SECTION II. MODELING

Polyakova I.S., Khisamov F.G.

Mathematical modeling of commissioning activities using differential equations of dynamic transitions and the Monte Carlo method

Kuban State Technological University
(Russia, Krasnodar)

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Abstract

The article defines and highlights the tasks of commissioning, describes mathematical methods that can be used to obtain various models of commissioning in construction. Mathematical modeling of commissioning can be described by differential equations of dynamic transitions and the Monte Carlo method. To simulate the commissioning process using differential equations of dynamic transitions, it must be split into separate elements.

Keywords: commissioning, modeling, Monte Carlo method, differential equations, dynamic transitions method, optimization.

Commissioning works are a set of works that are performed during the period of preparation for operation of the capital construction facility during its commissioning, construction, reconstruction or overhaul [1, P.35]. The tasks of commissioning are detection of probable errors of design and construction and installation works and detection of deficiencies in the operation of equipment before the start of its operation at capital construction facilities [2, P.67]. Commissioning works are the final part of construction and installation works.

Modern commissioning is a rather complex process that requires high qualifications of specialists, and their coordinated work. Commissioning works take place in constantly changing conditions. The elements of the commissioning process are interconnected and constantly influence each other, which complicates their analysis and search for the optimal model [3], [4].

Mathematical modeling of commissioning activities should provide optimal engineering solutions that ensure high labor productivity and resource saving [5].

Simulation modeling successfully reflect the dynamic behavior of systems, so they can effectively reflect random stochastic processes, as commissioning is a stochastic process. Simulation modeling allow you to comprehensively investigate the behavior of the system to find the optimal control [6].

Imagine commissioning as some unmanaged dynamic process dependent on random factor ξ with some probability distribution law. Then the commissioning process can be described by the equation:

$$\frac{dx}{dt} = f(x, t, \xi) \quad (1)$$

This equation describes many trajectories of the system. Let the initial state be fixed: $x(0)=x_0$. To determine the average value of the components of vector $x(t)$ at time $t=T$, a random number generator is used. Then we get a system of equations:

$$\begin{aligned} \frac{dx_1}{dt} &= f(x_1, t_1, \xi_1), \\ \frac{dx_2}{dt} &= f(x_2, t_2, \xi_2). \end{aligned} \quad (2)$$

By solving these equations, you can get the average value of $x(T)=1/N\sum x_n(t)$, where N is the number of tests during T . This is a simulation model. Using simulation modeling allows

you to optimize control in commissioning. In modern system analysis simulation systems become the basis for modeling stochastic systems, including commissioning activities.

Dynamic system modeling based on the compilation of differential equation systems is a complex and time-consuming process that requires excellent knowledge of the subject area.

The commissioning process can be presented as a diagram (Figure 1).

Let the commissioning activity be determined by the actions of several subjects of the commissioning activity, which have their own management at their disposal. Then during the process of functioning, the elements of the «Commissioning process» interact with each other and mutual transitions between individual elements are also possible.

Figure 1 – «Commissioning» process diagram

Then the mathematical models of these elements of the Commissioning process can be represented as a system of differential equations [7, P.55]:

$$\begin{aligned}\frac{dy_1}{dt} &= \sum_{j=1}^n \alpha_{1j} y_j + b_1, \\ \frac{dy_2}{dt} &= \sum_{j=1}^n \alpha_{2j} y_j + b_2, \\ &\dots\dots\dots \\ \frac{dy_n}{dt} &= \sum_{j=1}^n \alpha_{nj} y_j + b_n,\end{aligned}\tag{3}$$

where α_{ij} – are transition coefficients; y_i – volumes of "Commissioning" process elements; b_i – are influence factors from an external environment.

Now let's consider a specific mathematical model of the commissioning process for four elements with mutual transitions according to the following scheme (Figure 2).

Then the system of differential equations for the mathematical model of the Commissioning process of four elements will be as follows:

$$\begin{aligned}\frac{dA_1}{dt} &= -\alpha_{12}A_1 + \alpha_{21}A_2, \\ \frac{dA_2}{dt} &= -\alpha_{23}A_2 + \alpha_{12}A_1 + \alpha_{32}A_3 - \alpha_{21}A_2, \\ \frac{dA_3}{dt} &= -\alpha_{34}A_3 + \alpha_{23}A_2 + \alpha_{43}A_4 - \alpha_{32}A_3, \\ \frac{dA_4}{dt} &= \alpha_{34}A_3 - \alpha_{43}A_4.\end{aligned}\tag{4}$$

Here A_i is the volume of work of the commissioning process, α_{ij} is the intensity of transitions obtained from observations.

Figure 2 - Mathematical model of "Commissioning" process for four elements

The first equation $\frac{dA_1}{dt} = -\alpha_{12}A_1 + \alpha_{21}A_2$, describes the interaction between the first and second elements of the commissioning process: the element A_1 transfers its resources with intensity α_{12} to the element A_2 . In return, A_2 returns some of its resources with intensity α_{21} to the element A_1 . The remaining differential equations are similar.

Thus, the commissioning process can be described by the Monte Carlo model, as well as by means of differential equations of dynamic transitions. To do this, the commissioning process must be divided into separate elements, each of which can be described by a corresponding differential equation.

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