Assessment and quality management of construction and installation works

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Abstract. The work is devoted to the study of procedures for assessing the quality of construction and installation works. It is emphasized that there are significant differences in the parameters for assessing the state of an object and a process. When the process is flowing, it most often requires smoothness, the absence of spasmodic changes. Violation of these requirements affects the technological process final result - the finished product’s quality. It was revealed that the quality of the process can be determined by decomposing it into the operations and evaluating deviations in synchronization, coordination, technological modes and the costs of their implementation. However, the sequentially carried out processes, as follows from the theory of metasystems, can be evaluated by the readiness of the next operation. In this regard, the task of optimal availability control is further posed and solved.

1. Introduction

According to the reports, the construction quality is more than 80% determined by the quality of construction and installation works [1]. On the other hand, at present, the predominant number of the parameters used to assess quality relate to the construction object, and not to the process of its production [2].

The quality assessment is significantly different depending on whether it relates to an object or process. This is based on differences in the parameters for assessing the state of an object and a process. The condition of an object is usually estimated by the value of various physically measured internal parameters. The process, first of all, is subject to the requirements of smooth flow, the minimum number of spasmodic changes that deviate the process from technology. Violation of these requirements is reflected in the quality of the technological process’ final result - in finished products, evaluating which we can also judge the process quality, but already as a fait accompli.

From this analysis, it is obvious that the special procedures are needed to assess the quality of construction and installation works, and the special control actions are necessary to ensure it.

2. Theory

Modern requirements for the construction quality are summarized in building codes and rules [3, 4].

Any technological process is usually divided into operations and the coordination of these operations in time (synchronization) and the coordination of the means’ movements that realize them come to the fore. In addition, it is important that the technological regimes are observed in each operation, since the deviations of a technological parameter in a previous operation become a disturbing effect for the subsequent operations. For example, the deviations in the horizontal position
of the foundation (of course, if they are within the tolerance) entail differences in the thickness of the mortar layer at the next masonry, an excessive delay in any operation, forces other operations to not disrupt the construction period, avoiding the verticality of one floor (again within tolerances) is compensated for the subsequent ones. In addition to this, the wide variation in technological conditions depends on a person who can be distracted, forget to take any action, overlook something, and finally, fatigue can prevent him. As a result, the smoothness of the process, and, therefore, the quality of its implementation is deteriorating. Of course, the deviations in one operation can be eliminated in subsequent ones, but then it becomes important what costs of energy, materials, raw materials, and, ultimately, finance, are they eliminated. Thus, a decrease in the quality level of the process, expressed primarily in violation of the smoothness of its course, which can be determined through deviations in synchronization, coordination, technological conditions and the costs of carrying out its constituent operations.

The process quality concept is abstract [5] and has the specifics in that it is possible to evaluate and control its level only indirectly. Usually the abstract objects are the control objects of the upper hierarchical levels.

We study a two-level quality management system for construction and installation works. The corresponding composition and the relationship of its elements are presented in Figure 1.

![Figure 1. The scheme of the construction and installation works’ two-level quality management](image-url)
The classical notation is applied here: for vectors of controlled quantities - \( \bar{Y} \), control and disturbing actions, respectively - \( \bar{U}, \bar{F} \). The circuit depicted in Figure 1 can be described by the operator equations

\[ \bar{Y}_i = W_i^U \cdot \bar{U}_i + W_i^F \cdot \bar{F}_i, \quad i = 1,2. \] (1)

Here \( W_i^U \) and \( W_i^F \) are the transfer functions of the control system with respect to control and disturbing actions, respectively.

At the first level, construction and installation work is directly controlled, therefore the controlled quantities, controlling and disturbing influences are most often real, physically measurable. At the second level, since the direct actions are managed by the control system of the first level, only indirect actions are possible - parametric, structural or organizational changes, therefore, special operators are needed to form control actions and evaluate the controlled quantity

\[ A[\bar{Y}, \bar{V}] = W_1^U \cdot B[P, S, Org] + W_2^F C[\bar{F}, \bar{X}]. \] (2)

Here, respectively, it is indicated: \( A[\bar{Y}, \bar{V}] \) - the operator of forming the level of the quality of the process \( \bar{V} \) - additional indicators that affect the quality of the process, \( B[P, S, Org] \) - the operator that integrates parametric, structural and organizational changes and impacts in the quality management system, with the aim of increasing its level, \( C[\bar{F}, \bar{X}] \) - the second-level operator, forming disturbing effects on the entire technological system. The components of the vector \( \bar{X} \) reflect the quality of the input raw materials, materials, energy.

The quality level of the process can be evaluated in various ways. Examples of such operators can be additive, multiplicative, or combined convolution. For example, it is possible to use the additive convolution as the operator

\[ Y_2 = \sum_{i=1}^{N} \alpha_i Z_i. \] (3)

where \( \alpha_i \) is the weighting coefficient, \( Z_i \) is the value that determines the parameters’ quality level (in Figure 1, these are the deviations in time, coordinates, technological modes and costs of operations).

However, this assessment method does not give zero if any component of the quality management system, even the most important one, is completely out of order and the quality level in this case should be zero. In this case, the multiplicative operator \( A \) helps out

\[ Y_2 = \beta \prod_{i=1}^{N} Z_i. \] (4)

Here \( \beta \) is the coefficient equalizing the dimension.

3. Model

Technological processes, from the point of view of simultaneous or separate execution of operations, can be divided into two classes: parallel and sequential. Since each operation can be represented by a certain system of actions carried out under certain conditions, the technological process can be looked at as an integration of systems, more precisely, as a metasystem of sequential action [6]. The metasystem is defined as a triple:

\[ \text{MS} = (W, S, r) \] (5)

where \( W \) is a parametric set; \( S \) - can be the set of any systems, in this case - it is a set of structured data systems SD, which parametric sets are subsets of \( W \); \( r \) is the replacement procedure that implements a certain function of the form

\[ r: W \rightarrow S. \] (6)

This formula defines the rule of replacing one operation with another.

For the most efficient implementation of the replacement of one functioning system with another, it is necessary to pose and solve six metasystem problems. In this work, almost all of these tasks and their solutions, as well as the replacement of systems, are strictly regulated by the progress of the technology for the production of construction and installation works, and the assessment and management of the level of readiness of systems for operation is highlighted. Indeed, if the level of readiness before the operation is sufficient, then immediately the issue is solved with synchronization and coordination, favorable conditions are created to minimize deviations of technological modes and
costs of its implementation. In addition, it is clear that the course of preparation for the next operation should be combined with the current one and be consistent with its course.

Let the probability of performing the \( i \)-th operation depending on the time \( t \) and the amount of work \( x \) remaining in this operation obey the Kolmogorov equation

\[
\frac{\partial \omega_i}{\partial t} = b \frac{\partial^2 \omega_i}{\partial x^2} + u_i(x, t)
\]  

(7)

where \( \omega_i \) is the density of the probability described above, \( b \) is the diffusion coefficient, which determines here the variance of the remaining amount of work in relation to the plan. 

The readiness of the \((i+1)\)-th operation of construction and installation work should go to the control equation by an equation similar to (7). Let \( u_i(x, t) \) be the number of shares of control resources allocated for organizing the readiness of the \((i+1)\)-th operation. Denoting the probability density of readiness of the \((i+1)\)-th operation, we have:

\[
\frac{\partial \omega_{i+1}}{\partial t} = b \frac{\partial^2 \omega_{i+1}}{\partial x^2} + u_i(x, t)
\]  

(8)

We subtract from (7)-th equation (8)-th and get:

\[
\frac{\partial (\omega_i - \omega_{i+1})}{\partial t} = b \frac{\partial^2 (\omega_i - \omega_{i+1})}{\partial x^2} - u_i
\]  

(9)

We introduce the notation of probabilistic unavailability of the \((i+1)\)-th operation

\[
S = \omega_i - \omega_{i+1}
\]  

(10)

Then (9) is transformed as follows

\[
\frac{\partial S}{\partial t} = b \frac{\partial^2 S}{\partial x^2} - u
\]  

(11)

The unavailability of the \((i+1)\)-th operation decreases after each dosed organizational managerial impact by \( q \). Considering the managerial impacts to be independent, we obtain the general change in the readiness of the operation for execution in the form of a product or exponential function \( q_j^{u_j} \). Then the general probability that describes the readiness of the operation as a whole will be expressed as

\[
P = \prod_{j=1}^{n} (1 - q_j^{u_j})
\]  

(12)

Here \( n \) is the number of management steps during the preparation of the \((i+1)\)-th operation.

To simplify the expression (12), we take \( P_j = 1 - q_j \rightarrow 1 \). By multiplying and freeing ourselves from the values of the second and higher orders of smallness, we obtain the general unavailability of the operation

\[
Q(\bar{u}) = \sum_{j=1}^{n} q_j^{u_j}
\]  

(13)

where \( \bar{u} = \{u_1, u_2, ..., u_n\} \) is the vector of shares of the control actions.

Similar considerations lead to a similar formula for the probabilistic unavailability of \((i+1)\)-th operation depending on the fulfillment of the requirements for compliance of preparatory actions with the performance of work on the \( i \)-th operation

\[
S(\bar{s}) = \sum_{j=1}^{n} s_j^{p_j}
\]  

(14)

where \( \bar{s} = \{s_1, s_2, ..., s_n\} \). In this case, the probabilistic unavailability of the \((i+1)\)-th operation decreases after each dosed organizational managerial impact by \( p_j \) .

The total costs of organizational activities related to improving the availability of operations are expressed as a linear relationship:

\[
C = C(\bar{u}) = \sum_{j=1}^{n} c_j u_j
\]  

(15)

where \( c_j \) is the cost of a single organizational event that increases the availability of the \((i+1)\)-th operation.

The control task is set as follows: to find the optimal distribution of the shares of the control actions \( u_j \) to ensure minimum costs at a given level of unpreparedness to perform the \((i+1)\)-th operation.

To solve the problem of optimal control by the Euler - Lagrange method, we compose the Lagrangian:

\[
F(\bar{u}) = \sum_{j=1}^{n} c_j u_j + \sum_{j=1}^{n} \alpha_j p_j s_j + \sum_{j=1}^{n} \psi_j \left( \frac{\partial S_j}{\partial t} - b \frac{\partial^2 S_j}{\partial x^2} + u_j \right) + \sum_{j=1}^{n} \xi_j \left( \alpha_j p_j s_j - q_j^{u_j} \right)
\]  

(16)
Here, the first two terms are taken from the integrand in the functional, the third requires satisfying the equations of the control object, and the latter fulfills the set constraints.

To ensure the extremum \( F(\bar{u}) \), we compose the Euler equations in all variables:

\[
\begin{align*}
\frac{\partial F(\bar{u})}{\partial u_j} &= c_j - \psi_j c_j - \varepsilon_j q_j \ln q_j = 0 \\
\frac{\partial s_j}{\partial t} - b \frac{\partial^2 s_j}{\partial x^2} + u_j &= 0 \\
\alpha_j p_j s_j \ln p_j - \frac{d \psi_j}{d t} &= 0 \\
\alpha_j p_j s_j - q_j &= 0, \quad j = 1, ..., n
\end{align*}
\]  

(17)

A similar problem was solved in [7]

4. Results and discussion

To illustrate the dependence of the control action, which optimizes the distribution of resources allocated to increase the readiness of one of the operations in the construction and installation works, we will construct a schedule. From the above-mentioned theory, we have

\[
u(x, t) = A_4 e^{-\frac{M v p_j t}{m p_j}} \text{sh} \left( x \frac{\text{arsh}(v)}{x_0} \right)
\]  

(18)

Figure 2 shows a graph of the dependencies of the control action separately: the exponential graph (at the beginning of the abscissa axis is the upper one in Figure 2) - versus time and the logarithmic graph (the lower one at the beginning of the abscissa axis in Figure 2).

\[\text{Figure 2. Change in the control action components (green - time dependence, red - dependence on the amount of work remaining on the i-th operation)}\]

Here, the control actions are plotted along the ordinate axis in fractions (dimensionless), on the abscissa axis - time in days and the volume of the work performed in percent. As it is possible to see, the control actions’ dependence on time is exponential: the value of organizational control resources decreases with distance from the beginning of the i-th operation. The dependence on the remaining work volume is logarithmic and the magnitude of organizational control resources increases with this volume.

Based on the revealed dependence, the method of optimal redistribution of control resources is easily developed, which should direct the resources in time exponentially and coordinate the value of
these resources with the logarithm of the amount of work remaining until the completion of the operation.

5. Summary
Thus, the optimal distribution of organizational management resources in the operations’ preparation can significantly improve the construction and installation works’ process quality. Of practical importance is the fact that the dependence of preparatory control actions on time is exponential: the value of organizational control resources decreases with distance from the start of the current operation. The dependence on the volume of remaining work is logarithmic and the size of the organizational control resources increases as this volume increases.

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