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Modeling of production process by the method of works maximum approximation

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The work is devoted to mathematical modeling of production processes. Existing methods of production processes modeling are analyzed. Calculated workflow schemes are proposed when planning the manufacturing process by maximizing work approximation. The dependences of the time parameters calculation and the conditions of the proposed calculation schemes application are given. The method of the time parameters calculation of production processes execution by the method of works maximum approximation is offered. The procedure of calculation and construction of production processes calendar schedule is given. The advantages of the proposed methodology in comparison with existing modeling methods are analyzed

Keywords: mathematical modeling of production, method of works maximum approximation, calculation schemes, calculation of time parameters of production processes execution, calendar schedule

Моделювання виробничого процесу методом максимального зближення робіт

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Метою статті є розроблення розрахункових схем взаємозв'язків між роботами, які дозволять виконувати планування виробничого процесу методом максимального зближення робіт, та отримання залежностей для розрахунку параметрів часу виконання робіт; розроблення методики розрахунку параметрів часу виконання робіт методом їх максимального зближення, а також побудова календарного плану із зазначенням критичного шляху. Виявлено, що різноманіття взаємозв'язків між роботами зводиться до трьох видів: послідовне, паралельне й послідовно-паралельне виконання робіт. Перетворення цих відомих взаємозв'язків на розрахункові схеми дозволяє створити принципово нову математичну модель планування виконання робіт. Запропоновані схеми дають змогу відмовитися від жорстких просторових захваток при організації послідовно-паралельного виконання робіт. Метод максимального зближення робіт являє собою нову аналітичну модель планування виробництва з наочним відображенням організаційних і технологічних взаємозв'язків робіт. Розроблений метод надає можливість простіше переходити від аналітичного моделювання до графічних календарних графіків. Метод максимального зближення робіт легко піддається автоматизації обчислень за допомогою електронно-обчислювальної техніки, а також автоматизації графічної побудови. Це дозволяє більш ефективно виконувати оптимізацію планування виробництва (як за тривалістю, приводячи її до директивної, так і за ресурсами), своєчасно враховувати зміни виробничих обставин. Такий метод дає змогу брати до уваги організаційні й технологічні обмеження, при цьому виключаючи простої бригад, що виконують роботи. Запропоновані розрахункові схеми та залежності для визначення параметрів часу дозволяють охопити все різноманіття взаємозв'язків робіт (послідовне, паралельне, послідовно-паралельне виконання робіт)

Ключові слова: математичне моделювання виробництва, метод максимального зближення робіт, розрахункові схеми, розрахунок параметрів часу виконання виробничих процесів, календарний графік

Introduction

Modern industrial production, which combines a large number of contractors with complex and diverse relationships between them when executing work on a joint project, is impossible without flexible and timely planning. Such planning is possible only on the basis of application of the works organization calculated methods. In addition, the management of modern production is characterized by a multitude of solutions, the choice of the best due to the variety and complexity of technologies is not an easy task. The solution to this problem is possible through the use of economic and mathematical methods for modeling the production process and computer. Thus, developing a management model that would most adequately reflect the main features of the production process and be amenable to automated calculation, would be easy to use and enable the visualization of results, is an urgent task.

Review of the research sources and publications

Today there are many methods of planning the production process, each of which is characterized by its positive and negative qualities, quite widely covered in the literature [1 – 13]. Models that have become widely used in the planning of production processes in construction include Gantt charts, various network models, matrix models. In most cases, these mathematical models are ultimately interpreted into graphical calendar models that are close in structure to linear graphs. Along with the positive qualities that make it possible to use these methods, they have some disadvantages. Thus, the disadvantages of Gantt charts [4, 6] include the lack of clearly illustrated relationships between work, the inflexibility and rigidity of the chart structure, the complexity of its adjusting, the complexity of variant processing, the inability to use computing to automate calculations. The disadvantages of network modeling include the lack of the production processes display clarity, the complexity of the structure, especially in the serial-parallel execution of works, high complexity of calculations. The main disadvantage of matrix modeling is the need to separate objects into rigid spatial captures. Therefore, the existence of serious shortcomings in existing planning methods make research in this area relevant.

Definition of unsolved aspects of the problem

Despite the large amount of work devoted to this problem, a method of modeling the production process, which adequately reproduced the main features of the production process and made it possible to automate the calculations, was easy to use and made it possible to clearly visualize the results of modeling, is not proposed.

Problem statement

The purpose of the article is to develop computational diagrams of relationships between works that will allow planning of the production process by the method of works maximum approximation, and to obtain dependencies for the calculation of the work execution time parameters. Development of a method for calculating the work execution time parameters by the method of their maximum approximation, as well as the construction of a calendar plan indicating the critical path.

Main material

Based on the analysis of the relationships of works that are characterized the construction industry [4, 6], their diversity can be reduced to three ways of linking works in time: this is a serial, parallel and serial-parallel execution of work. Technological and organizational peculiarities of process execution make demands for time lag of one work from another on the minimum acceptable technological or organizational break. Such interconnections of work, taking into account organizational and technological breaks, make it possible to bring their execution as close as possible to serial-parallel execution without splitting the object into captures. As a result, the paper offers computational diagrams that allow you to simulate these three ways of linking work in time and to calculate the work execution time parameters using the maximum approximation method.

The first design scheme 1. Serial execution of works (Fig. 1). The serial execution of works is planned in the case when the full completion of the previous work is required to start the next work, and a time gap is possible between them.

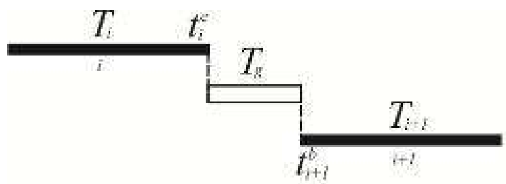

Figure 1 – Design scheme of works serial execution

The strength of concrete is obtained after the work of concreting the foundation for the equipment. Then the equipment installation work is carried out. The completion of a previous job is associated with the beginning of the next job in the serial work execution of. The calculation of time parameters when using such a scheme is performed according to the following dependencies:

$$t_{i+1}^{eb} = t_i^{ee} + T_g ; \quad (1)$$

$$t_{i+1}^{ee} = t_{i+1}^{eb} + T_{i+1} ; \quad (2)$$

$$t_i^{le} = t_{i+1}^{lb} - T_g ; \quad (3)$$

$$t_i^{lb} = t_i^{le} - T_i , \quad (4)$$

where t_i^{lb} – late beginning of work i;

t_i^{ee} – early ending of work i;

t_i^{le} – late ending of work i;

t_{i+1}^{eb} – early beginning of work i+1;

t_{i+1}^{lb} – late beginning of work i+1;

t^{ee}_{i+1} – early ending of work i+1;

T_i – duration of work i;

T_{i+1} – duration of work i+1;

T_g – the minimum allowable gap time between works.

The second design scheme 2a, 2b. Parallel works execution (Fig. 2-3). Work is carried out independently of each other in parallel execution. However, it may be necessary to link the beginnings or endings of work.

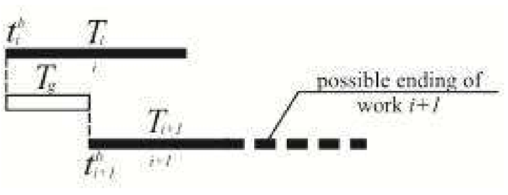

Figure 2 – Design scheme 2a of parallel works execution

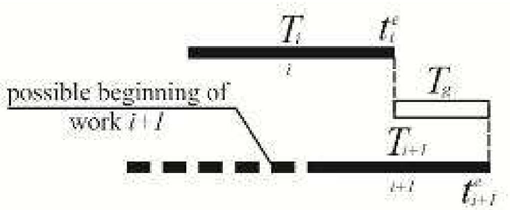

Figure 3 – Design scheme 2b of parallel works execution

For example, electricians should start work on laying electricity before plasterers; the break between works should provide the front of the plastering work throughout the site. In the future, electricians and plasterers do their jobs independently, ending one job affects the ending of another. Painting and sanitary works can be carried out in parallel and independently. In terms of the interrelationship of these works, their beginnings are not interconnected, but the finishing of the painting works should be later than the sanitary works with such a gap in time between their endings, which allows the painters to complete the final painting of the sanitary fixtures and communications. The time parameters when using Scheme 2a, that is, when work is related to beginnings, are defined as follows:

$$t^{eb}_{i+1} = t^{eb}_i + T_g ; \quad (5)$$

$$t^{lb}_i = t^{lb}_{i+1} - T_g , \quad (6)$$

where t^{eb}_i – early beginning of work i.

In the case of combinations of works with finishes, the time parameters are defined as follows:

$$t^{\mathrm{ee}}_{\mathrm{i+1}} = t^{ee}_i + T_{\mathrm{p}} ; \quad (7)$$

$$t^{\mathrm{le}}_{\mathrm{i}} = t^{le}_{i+1} - T_{\mathrm{g}} , \quad (8)$$

where t^{le}_{i+1} – late ending of work i+1.

The third design scheme 3a, 3b. Serial-parallel works execution (Figs. 4, 5). Serial-parallel works execution implies a constant lag of the next job from the previous one for a certain time, which cannot be less than the minimum allowable gap between the works. The minimum acceptable interval is taken depending on the requirements of safety or work technology. For example, between the soil excavator and the completion of a soil manually, such a gap in time is required, which guarantees a safe distance between the excavator and the workers. Between the plastering and painting works take the technologically necessary gap in time, which ensures the plaster will dry up before the painting works begin. In order to ensure a minimum allowable time gap between the works during their serial-parallel execution, it is necessary to observe this gap throughout the work execution (both at the beginning and at the end).

Depending on the ratio of the previous and subsequent works duration, it is possible to establish the need to introduce a gap between the beginnings (scheme 3a) or the endings of works (scheme 3b).

If the duration of the next work is greater than or equal to the previous one, then the delay of the next work beginning from the previous one to the minimum permissible gap guarantees at least a delay during the whole time of their joint execution (scheme 3a, Fig. 4).

If the duration of the next job is less than or equal to the duration of the previous one, then to guarantee the delay of the next job from the previous one during the whole time of their execution by the value of the minimum gap, a sufficient delay of their endings by the minimum acceptable gap (scheme 3b, Fig. 5).

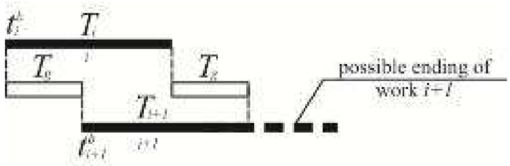

Figure 4 – Design scheme 3a of serial-parallel works execution

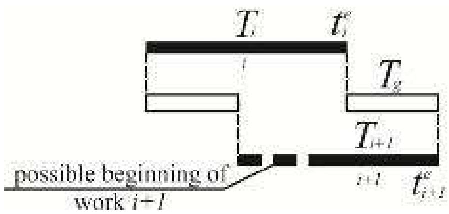

Figure 5 – Design scheme 3b of serial-parallel works execution

When using serial-parallel works execution schemes, the calculation of time parameters is performed by dependencies (5, 6, for scheme 3a) and (7, 8, scheme 3b).

In order to start calculating time parameters, it is necessary to have an organizational and technological scheme of work. It is proposed to draw up such a scheme in the form of a table (Table 1) using the following design schemes. The works are separated by the minimum possible permissible gaps in the development of organizational and technological scheme. The works are entered in the table in the order of their execution. The work code is its serial number. At the same time, the work duration graph is filled. Then each work is considered in relation to previous works, as a result of the analysis the codes of the previous works and the numbers of the design schemes are filled. If the work under consideration is related to several previous works, then the design scheme of relationship and the gap between each of them are indicated. The value of the minimum permissible gap between the works is taken from the conditions of the lag during the technological or organizational break or by the requirements of the backlog in space. The justification for the need to enter the work gap is indicated in the last column of the table.

Calculation of time parameters is proposed to be performed in tabular form (Table 2) according to the given design dependencies. The spreadsheet consists of two parts: the left one, which describes the organizational and technological interrelationships of the works, and the right one, in which the parameters of the works execution time are calculated. First, the left part of the table is filled, the data for which is received in accordance with the organizational and technological scheme (table 1).

The calculation starts with the determination of the early parameters. The calculation is performed for each job, moving from work to work from top to bottom. The calculations use dependencies that correspond to the design diagrams of the relationship between the works. If the work in question is related to several jobs, then the early parameters maximum values calculated for that work are taken into account for the determination of this work execution time parameters.

Table 1 – Organizational and technological scheme of works execution

Code of work	The name of the work	Code of previous works	Accepted link between works					Minimum gap in days, T_d	Minimum gap in days, T_i	Justification of the gaps between the works
			Serial	Parallel		Serial-parallel				
			E-B	B-B	E-E	B-B	E-E			
			Number of the design scheme							
			1	2a	2b	3a	3b			
1	Excavation processes	-	-	-	-	-	-	-	9	-
2	Concreting of foundations	1	-	-	-	+	-	1	21	Safety norms
3	Return backfill	1	+	-	-	-	-	1	12	Mechanism transition
		2	-	-	+	-	-	3		Formwork removal
4	Installation of columns	2	-	-	-	-	+	16	15	Concrete strength set
		3	-	+	-	-	-	2		Safety norms

Table 2 – Calculation of works execution time parameters by the method of works maximum approximation

Organisational relationships						Calculation of time parameters				
Processes code	Processes name	Previous processes code	Calculation scheme number	Minimal gap, T_g	Duration of the process, T_i	Early parameters		Late parameters		Time reserves, R
						Start, t_i^{eb}	End, t_i^{ee}	Start, t_i^{lb}	End, t_i^{le}	
1	Excavation processes	-	-	-	9	0	0+9=9 9	20-9=11 1-1=0 0	21-1=20 0+9=9 9	0
2	Concreting of foundations	1	3a	1	21	0+1=1 1	1+21=22 22	22-21=1 30-21=9 1	38-16=22 33-3=30 22	0
3	Return backfill	1	1	1	12	9+1=10 25-12=13 13	10+12=22 22+3=25 25	23-2=21 21	21+12=33 33	8
		2	2b	3						
4	Installation of columns	2	3b	16	15	38-15=23 13+2=15 23	22+16=38 15+15=30 38	38-15=23 23	38	0
		3	2a	2						

After calculating the early parameters, the late parameters are determined. The calculation is carried out for each work, moving from the bottom up. In the final work, the early and late parameters are the same. The calculation is based on the dependencies that correspond to the calculation schemes. As there are several references to the work in the following works, minimal values are taken from the calculated parameters for each reference of the works execution time.

After calculating the early and late parameters of the works execution time, time reserves are determined. They are calculated as the difference between late and early parameters.

According to the results of the execution time parameters calculating, the mathematical model of production should be represented in graphical form. Graphic representation of the mathematical model allows to present it in a clearer form, to attach the works execution to the calendar basis, which in turn makes it possible to plan the provision of resources production and to control the timely execution of planned works. The most visual and convenient to use are linear calendar graphics. The basis for drawing the calendar schedule is the form1, which is given in [13].

The calculation of the production organization planning by the method of works maximum approximation (table 2) makes it easy to translate it from analytical to graphical form.

Construction of a linear graph is performed according to early time parameters. Scale bar graphs indicate work planed on early parameters, time gaps between works, possible late endings of works, time reserves, links between work, and the critical path of the schedule. An example of constructing a linear graph is shown in Fig. 6.

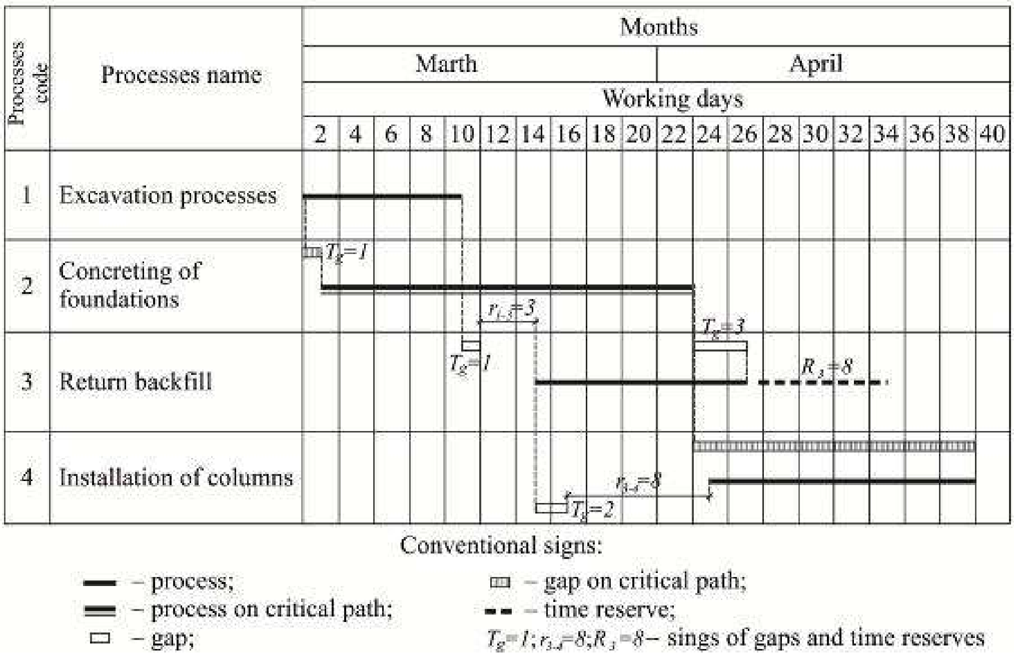

Figure 6 – Linear calendar chart based on the calculation results

Conclusions

It is known that all the diversity of relationships between jobs comes in three types: serial, parallel, and serial-parallel works execution. The transformation of these known relationships into computational schemes allows us to create a fundamentally new mathematical model of work scheduling. The proposed schemes allow to avoid rigid spatial engagements when organizing serial-parallel works execution. Replacing the work lags in space by the lags in time makes it possible to naturally take into account the technological and organizational gaps between works in the time parameters calculations, which in turn allows us to maximize closeness of the works execution between works.

The method of works maximum approximation is a new analytical model of production planning with a visual representation of the organizational and technological interconnections of the work. It allows you to develop the positive qualities of previous models and to some extent eliminate their negative properties. The developed method makes it easy to move from analytical modeling to graphical calendar graphs. The method of works maximum approximation is easily subjected to automation of calculations by means of electronic computing, as well as automation of graphical construction. This makes it possible to optimize production planning more efficiently (both in terms of duration, leading to policy and resources), and to take into account changes in production circumstances in a timely manner. The developed method allows to take into account organizational and technological constraints, while excluding simple brigades performing the works. The proposed calculation schemes and time-dependencies allow us to capture the full range of work relationships (serial, parallel, serial-parallel works execution).

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