
- c_{ikst} – Monthly costs of the i phase (activity), when that phase (activity) is executed by the k contractor with the s variant of payment in the t month [EUR/month], $i \in l_k$, $k \in K$, $s \in S_{ik}$, $t = 1, 2, \dots, T$;

$$c_{ikst} = \begin{cases} c_{iks} t_{iks}, & \text{if } t = t_{iks}^{\text{start}}, & \text{if } s = 1, x_{ik1} = 1 \\ c_{iks}, & \text{if } t_{iks}^{\text{start}} \leq t \leq t_{iks}^{\text{end}}, & \text{if } s = 2, x_{ik2} = 1 \\ c_{iks} t_{iks}, & \text{if } t = t_{iks}^{\text{end}}, & \text{if } s = 3, x_{ik3} = 1 \end{cases}$$

where: t_{iks}^{start} – is the start of the i activity; t_{iks}^{end} – is the end of the i activity; $s = 1$ – total costs of the initial month of the execution of the phases (activities); $s = 2$ – monthly costs in each month of the activity execution; $s = 3$ – total costs of the ending month of the phase (activity) execution.

According to the previously given parameters, one can form the general postulate of the multi-criteria mathematical model for the choice of the most favourable contractor of an investment object with the independent phases:

$$\min \{T_p = \max_{\{x_{iks}=1\}} t_{iks}, \quad i \in I_k, k \in K, s \in S_{ik}\}, \quad (9)$$

$$(\min) C_p = \sum_{i \in I_k} \sum_{k \in K} \sum_{s \in S_{ik}} \sum_{t \in T} c_{ikst} x_{iks}. \quad (10)$$

The criterion (9) minimizes the duration of the project, while the criterion (10) minimizes the costs of the project.

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

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

The equation (11) considers the monthly costs of the project, while the equation (12) comprises the costs of the individual contractors. One can perform the minimization of the payment of the certain contractors and maximize the value of the works assigned to the certain contractors.

This formed general multi-criteria mathematical model for the choice of the most favourable contractor of an investment object with the independent phases (9, 10, 11 i 12) has the following limiting system:

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

$$x_{iks} = 1, \quad k \in K_0, \quad i \in I_{0k}, \quad s \in S_{ik}, \quad (14)$$

$$\sum_{i \in I_k} \sum_{s \in S_{ik}} x_{iks} \leq m_k, \quad k \in K_1, \quad (15)$$

$$\sum_{i \in I_k} \sum_{k \in K} \sum_{s \in S_{ik}} c_{ikst} x_{iks} \leq C_{ot}, \quad \text{for some months } t \in T, \quad (16)$$

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

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

$$x_{iks} \in \{1, 0\}, \quad i \in I_k, \quad k \in K, \quad s \in S_{ik}. \quad (19)$$

Each phase (activity) in the project has to be executed, as defined by the limitation (13). The limitation (14) ensures that the required phases (activities) are assigned to the certain contractors. The limitation (15) maximizes the number of the phases (activities) which are assigned to the certain contractors. The limitation (16) limits the cost of the project for the given months (to values C_{ot}), while (17) limits the total costs of the certain contractors (to the value $\underline{C}_{ok}$). The limitation (18) ensures that the contractors have the smallest realization of the costs from the $\underline{c}_{ok}$ value, and the nature of the variables is defined by the limitation (19).

4. Conclusion

Here is presented the application of the method of the multi-aimed decision making. The general postulations of each group of the problems are given, the general and the concrete mathematical models are formed and the methods for the solution of the efficient solutions to the choice of the most favourable investment object contractors are given. When solving the multi-attributive decision making, there is a provision that through the definition of the starting data, a matrix of decision making is formed, and so the appropriate mathematical model. Then, the choice of one or more methods for solution is done, and the solutions are determined and analyzed. The repeated problem solving is done with the appropriate changes of some of the parameters in the mathematical model.

The researches in different fields of planning of the organized business and realization of certain tasks confirm that, most often, it is necessary to simultaneously consider many criteria for the evaluation of the efficiency of the solution. The number of the criteria depends on the very type of the solved problem.

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ЕКСПЕРИМЕНТАЛЬНІ ВИПРОБУВАННЯ ПЛАНЕТАРНО-КОЛІСНОГО РУШІЯ

Розглядаються питання експериментальних випробувань веденого планетарно-колісного рушія. Подано опис конструкції досліджуваного рушія з устаткуванням для проведення випробувань, тарувальні графіки давачів та отримані залежності для різних режимів руху.

Ключові слова: планетарно-колісний рушій, давач, осцилограф, осцилограма.

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Experimental tests of planetary-wheeled mechanism

The questions of experimental tests of conducted planetary-wheeled mechanism are examined in the article. Description is given to construction of explored mechanism with the equipment for testing, tare graphics of sensor and dependences are got for different modes of motion.

Keywords: planetary-wheeled mechanism, sensor, oscillograph, oscillogramm.