Linking and Optimization of Construction Works

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Abstract. Due to the complexity of the organization and management of construction of complexes of buildings and structures, it is necessary to come up with the simplest method for assessing the duration and volume of material and technical resources. This article developed a method for calculating the minimum duration in the Python 2.7 programming language. Standard methods of calculation use a priority coefficient, that is, the order of constructional production lines is built to minimize construction time for all the processes. The priority coefficient gives a duration close to the minimum, but does not reach it. Using the example of a small object with four constructional production lines and four processes, the difference between the previous method and the program is shown. The program was verified on a small dimension of a non-rhythmic in-line matrix with a heterogeneous rhythm. For a matrix with the number of rows more than 3, enumerating all sorts of variants is considered impractical. In the future, it is planned to use a matrix for one object to build a network model (graph) in which the basic input data will be described, objects and processes will be coordinated. This task significantly reduces the workload for calculating the duration, gives a reliable result for the preliminary calculation of the duration.

1. Introduction
The current increasing complexity of building systems and processes leads to the difficulties in making optimal decisions on organization and management. Proper distribution of time and material and technical resources guarantees a financially stable situation in construction. Analytical models of organization and construction management must be developed and optimized for the analysis of possible decisions [1,2,3,4].

2. Methods
Designing the development of residential complexes is a sequence of complex and simple activities. Complex processes are a combination of simple processes that are associated with strict technological dependence. Three main methods are used for organization of the production of simple and complex construction activities and processes: sequential, parallel and in-line. Each of these three discussed below methods is characterized by its advantages and disadvantages which determine the rational area of use [5].

The sequential method of work is characterized by the following features: at each moment of time no more than one activity is performed. At the same time, the duration of the construction processes is determined by the sum of the durations of the individual activity constituting it, so downtime often occurs in the sequential method.
The parallel method is such an organization of work that can be characterized by the following features: several works can be performed at any given time. Using the parallel method such difficulty as a large consumption of resources arises.

The in-line method of organizing work is formed by spatial division of the general front of the work into elementary fronts and the parallel execution of diverse types of elementary constructional production line on them. In the in-line method homogeneous processes are performed sequentially one after another and heterogeneous processes are performed in parallel (Fig.1) [5].

![Sequence diagram of work (in-line method)](image)

**Figure 1.** Sequence diagram of work (in-line method).

The basic principles of production line design [5]:
1) the identification of objects that are close to each other in space-planning and structural solutions as well as the technology of their construction
2) a division of the process on elementary activities that are equal or multiple in complexity
3) assignment of certain types of activity to certain teams of workers
4) calculation of the main production line parameters taking into account the combination of most of the work.

Constructional production lines can be classified according to the nature of rhythm: rhythmic and non-rhythmic (rhythm is a duration of one team work on one division).

Non-rhythmic constructional production line, in turn, can be with a homogeneous and heterogeneous change of rhythm.

This article details the non-rhythmic constructional production line with a heterogeneous rhythm change, as a general case of a building flow. Optimization of non-rhythmic constructional production lines is carried out graphically and analytically. The analytical method allows to cope with large volumes of information, allowing to process faster with tasks.

A network model is used as a model reflecting the technological and organizational interconnections of the construction work process in network planning and management systems. The network model is depicted in the form of a graph consisting of arrows and circles. The network diagram is a network model with calculated time parameters (Fig.2).

![Network diagram](image)

**Figure 2.** Network diagram.
There are several definitions:

Work is a production process that requires time and material resources and leads to the achievement of certain results (work on the network diagram is represented by one solid arrow).

An event is the fact of the end of one or several works (activities) that is necessary and sufficient to start the next work (events are depicted by circles or other geometric figures, inside of which a number is indicated or an event code).

The basic rules for building a network are:
1) the direction of the arrows in the network should be taken from left to right.
2) the form of the schedule should be simple, without unnecessary intersections, most of the work should be depicted in horizontal lines.
3) when parallel activities are performed, that is, if one event serves as the beginning of two or more activities that end with another event, a dependency and an additional event are introduced, otherwise different activities will have the same code.
4) if some work begins after the partial implementation of the previous one then this work should be divided into parts. Moreover, each part of the work in the schedule is considered an independent work and has its previous and subsequent events.

It turns out that, having built a network model for objects separately, it is necessary to stitch together all the network models, and receive a certain graph that analyzes the main parameters of the building complex. How this can be implemented in practice: there are two methods for optimizing production lines during the construction of complexes: according to the minimum duration (more resources are spent) and the minimum amount of resources (in this case, duration is a secondary factor). In the general case, it is necessary to coordinate both criteria in order to achieve the best result. Based on the minimum duration of one object a network model can be built, the result of which is the minimum duration for all works of the entire complex of buildings. To this end, the objects of the complex are connected into enlarged blocks (several objects are included in one block) according to the construction stage. Next, the network model is constructed by the in-line method: the team that finishes work on the object \( n \) passes to the object \( (n+1) \), this ensures the minimum duration. \([5,6,7]\) For the optimal distribution of material and technical resources, it is necessary to analyze a considerable amount of information: the calculation of labor costs, the choice of a technological solution, the choice of the constructional production line development scheme, the determination of the main stages and priorities are based on the space-planning and structural solutions of the complex. Next, the parameters for the production of work and the development of a construction model are selected. \([8,9,10,11]\) (Fig.3).

![Figure 3. The optimal distribution of material and technical resources.](image)

### 3. Results

This article considers the approach to calculating the matrix for non-rhythmic constructional production line with a heterogeneous rhythm change and the optimization of the main calculation parameter: the total duration of the whole work. The optimal order of commencement of work is calculated using the priority coefficient, however, this algorithm does not allow to determine the minimum possible duration of work depending on the order of execution on the divisions, therefore, a program was written that...
considers the duration of work according to various variants (and there are N! of variants, where N! - the number of matrix row permutations, i.e. divisions).

The program is written in Python 2.7 in the Spider software environment (it is a free interactive IDE for scientific calculations in the Python language, providing ease of use of functionality and lightness of the software part). The code was debugged on simple tasks with a small number of rows and columns for possible verification with a regular account without computer (using standard methods). The program is divided into semantic blocks.

In the first enlarged block, a function is written that fills in two additional matrices: the matrix of the beginning of work and the matrix of the end of work. It also takes into account the moment of critical rapprochement: when the previous process at this division has not yet ended, and the next has already begun. Next, the search for the minimum duration as the value of the corner element of the matrix of the end of the process is realized.

Then, in the second enlarged block, an algorithm is implemented to perform such operations for each matrix: all kinds of permutations of the divisions (that is, rows) are sorted out, a minimum time is searched for them. There is a comparison with the previous result with the choice of the smallest.

Thus, the program produces a vector and a number: the vector corresponds to the order of captures to achieve the best result, and the number corresponds to the minimum duration of all work on all captures.

Here is an example of comparing the effectiveness of the enumeration method over an analytical method that uses a priority coefficient. The matrix was taken and calculated by the analytical method and the initial data was entered into the program. The leading process is the first process, because it takes much time. Then the priority coefficient is calculated by the division of the duration of the processes before the leading process and after the leading process.

According to the analytical method, the duration is 28 days, and the program provides a sequence of divisions and a duration of 24 days. Checked by analytical method the result given by the program it was obtained that, indeed, the variant of 23 days was not taken into account by analytical method (Fig. 4).

|   | 1   | 2   | 3   | 4   | ∑t₁ | ∑t₂ | K₀  |
|---|-----|-----|-----|-----|-----|-----|-----|
| I | 3   | 4   | 5   | 3   | 3   | 12  | 0.25|
| II| 3   | 10  | 15  | 20  | 5   | 14  | 0.36|
| IV| 4   | 2   | 3   | 1   | 4   | 6   | 0.67|
| III| 6   | 2   | 1   | 4   | 6   | 7   | 0.86|

**Figure 4.** Analytical method of calculation.
Consequently, the analytical method gives time close to the minimum, but not the minimum. For a matrix with four divisions and four processes, $4! = 24$ searching variants is possible, and for nine divisions the number of permutations is already becoming huge: $9! = 362880$ variants.

To summarize, in this article, a streamlined algorithm was obtained that allows us to consider the minimum duration of a non-rhythmic constructional production line with a heterogeneous rhythm change, which reduces the calculation time by many times and eliminates arithmetic errors. In the future,

![Program of the calculation of the matrix of for non-rhythmic constructional production line with a heterogeneous rhythm change. Sequence of divisions: 3, 1, 2, 4. Duration: 24.](image)

**Figure 5.** Program of the calculation of the matrix of for non-rhythmic constructional production line with a heterogeneous rhythm change. Sequence of divisions: 3, 1, 2, 4. Duration: 24.

4. Conclusion
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To summarize, in this article, a streamlined algorithm was obtained that allows us to consider the minimum duration of a non-rhythmic constructional production line with a heterogeneous rhythm change, which reduces the calculation time by many times and eliminates arithmetic errors. In the future,
it is planned to build a graph: a network model that takes into account the relationship between the objects of the complex.

5. References

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