Matrix calculation of the period of non-rhythmic flow balanced at a slow rate

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Abstract. When designing the organization of construction by the flow method, the presence of unbalanced non-rhythmic flows is inevitable. The article deals with the issues of balancing non-rhythmic construction flows at a slow pace on the basis of a matrix algorithm for calculating the parameters of the construction flow. Methods of balancing construction flows are described. The matrix calculation of the parameters of the non-rhythmic flow balanced at a slow rate showed the properties of potential and paradoxical works. From the calculation results it is seen that increasing the rhythm accelerated processes on the allowed organizational downtime between jobs on the hook improves the quality of the construction of the flow, namely increasing the density ratio of the graph, reducing the total amount of organizational downtime, improve utilization of the scope of work. The total duration of the construction flow remains the same when using the properties of potential works and decreases when using paradoxical works.

1. Introduction

Scientific research and the practice of industrial production show that the most progressive organization of production is in-line, providing continuous and uniform output [1-6]. In terms of construction production with a large variety of designs of an object or a significant number of divisions with different complexity is difficult to establish a rational sequence and continuity of implementation of construction work on divisions with providing policy or minimum term and continuous work teams of workers.

When organizing construction and production of construction and installation works by the flow method, the presence of unbalanced non-rhythmic flows is inevitable. Unbalanced flows are characterized by interruptions in the capture between heterogeneous processes. When organizing short-term construction flows, unbalanced forms are acceptable, which is impossible when organizing long-term construction flows.

The main indicators of the construction quality of the flow within line method are: the total duration of the construction of the flow, the density ratio of the graph (matrix), the coefficient of combining processes, utilization of the scope of work.

This problem can be solved on the basis of construction matrix calculation of the flow balanced at a slow pace.
2. Materials and methods

The slow-motion balancing of construction flows can be performed using analytical, graphical, and matrix methods [7-9]. The paper [9] shows the feasibility of balancing the non-rhythmic construction flow at a slow pace while maintaining the rhythms of accelerated processes, and provides an algorithm for calculating the total duration of the slow multi-rhythmic and non-rhythmic flows.

The matrix method of calculating the construction flow parameters allows us to distinguish three types of work: critical, potential and paradoxical [2, 3]. Critical work determines the total duration of the construction flow. The duration of potential work can be increased due to organizational downtime on the gripper without increasing the total duration of the entire complex of work. Paradoxical work has increasing life expectancy that leads to a reduction in the duration of the whole complex of works, and reducing the duration of the increase in the total duration of the works.

Using the properties of potential and paradoxical works, we perform a matrix calculation of the duration of an irregular flow when it is balanced at a slow rate. The rhythm of accelerated processes will be increased by the amount of organizational downtime of work on the division.

Let's consider a matrix algorithm for calculating the non-rhythmic flow and the properties of potential and paradoxical works on a specific example. Let's assume that five processes are performed on seven objects or grippers that are heterogeneous in terms of construction and scope of work. The terms of work on the divisions are different (Figure 1).

Let's evaluate the quality of the organization of the construction flow. The total duration of the construction flow is 38 units of time. The work schedule density coefficient, i.e. the ratio of the total duration of net work performed on all grippers to the total duration, taking into account downtime, is 0.4. The process alignment coefficient, i.e. the ratio of the total duration of net work performed on all division to the total duration of the construction flow, indicated in the lower corner 5 of the process on the VII division, is 2.08.

![Figure 1. Matrix algorithm for calculating non-rhythmic flow.](image-url)
To determine the potential work, we will mark the places of critical convergence of processes with a horizontal line (Figure 1). Potential work in the matrix is work in the flow (process), located below the lowest place of critical convergence on the right. These works in the matrix are indicated by horizontal lines. Work in the flow (process), located above the highest point of critical convergence on the left, will also be potential. These works in the matrix are indicated by vertical lines (Figure 2).

Works marked twice (horizontal and vertical hatching) are paradoxical (Figure 2).

| operation divisions | 1  | 2  | 3  | 4  | 5  | \( \sum_{j} t_{j} \) | \( \sum_{j} t_{j} + \sum_{i} t_{i+1} \) |
|---------------------|----|----|----|----|----|----------------|-----------------|
| I                   | 1  | 2  | 3  | 4  | 5  | 9              | 20              |
| II                  | 2  | 5  | 7  | 2  | 9  | 9              | 20              |
| III                 | 1  | 2  | 5  | 15 | 10 | 10             | 18             |
| IV                  | 2  | 3  | 7  | 22 | 24 | 13             | 15             |
| V                   | 9  | 13 | 22 | 24 | 24 | 13             | 16             |
| VI                  | 4  | 1  | 2  | 2  | 2  | 13             | 15             |
| VII                 | 1  | 2  | 28 | 6  | 12 | 12             | 13             |
| (m)                 | 14 | 15 | 29 | 10 | 11 | 79             |                |

![Figure 2](image)

Figure 2. Potential and paradoxical cells of the matrix.

Works of 2 processes on I, V, VI, VII divisions, 4 processes on I, II, III, IV, V, VII divisions, 5 processes on I, II, III divisions are potential. Works of 2 processes on II, III, IV divisions and 4 processes on VI divisions are paradoxical.

3. Results and discussion

We create new matrices taking into account the properties of potential and paradoxical works. By increasing the rhythm of accelerated processes by the amount of organizational downtime, we will simultaneously solve the problem of improving the quality assessment indicators of the construction flow, namely, reducing downtime on the gripper, which, in turn, leads to a reduction in the total duration of all work on the gripper and an increase in the utilization rate of the work front. Figure 3 shows a matrix algorithm for calculating non-rhythmic flow parameters using the properties of potential jobs. The calculation shows that an increase in the rhythms of accelerated processes 2, 4, 5 does not lead to an increase in the total duration of the construction flow (Figure 3). The total duration of organizational downtime at all divisions decreased from 117 to 48 units of time. The ratio of the density of the graph is equal to 0.72. Coefficient of combining processes is 3.3.
Figure 3. Matrix calculation of non-rhythmic flow parameters at a slow rate using potential works.

An increase in the duration of paradoxical work (Figure 4) leads to a decrease in the total duration of construction and is 36 units of time. The ratio of the density of the graph equal to 0.5. Ratio of combination of processes is equal to 2.5.
Figure 4. Matrix calculation of the parameters of non-rhythmic flow at a slow rate using paradoxical works.

For clarity, we built flow diagrams and determine the nature of the rhythm (Figure 5). By comparing the data, we determined the increase in the rhythms of accelerated processes, using potential work, leads to a reduction in the breaks between processes 2 and 3 on divisions V-VII and processes 3 and 4 on divisions I-V (Figure 5a, 5b). Using the properties of paradoxical work (Figure 5c) leads to the balancing of flows, but to a lesser degree.
b) \begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{non_rhythmic_flow.png}
\caption{Non-rhythmic flow parameters diagram:}
\end{figure}

Figure 5. Non-rhythmic flow parameters diagram:
a) initial data, b) slower pace of potential works, c) slower pace of paradoxical works.

\begin{table}[h]
\centering
\caption{Organizational downtime at work.}
\begin{tabular}{|c|c|c|c|}
\hline
Divisions & Figure 1,2 & Figure 3 & Figure 4 \\
\hline
I & 20 & 0 & 18 \\
II & 20 & 3 & 17 \\
III & 18 & 4 & 15 \\
IV & 15 & 12 & 9 \\
V & 16 & 10 & 14 \\
VI & 15 & 9 & 9 \\
VII & 13 & 10 & 11 \\
\hline
Total & 117 & 48 & 88 \\
\hline
\end{tabular}
\end{table}

4. Summary
Comparing the results of calculating the parameters of the non-rhythmic unbalanced flow and the balanced flow at a slow rate using potential work, we see that the rates of the processes are very close to the rate of the leading process 3 equal to 29 units of time and are 27-28 units of time. The graph density coefficient of 0.72 is higher than 0.4. The total duration of organizational downtime is 48 units of time, which is less than 117 in Figure 1 and Table 1. These indicators indicate an increase in the
degree of utilization of the work front. When using the properties of paradoxical works, the quality indicators of the flow organization also improve, but to a lesser extent than potential works. But in this calculation, we see a decrease in the duration of the total time flow by 2 units of time.

5. References
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