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Modeling and Optimization of Commissioning

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Abstract. The article describes the characteristics of commissioning works, outlines optimization methods that can be used to obtain various models of commissioning works in construction. Mathematical modeling of commissioning activities can be described by linear and nonlinear equations. Nonlinear models are now spread more widely but they complicate the solution of such problems. A simpler problem with determining the optimal distribution of m workers for performing commissioning works at n capital construction facilities can be described by a linear programming model. The most important drawback of the linear model, namely the average rate of work execution, does not take into account the possibility of performing work at a separate facility.

INTRODUCTION

Commissioning is the final part of construction and installation work [1]. Commissioning works are carried out during the period of preparation for operation of capital construction facilities during their commissioning, construction, reconstruction or overhaul [2]. The problems of commissioning are to detect probable errors in design, construction and installation works and to search for defects in the operation of equipment before its operation at capital construction facilities.

Mathematical modeling and optimization of commissioning activities, focused primarily on studying the patterns of organization of the commissioning process, are relevant and have not been carried before.

Nowadays the practice of commissioning is regulated by the manager independently without taking into account the real laws of the commissioning process. Therefore, this always leads to unreasonable excessive material resource costs in commissioning, which negatively affects the financial activities of commissioning organizations. Therefore, the task of the analytical description of the commissioning process for scientifically based allocation of the number of employees and material resources for commissioning is relevant.

The objectives of this study are to:

- consider commissioning simulations using operations research methods, in particular linear equations;
- consider non-linear modeling for commissioning activities;
- check the linear model in the real enterprise.

DISCUSSION

Last decades nonlinear models have replaced linear ones in various fields of science and technology 3, 4, 5. This replacement is due to the need for a comprehensive analysis of operating conditions and physical processes occurring in industrial devices, systems and processes, including in construction 6, 7, 8. On the other hand, the rapid development of computer technology makes it possible to use more complex mathematical models not only in scientific applications to study certain processes or to determine new laws but also as elements of control systems for various devices. There are many papers about design and usage of state variables observers. These observers are based on mathematical models of controlled processes or devices.

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Mathematical modeling of commissioning activities can be described by operations research methods, linear and non-linear equations. Let the problem be given with determining the optimal distribution of m workers for commissioning at n capital construction facilities. Let the required rate of commissioning and the norm of their execution for each work be given – q_i.

It is necessary to find such a distribution of workers so that the rate of all commissioning is maximized.

Denote as V_i^p the required rate of commissioning at the i^{th} facility;

q_i is the norm for commissioning at the i^{th} facility (works);

x_i is the number of commissioning workers at the i^{th} facility (people).

Then the function:

$$V_i = V_i(x_i, q_i) \tag{1}$$

characterizes the rate of commissioning operations at the i^{th} facility when x_i commissioning workers are allocated to the facility.

When setting a problem linearly, the function V_i and the constraints must be linear. The objective function can be written as:

$$V_i = x_i \cdot q_i \tag{2}$$

So the graph of the facility commissioning rate versus the number of workers is direct (see Fig. 1). In commissioning organizations, the teams performing work, as a rule, consist of a small number of workers, therefore, the number of workers less than or equal to three in this case is relevant. Commissioning does not require a large number of workers.

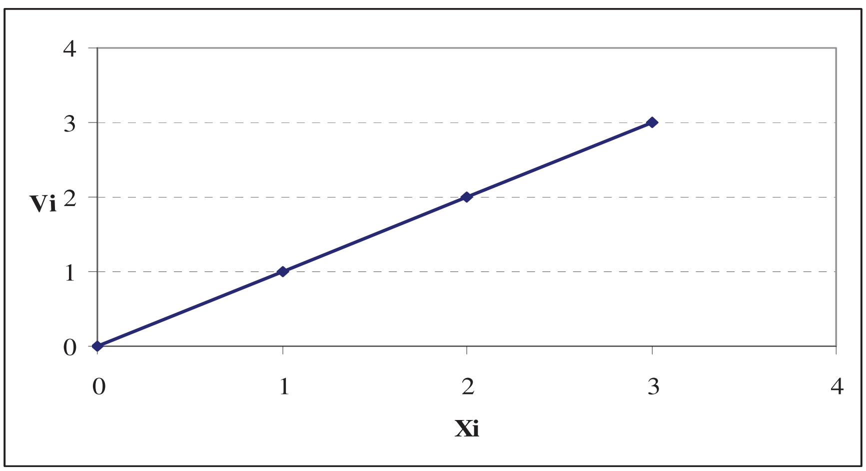

FIGURE 1. The graph of the commissioning rate versus the number of workers

You can select the average commissioning rate for n objects as a criterion.

$$V_{cp} = \frac{1}{n}\sum_{i=1}^{n} q_i x_i \tag{3}$$

If you redefine the value $\frac{1}{n}q_i$ through C_i, the objective function will be:

$$V_{cp}(x_1, x_2, \ldots x_n) = \sum_{i=1}^{n} C_i x_i \tag{4}$$

The constraint system will be as follows:

$$x_1 + x_2 + \dots x_n \le m;$$
$$q_i \cdot x_i \le V_i^{\,p}; \tag{5}$$
$$x_i \in N$$

So, in this case, the formulation of the linear programming problem is as follows: it is necessary to find a number of workers for commissioning x_i on the i^{th} facility, at which the maximum of the objective function is achieved:

$$V_{cp} = \sum_{i=1}^{n} C_i x_i \tag{6}$$

And the constraints are:

$$x_1 + x_2 + \dots x_n \le m;$$
$$q_1 \cdot x_1 \le V_1^{\,p};$$
$$q_2 \cdot x_2 \le V_2^{\,p};$$
$$\dots\dots\dots\dots\dots$$
$$q_n \cdot x_n \le V_n^{\,p};$$
$$x_i \in N; \tag{7}$$

So we got simpler calculation methods. In practice for the case $x_i > 3$, the function $V_i(x_i)$ is often considered nonlinear.

Taking into account the tendency of saturation, the graph of changes in the total productivity of workers from their number can be the function of the square root.

Let us give calculations for two real existing facilities (n = 2) of the real existing enterprise ANO IL EZ «VYAZ 97», which employed 3 and 4 employees, respectively, who performed commissioning. In this case, the commissioning rate is equal to 2, that is two works per shift: $x_1=3$, $x_2=4$, $q_i=2$, n=2. Then

$$V_1 = q_i \cdot x_i = 3 \cdot 2 = 6 \tag{8}$$
$$V_2 = 4 \cdot 2 = 8$$

With the simultaneous implementation of commissioning works at two facilities, the number of workers was 3 and 4, respectively, then:

$$V_{cp} = \frac{1}{n} \sum_{i-1}^{n} q_i x_i = \frac{1}{2}(2 \cdot 3 + 2 \cdot 4) = 7 \tag{9}$$

The linear programming problem will be as follows:

$$V_{cp} = \frac{1}{n} \sum_{i=1}^{n} q_i x_i = \frac{1}{2}(2x_1 + 2x_2) = x_1 + x_2 \tag{10}$$

With the constraints:

$$\begin{aligned} &x_1 + x_2 \le 10; \\ &2 \cdot x_1 \le 6; \\ &2 \cdot x_2 \le 6; \\ &x_i \in N; \end{aligned} \tag{11}$$

where m = 10 is due to the limited number of qualified personnel at this commissioning enterprise, for this enterprise $V_i^p = 6$. Then the solution to this linear programming problem will be the following values: $x_1=3$, $x_2=3$.

Thus, thanks to the created model, it is possible to calculate the required number of workers to perform commissioning. To carry out commissioning works at the first facility, 3 workers were involved, which is optimal under these conditions, while at the second facility, the number of workers involved was 4, and according to the model, there could be 3. So the presented linear model allows you to optimize the number of workers required to perform commissioning, at which the maximum of the average objective function (6) is achieved.

Thus the linear model was applied at the real organization ANO IL EZ «VYAZ 97», which made it possible to optimize the number of employees for commissioning. The calculations were applied and gave a positive effect, and the effectiveness of the proposed model can be estimated in the salary of an extra employee on the second facility, which is equal to 20 thousand rubles. So the economic effect of the proposed model is 20 thousand rubles.

The most important drawback of the linear model described above, namely the average rate of work execution, does not take into account the possibility of performing work at a separate facility. Now consider the nonlinear setting of the problem when function $V_i(x_i)$ and the objective function F $(x_1, x_2, \ldots, x_n)$ has an arbitrary form.

$$V_{cp} = \frac{1}{n}\sum_{n}^{1} C_i x_i \tag{12}$$

A more comprehensive criterion will be based on the principle of taking into account distances or «shortage» of performance indicators for individual objects, in this case the rate of commissioning:

$$\Delta V(x_i q_i) = V_i^{\,p} - V(x_i q_i) \tag{13}$$

«Shortage» can be expressed in relative quantities:

$$\Delta V(x_i q_i) = \max\left(\frac{V_i^{\,p} - V_i\ (x_i q_i)}{V_i^{\,p}}\right) \tag{14}$$

The objective function can then be written as:

$$\Delta V(x_1, x_2, \ldots x_n) = \max\left(\frac{V_i^{\,p} - V_i\ (x_i q_i)}{V_i^{\,p}}\right) \rightarrow \min \tag{15}$$

The lower the maximum «shortage» in the rate of commissioning, the more efficient commissioning is. In this case, the restrictions will be as follows:

$$\begin{aligned} &\sum_{i=1}^{n} x_i \le m \\ &\Delta V(x_i q_i) = V_i^{\,p} - q_i \\ &x \in N \end{aligned} \tag{16}$$

Recall that in the linear formulation of the problem the dependence of the rate of commissioning work on the number of workers is described by the formula 2. Then in the nonlinear formulation of the problem can be described by the formula:

$$V_i = l_i \times q \times x_i^{\alpha i} \tag{17}$$

where l_i – coefficient taking into account commissioning conditions.

If l_i=1, α_i=0.5, i∈[1,3], the graph of the function $V = 2\sqrt{x}$ is shown in Fig. 2.

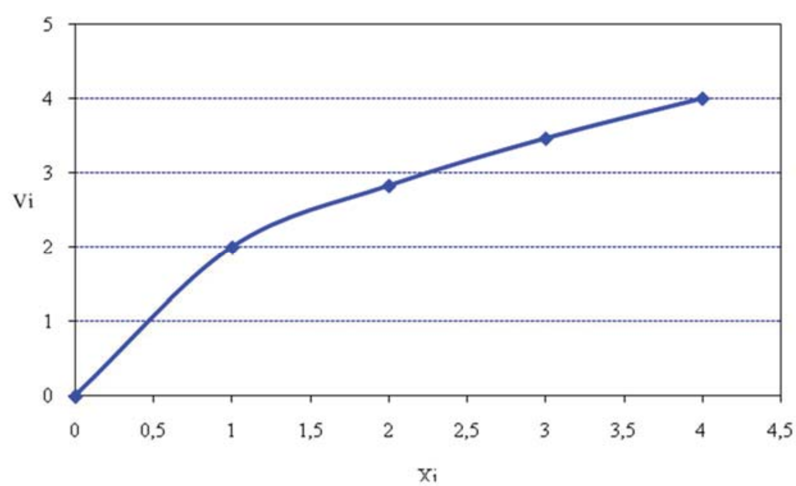

FIGURE 2. The graph of commissioning rate versus number of employees in case of nonlinear formulation of the problem with the specified parameters

Sometimes you can use the deviation of the required commissioning time from the estimated as a «deficit»:

$$\Delta T_i = \max\left(\frac{T_i(q_i x_i) - T_i^{\,p}}{T_i}\right), i = \overline{1, n} \tag{18}$$

The objective function will then be:

$$F = \max_{l \le i \le n} \left(\Delta T_i \right) \tag{19}$$

In this case, this problem is solved using nonlinear programming methods. If the objective function is sought in conditions of uncertainty, then such a problem relates to the problem of stochastic programming. For the construction industry, nonlinear programming refers to the least studied topics. The developed nonlinear solution to the problem of commissioning works allows to reduce the «deficit» of efficiency indicators for individual objects, which can further reduce the costs of commissioning enterprises obtained in the linear formulation of the problem.

CONCLUSION

Thus, the problem of determining the optimal distribution of m workers for commissioning at n capital construction facilities can be optimized using a linear programming model, which greatly simplifies the calculations.

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