The application of simulation modelling in making operational decisions in construction

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Abstract. The emergence of new organizational methods such as controlling, including strategic and operational-production, is a response of investment and construction activities to new challenges generated by the development of science and technology, as well as socio-economic conditions. The need of society, as a kind of aggregated customer of capital construction projects, is to reduce the cost, duration of their construction, improve the quality of buildings and structures. Achieving such results is possible through the use of new materials, equipment, technologies. However, the conditions for the construction of a specific facility, the current operational situation are conditioned by the presence of disturbing influences of both technical and managerial nature, and which must be stopped in time and, if possible, prevented. Thus, a toolkit is needed that involves the implementation of the functions of analysis, monitoring, but also the development and even adoption of operational technical and managerial decisions. It is on these principles that operational and production controlling is based. The adoption of appropriate tactical decisions is the central point in the organization of operational and production controlling in construction production, and also the fact that the real tasks of organizing construction are not always fully solved analytically. One of the promising ways can be the use of optimization methods in combination with simulation models and the provisions of the theory of experiment planning. The article proposes to consider the use of simulation modeling when optimizing the calendar schedule for the implementation of a complex of construction and installation works, carried out in the process of operational and production controlling.

1. Introduction
The adoption of appropriate tactical decisions is central to the organization of operational and production controlling in construction.

The situation in which such decisions are made is characterized by:
- goal;
- alternative ways to achieve the goal;
- limiting factors.

The optimality criterion represented by the function can serve as a formalized description of the goal, in turn, its value depends on a number of factors, which can be divided into two groups:

a) controlled factors, their values can be changed during operation, these include control variables and some parameters of the system itself;

b) uncontrollable factors that the subject of management cannot influence. Depending on the information available, they can be divided into three groups:
deterministic factors, the values of which are reliably determined;
- stochastic factors - random variables and processes with known distribution laws;
- uncertain factors, for each of which the range of possible values of the factor is known.

Thus, the problem of forming solutions is formulated in the following form: for given values of uncontrollable factors, it is necessary to find such values of controls from the range of their permissible values, at which a maximum (minimum) is achieved according to the optimality criterion \[1, 2, 12, 14\].

Usually, the task of forming operational decisions in the field of construction management is sought to be reduced to a well-known mathematical scheme of linear, nonlinear or discrete programming in a deterministic or stochastic setting in order to solve it by known methods.

However, the real tasks of organizing construction are not always possible to fit into traditional schemes due to their complex nature of building systems, which cannot be fully described in an analytical form \[3-5, 13-17\].

In this regard, it is necessary to find a solution to overcome the existing difficulties. One of the possible such methods can be the use of optimization methods in combination with simulation models and principles of the theory of experimental design. In this case, the simulation model must be supplemented with an optimization block, which includes:
- proper optimization algorithms for solving one and multi-extreme problems;
- algorithms for planning experiments on a simulation model.

Combining the optimization block with the simulation model leads to the formation of a decision contour. In this case, various conjugation schemes are possible, since the decision circuit can contain an optimization block both in the forward circuit and in the feedback circuit \[6, 7\].

2. Methods
The choice of a specific interface scheme is determined by the peculiarities of the problem being solved; therefore, the optimization block should be to a certain extent universal, allowing to solve a fairly wide range of problems.

Let us consider the application of the “gradient method” and simulation modeling when optimizing the calendar schedule for the implementation of a complex of construction and installation works carried out in the process of operational and production controlling.

Calculations on the simulation model form the search area for the extremum of the objective function, corresponding to the real conditions of production, as if separating from the theoretically possible search area for the extremum the zone in which there are admissible solutions that are real for implementation in construction practice. Then the optimization procedure selects from this zone a solution that delivers min (max) to the desired function \[8-11\].

3. Results and discussion
The mathematical formulation of the problem of optimizing the calendar schedule of a complex of construction and installation works at one construction site with a given organizational and technological reliability of its implementation can be formulated as follows:

We denote \[x^i = (x_{1}^i, x_{2}^i, ..., x_{m}^i)\], where \[x_{k}^i\] is the moment of delivery of the \(k\)-th resource to the object considered in the \(i\)-th iteration. \[R^i = (R_{1}^i, R_{2}^i, ..., R_{m}^i)\], where \[R_{k}^i\] is the used amount of the \(k\)-th resource \((k = 1, ..., m)\), \(t(x, R)\) is the time completion of a set of works with a calendar schedule \((x, R)\).

The limits of possible change of each resource \(R_j\), \(\min R_j \leq R_j \leq R_j, \max\), where \(R_j, \min\) and \(R_j, \max\), respectively, the maximum and minimum amount of the \(j\)-th type resource are set.

It is believed that a certain indicator is given that evaluates the quality of the work calendar - the criterion of optimality \(f(x, R)\). As a criterion of optimality, the cost of construction and installation works, idle time of resources, uniformity of resource use, etc. can be taken.

As a limitation on the execution time of a complex of construction and installation works, \(t_p\) is the duration of the planning period.
Since the implementation of the calendar schedule is carried out under the influence of random factors, the constraints can be probabilistic. As the main limitation, the requirement is considered, in which the probability of completing a set of works within a specified time frame should be no less than the selected reliability level

\[ F(x, R) = P \{ t(x, R) \leq t_p \} \geq \alpha, \]  

where \( t(x, R) \) is the term of completion of the work package calculated in the model for the selected calendar schedule \((x, R)\), \( t_p \) is the planned completion date.

In this situation, the optimality criterion can be a random function, so it is natural to go to its averaged value. Thus, in general terms, we come to the following mathematical problem:

\[ \text{Min } Mf(x, R); \]  

\[ F(x, R) \geq \alpha; \]  

\[ R_{j, \text{min}} \leq R_j \leq R_{j, \text{max}}; \]  

where \( Mf \) is the operator of the expectation of the function.

To solve the problem of forming a calendar schedule having a given level of organizational and technological reliability according to the selected optimality criterion, an empirical method for improving the plan according to a given criterion \( f(x, R) \) is proposed, where the vector \( x \) determines the moment of supply of resources to the object and is considered as a continuously changing value, and the vector \( R \) - the resources used have components that take discrete values.

Taking into account the specifics of the variables \( x \) and \( R \), a modification of the gradient minimization method is chosen. The solution is sought in an iterative procedure, and the pair \((x^i, R^i)\) is the calendar schedule considered in the \( i \)-th iteration.

The procedure for forming a calendar schedule for performing a complex of construction and installation works with a given level of organizational and technological reliability can be described by the following sequence of steps:

1. A certain initial schedule \((x^0, R^0)\) is set:

\[ R^0_j = R_{j, \text{max}}, \]  

i.e., the maximum possible level of resources is taken, and \( x^0 \) is chosen so that the condition

\[ P\{ t(x^0, R^0) \leq t_p \} \geq \alpha, \]  

for example, \( x^0_j = 0 \) for \( j = 1, ..., m \).

If even for \( x^0_j = 0 \) and \( R^0_j = R_{j, \text{max}} \) for \( j = 1, ..., m \) this condition is not met, then the range of admissible values is obviously empty and the value of \( \alpha \) should be increased.

2. The calendar schedule \((x^i, R^i)\) is tested for local changes in resources. Let \( R^i(k) \) and \( R^i(k) \) denote vectors of variants of local changes in the schedule available at the \( i \)-th iteration; \( k \) - option number. These vectors, of which there are only \( 2m \), since \( k \) varies from 1 to \( m \), correspond to a change in the level of the \( k \)-th resource in the direction of its increase and decrease:
The value of the resource vector is taken as $R_{i+1}$, which minimizes the expression

$$
\min \left\{ f(x^i, R^i), \min_{1 \leq k \leq m} f\left(x^i, R^i(k)\right), \min_{1 \leq k \leq m} f\left(x^i, \bar{R}^i(k)\right) \right\}
$$

provided that $R^i_j(k) \leq R_{j,\text{max}}$ and $\bar{R}^i_j(k) \geq R_{j,\text{min}}$, i.e. That is, local changes are not moved outside the original limits.

Moreover, those $R^i(k), \bar{R}^i(k)$ for which

$$
P\{t(x^i, R^i(k) \leq t_n)\} < \alpha, P\{t(x^i, \bar{R}^i(k) \leq t_n)\} < \alpha
$$

If the minimum is reached on several vectors, then any of them is taken.

3. After choosing $R^{i+1}$, the moments of supply of resources are determined, the initial ones for the next $(i+1)$-th iteration $x^{i+1}$. For this, the values of the criterion are calculated

$$
y^i_1 = f(x^i_1 + L_i, x^i_2, ..., x^i_m, R^{i+1}):
$$
$$
y^i_2 = f(x^i_1, x^i_2 + L_i, ..., x^i_m, R^{i+1}):
$$
$$
\vdots
$$
$$
y^i_k = f(x^i_1, x^i_2, ..., x^i_m + L_i, R^{i+1}).
$$

A test step is made in the direction of the antigradient of the function $f$ at the point $(x^i, R^i)$:

$$
x^{i+1}_k = x^i_k - a \frac{y^i_k - f(x^i, R^i)}{L_i},
$$

where $a$ is the step size.

4. The main constraint is checked

$$
P\{t(x^{i+1}, R^{i+1}) \leq t_p\} \geq \alpha.
$$

If the main constraint is met, then the obtained values $(x^{i+1}, R^{i+1})$ are taken as the calendar schedule for the $(i+1)$-th iteration. Otherwise, the step size is sequentially halved until the value $x^{i+1}_k$ satisfying the main constraint is obtained. As a result, we get the next iteration.

5. The result will be final if the following condition is met:
where \( \varepsilon \) is the specified veracity.

If the difference between two successive iterations is insignificant, the resulting calculation result will be final; otherwise we return to step 2.

4. Conclusions
Simulation modelling makes it possible to analyze operational decisions of production management for a number of indicators, however, consideration of the problem of synthesis of solutions, which is most relevant in the management of complex building systems, requires the inclusion of special blocks for the purposeful formation of rational decisions in the simulation model. The model can be used both independently to study and evaluate various options for the structure of the calendar schedule of construction and installation works, and as an integral part of the mathematical support of the subsystem of operational and production controlling the construction of nuclear facilities.

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