

USING OBJECT CONSTRUCTION MODEL FOR IMPLEMENTATION BUILDING WORKS MANAGEMENT

E.V. Gusev, gusevev@susu.ru

South Ural State University, Chelyabinsk, Russian Federation

The main idea of the article is the importance of construction project scheduling in the construction management. Construction Execution Plan and Construction Project Schedule (which includes in the first one) are the main source of data for resolving logistical and engineering problems during the construction process. The author is analysed an order of Construction Production Plan in the article. The author highlights that existing methods, which used for preparation schedule of construction project, have some limitations. It is difficult: a) to measure minimum time of overall duration of a project; b) to maximize combination between interrelated works; c) to generate object construction model.

Project technological dependencies model (PTDM) is illustrated in the article. PTDM gives a view on a construction technology an object. There are the main parameters of PTDM:

- 1) quantitative assessments for the technological links between the works;
- 2) temporary range of the work;
- 3) criticality points for each works;
- 4) an overall duration of a project;
- 5) the maximal amount of manpower that can be used in construction an object.

Using PTDM gives the opportunity: a) to determine the minimum construction time an object; b) to maximize combination between interrelated works.

Keywords: project technological dependencies model (PTDM), construction project schedule, construction production plan, construction technology, organizational technological models.

Introduction

There is difference between management in the construction and management on the industrial enterprise [1, 2]. The basis of the management system in the industry is the process management model, whereas in the construction the main point is the control object model. There are different types of this construction organizational technological model (OTM), for instance, a Gantt chart, cyclic graph, or a network schedule.

A Construction Project Schedule (CPS) is among others a part of a Construction Production Plan (CPP), which is certainly one of the most important sections within a Construction Execution Plan (CEP). Moreover, quality CEP is the cornerstone for project's successful delivery, where it even serves as fundamental communication tool for company-wide operations. The CPP can be developed either in-house or externally, however, use of inner capacity suppose better knowledge of abilities and available capacity within organization. After the initial CPS is developed it is over time extended by further and necessary detail when its scheme and information content differs according its intended use. A general contract schedule aims to indicate sequencing for all work packages according previously agreed upon Work Breakdown Structure (WBS). Furthermore, it serves as simple reference tool for overall distribution of major capital constraints in time. On the other hand, a detailed production schedule already contains enhanced detail of information in order to deal with more practical part of production planning. Its objective is enable effective alignment of all tasks in order to secure plan's feasibility and efficiency in terms of resources, technology, and other concerned aspects (e.g. special limitations, site accessibility, etc.).

Determination of a work duration is an important part of the schedule development. This makes it possible to calculate the length of the distribution (break down) of work amounts in time and helps to solve many logistical problems. Therefore, to solve this problem a range of methods has been developed, including the simple methods of labor hours division (labor intensity) by the number of workers taking into account various additional factor, as well as the laborious methods. These laborious methods

include the method of expert evaluations, statistical method, probabilistic method and other methods. However, a variety of different factors that can affect the construction process cannot be taken into account, and constant adjustments are required. And that could influence the logistics (more detailed in the article [3]). The objective of determining the alignment of technologically interrelated works is rather difficult as well.

1. Method for solution the problem

The detailed production schedule overview is standardized in graphical representation as well as information form, when the required information about all concerned tasks is structured as is shown in Table 1.

Table 1

Sample form of Project for implementation of works on an object

Name	Quantity		Amount Labor Requirements	Plant Re-quirements		Duration, days	Number of shifts	Number of workers in the shift	Composition of the brigade	Schedule
	Units	Amount		Type	Amount					
1	2	3	4	5	6	7	8	9	10	11

The above table should be updated in accordance with the specific object, types of construction, the requirements for the unification of design documentation for a number of purposes, including the usage of automated control system in construction, as well as the including some additional columns (for example, the cost of works). The Construction Project Schedule can be divided into two parts.

The first part (1 to 10) – descriptive part. The second part is the graphical one (column 11). It is necessary to pay attention to the order of development a schedule, which is recommended in professional literature [4–9].

1. Works listing (procedural nomenclature).
2. Determining of the amounts of each type of works.
3. Choosing of the production method for major works and plants.
4. Calculating of the hours of labor and the hours of plants.
5. Determining of the required teams and units.
6. Constructing of technological sequence of works (technological works order).
7. Determining of shift-working arrangements.
8. Determining of the duration of every single work and possible works alignment. Adjusting the units and shifts.

9. Comparison of the estimated construction duration of an object with the standard (directive) construction duration and performing the appropriate adjustments.

The graphical part can be represented as a Gantt chart, cyclic graph, or an network schedule. These graphs are classified as organizational technological models (OTM), which reflect the technological and organizational decisions.

Organizational decisions include items 1, 3, 5, 7, 8 and 9 of to the schedule development order. The item 6 is the only one, which considers some construction technology and the only to the extent that reflects the technological interrelation between the works and their order (sequence).

Let's consider the item 9 in more detail. In order to obtain the estimated construction duration of an object, it is necessary to solve 2 problems:

1. To determine the duration of each work.
2. To determine the alignment of technologically interrelated works.

Let's consider the Fig. 1 as an example.

Fig. 1a shows a graph with the duration of the T_1 . If T_1 does not meet the regulatory, legislative or contractual duration of the construction project, then, in accordance with paragraph 9, it is necessary to make adjustment by changing the number of units and shifts, i.e. to reduce the durations of each work.

In arrow diagrams it is usually performed by reducing the works duration, that are on the critical path. In linier graphs, depending on the deviation, the adjustment are performed for main or secondary processes.

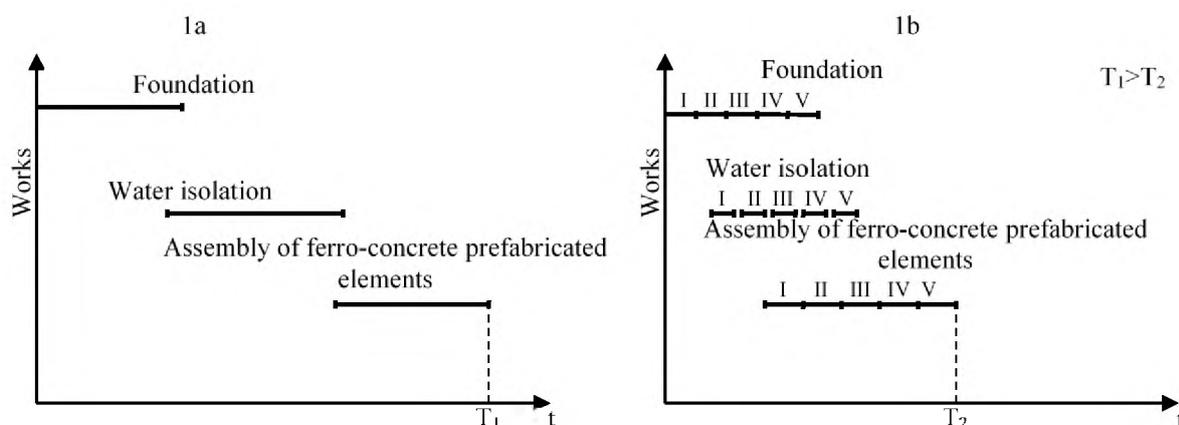


Fig. 1. Examples of combinations of interrelated works

It is more difficult to determine the necessary alignment (or combinations) of technologically interrelated works and to determine the minimum construction time an object. In the process of alignment we should take into account technological restrictions and limitations, different requirements and factors (for example, safety requirements), which determine the maximum possible alignment of technologically interrelated works. In other words, these restrictions, terms and conditions determine the minimum time lag between the start and the end of the preceding work and the start and the end of the following work. Usually, the work alignment is carried out on the basis of the experience, or some statistics, because there are no quantitative estimates of these borders. The most effective work alignment in order to reduce the duration of the construction can be carried out using the methods of the straight-line (sequenced-flow) construction organization, when the works are divided into work zones (catches) or areas (see. Fig. 1b).

If we compare the work duration in the Figures (see. Fig. 1a and 1b), it is clear that the work duration in Fig. 1b is shorter than the work duration in Fig. 1a ($T_2 < T_1$). Dividing into work areas can significantly increase the alignment of works and shorten the construction duration.

However, the practical use of this method of construction organization have revealed serious weaknesses. Firstly, some works can go from continuous (without breaks) production to intermittently production (with breaks), for example the work “Water isolation”. Secondly, work zones very often have different directions. E.g., the brickworks have a horizontal direction, and finishing works – vertical, which makes impossible the alignment of these works. And thirdly it is quite difficult to evaluate a work zone quantitatively.

Based on the mentioned above we can draw the following conclusions:

1. For the determination of minimal construction duration of an object (connected with some adjustments of works duration) the empirical methods are used. These methods cannot ensure the uniqueness (monosomy) of decisions.

2. There are no strictly defined limits of the alignment for the determining of the maximal alignment of technologically interrelated works, as well as there is no the earliest beginning and the end the work in relation to the beginning and the end of the preceding work.

3. To determine the limits of minimization of construction duration and the alignment of technologically interrelated works it is necessary to use a tool, which allows us to have a specific quantitative estimates.

2. Mathematical model of the solution

In construction there are two kinds of technology – technology for execution of certain works (construction operations) and the construction technology (technology for the construction of a facility/object).

Technology for execution of certain works, or more definitely, the technology of construction operations is a functional system, including the resources (time, labor and material), as well as restrictions and rules of interaction to achieve the desired result – the implementation of certain types of work, processes and elements of construction projects (objects). The main documents, which regulates technological rules during construction processes, types of work, the elements of buildings and structures are the Flowchart for the Production of Separate Works [10, 11].

In contrast to technology for execution of certain works (construction operations) the construction technology (technology for the construction of a facility/object) is not so dynamical. Where is not a complete definition of the concept “the construction technology (technology for the construction of a facility/object)” in professional literature contrary to the concept “technology for execution of certain works”. This can be explained by the fact that any changes that occur during the construction project refers to the construction technology, e.g. changes in the technology for execution of a work, changes in work zones (areas) priority, teams movements, intensity of production, as well as the replacement of vehicles, mechanisms, plants etc. All these changes and replacements are not classified. And the studies on the impact of different types of these changes to different productions of the building process are not carried out deeply. At the same time, it is possible to say antecedently that some changes in plans affect only the performance of work (its timing), some of them affect organizational decisions, some affect the technological sequence of works, i.e. the technological interrelationship, and the others affect the planned amounts of work, etc.

Construction technology considers an object (a facility, project) broadly, with its “internal” works interrelationship, which is typical for this type of object. As the rule, the development of this “internal” interrelationship between the works leads us to the setting up of the technological sequence (order) of works of this project. The construction project technology is usually finished on this and the technological sequence is displayed as arrow diagrams, network graphs, technological graphs etc. [12–15].

Such a basic order of technologically related works leads to a significant increase in the construction duration. Therefore, technological sequence reflects only the qualitative aspect of the construction technology with regard to the works coherence.

At the same time the works are connected between each other not according to a sequence i.e. qualitatively, but also quantitatively. Under current methods of organizational and technological planning of construction and assembly operations, quantitative ratio (more common as an alignment) of interrelated works are determined on the basis of the selected intensity, object division on work zones and other spatial areas, shifts etc., which are rather subjective.

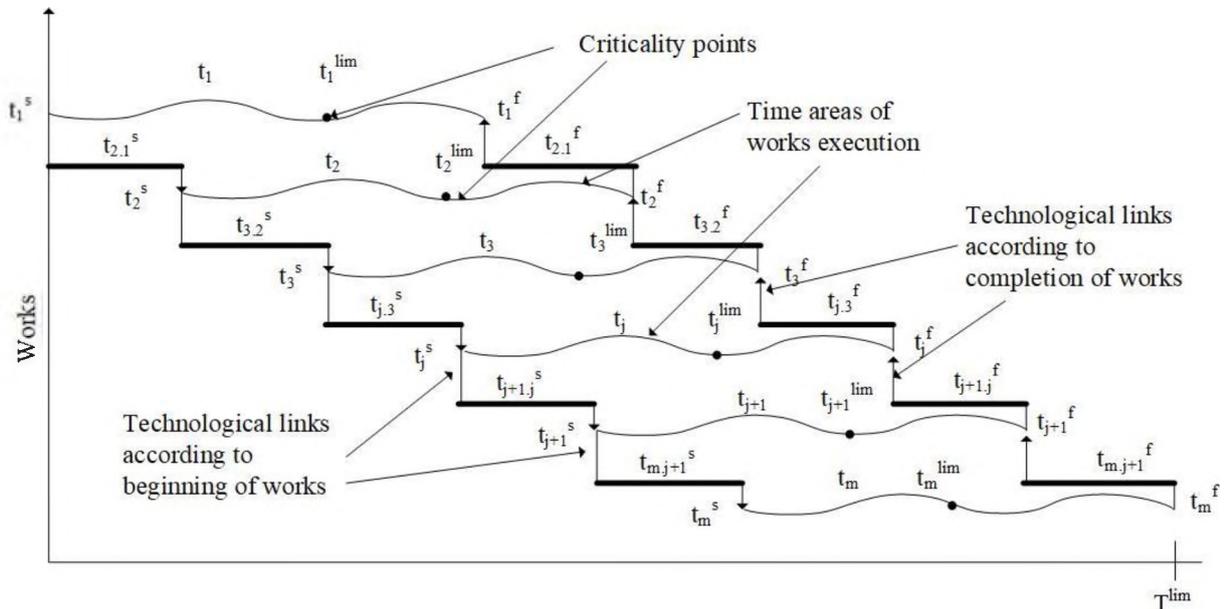
In practice, the quantitative ratios for the beginning and the end of the technologically related works are defined in accordance with production work regulations, with safety rules and other technical requirements. Moreover, the evaluation of these relations is based not on subjective assessments but on the regulations.

The term “construction technology” can be defined as follows: “it is a qualitative and quantitative assessment for the technological links between the works determining the work planning possibility and industrial organization depending on the results of the previous ones”. In this case, the point of the construction technology modelling is to establish technological links between various works and to determine a minimum volume of the previous works that give the possibility to plan a technologically interconnected volume of the following stage.

Such model describing the technological links between works stages and their quantitative assessment in the beginning and after their completion of work is designed and presented in Fig. 2. It is important that there are no organizational decisions when calculating quantitative assessments. This increases the model stability when planning works and construction organization. As technological dependences for the initial and final works determine the technological stages of the project works, we will term it as a project technological dependencies model (PTDM). This model is described in more details in Gusev’s monograph [16].

PTDM calculation is reduced to time assessments for technological dependencies for the initial (not earlier than the initial) and the final (not earlier than the final) works; time area for each stage (as opposed to the duration of the work according to OTM); criticality points of stages. “Not earlier than the initial one” means that follow-up work $j+1$ cannot start technologically if functional minimum volume

of work $V_{\min j+1}^s$ is not done on the preceding j ; “not earlier than the final one” means that follow-up work $j+1$ technologically may not end earlier if the minimum volume of work $V_{\min j+1}^f$ technologically essential after the previous work j is not be done.



T^{lim} – directory (normative, contractual) duration of the objection structure; t_j – duration of time area; t_j^s ; t_j^f – technologically possible beginning and completion of work; $t_{j-1,j}^s$; $t_{j-1,j}^f$ – minimum technological delays during the beginning and completion of the following work $j+1$ from the point of the beginning and completion of the previous work j ; t_j^{lim} – criticality point after which execution of the volume of work demands maximum intensity and can lead to disruption of work T^{lim}

Fig. 2. Graphic presentation of the project technological dependencies model

The presented model helps us to determine the minimal duration of construction which is technologically possible. This process is quite simple. If we decrease the duration (shift point T_{nor} to the left) together with the technological dependences of the end of the works, the temporary areas (time domains) of work are reduced. The newly obtained duration time domains of each work must be checked by means of the formula:

$$R_{j,i}^h = \frac{V_{i,j} \cdot w_j}{t_{i,j} \cdot \pi^n} \leq R_{j,i,max}^h,$$

where $R_{j,i,max}^h$ – the maximal amount of manpower of a specialty h , which can be directed to perform the work j on the project i , using the whole temporary area; $R_{j,i}^h$ – the calculated amount of manpower of a specialty h , which is necessary for the performing the work j on the project i , using the whole temporary area; $V_{i,j}$ – the amount of work j on the project i ; w_j – time allowance for performing per amount unit of work j ; π – rate of labor productivity increase.

If given ratio corresponds to this $R_{j,i}^h = R_{j,i,max}^h$, the minimal duration is reached.

PTDM helps us to perform the maximum possible alignment of technologically interrelated works. The essence the method of the project graph calculating is that we bind the time limits of the beginning and the end of follow-up work with respect to the preceding work within the time-domain, which is known from the relevant PTDM.

Calculating of the project graph we use not only the time-domain, but also such parameters of technological model, as a possible beginning of work t_j^s , possible end of work t_j^f , minimal initial and final gaps, the project construction duration etc.

Let's consider the example of binding, which shown in Fig. 3 (parameters $t_j^{s,w}$; $t_j^{f,w}$ are the estimated start and end dates of works).

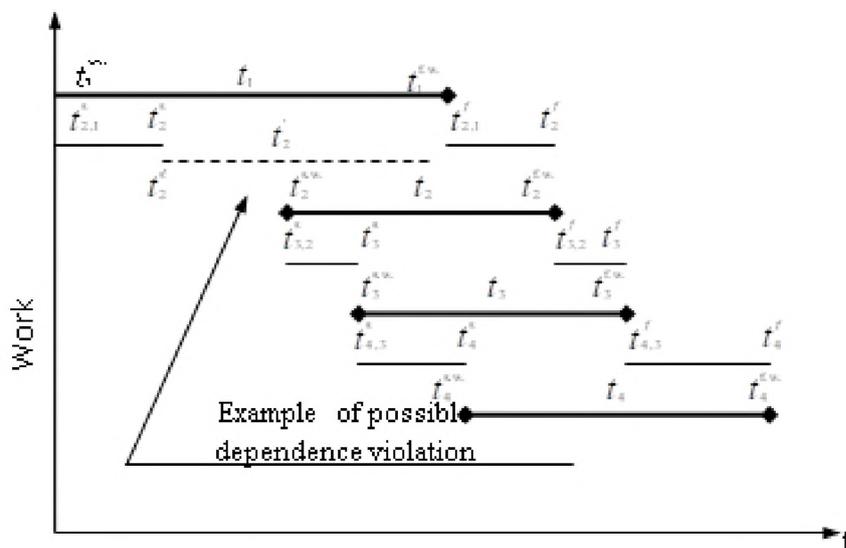


Fig. 3. Example of graphical representation for work dependencies based on MTSD with displayed boundaries for possible maximal work alignment in time

The work t_2 cannot be started before the point t_2^s and cannot be ended before the point t_2^f . If the beginning of work t_2 is aligned with the point t_2^s ($t_2^{s,w} = t_2^s$), its end will not be before the point t_2^f ($t_2^{f,w} < t_2^f$) and this will cause the violation of technological dependence (work t_2 shown by the dotted line). That's why the end of the work t_2 should be aligned with the point t_2^f ($t_2^{f,w} = t_2^f$).

The beginning of a work is defined by:

$$t_2^{s,w} = t_2^{f,w} - t_2.$$

The beginning $t_3^{s,w}$ of work t_3 is equal to t_3^s , and the end is

$$t_3^{f,w} = t_3^{s,w} + t_3;$$

$$t_3^{f,w} > t_3^f.$$

In general, the parameters of the beginning $t_j^{s,w}$ and the end $t_j^{f,w}$ of the work j are determined by the following formulas:

$$t_j^{s,w} = \begin{cases} t_j^{f,w} - t_j & \text{at } t_j^s + t \leq t_j^f; \\ t_j^f & \text{at } t_j^s + t \geq t_j^f; \end{cases}$$

$$t_j^{f,w} = \begin{cases} t_j^f & \text{at } t_j^s + t \leq t_j^f; \\ t_j^{s,w} + t_j & \text{at } t_j^s + t \geq t_j^f. \end{cases}$$

Conclusions

The proposed method of linear graph calculating on the basis of the Project technological dependencies model (PTDM) can significantly extend the capabilities of traditional linear graphs in the planning and organization of construction works, as well as a tool for the control, coordination, regulation and supervision of construction production.

References

1. Polesie P., Frödell M., Josephson P.E. Implementing Standardisation in Medium-Sized Construction Firms: Facilitating Site Managers' Feeling of Freedom through a Bottom-up Approach. *Proceedings for the 17th Annual Conference of the International Group for Lean Construction*. Taipei, Taiwan, 15–17 July 2009, pp. 317–326.
2. Borodin S.I. [Definition and Functions of the Developer on the Construction Market]. *Construction Economics*, 2011, vol. 3, pp. 50–53.
3. Gusev E.V. Construction and Assembly Works Planning: Optimization or Search for Solutions. *3-rd International Conference on Industrial Engineering (ICIE-2017)*. SHS Web Conf., 2017, vol. 35. DOI: 10.1051/shsconf/20173501147
4. Zhou J., Love P.E., Wang X., Teo K.L., Irani Z. A Review of Methods and Algorithms for Optimizing Construction Scheduling. *Journal of the Operational Research Society*, 2013, vol. 64 (8), pp. 1091–1105. DOI: 10.1057/jors.2012.174
5. Galloway P.D. Survey of the Construction Industry Relative to the Use of CPM Scheduling for Construction Projects. *Journal of Construction Engineering and Management*, 2006, vol. 132 (7), pp. 697–711. DOI: 10.1061/(ASCE)0733-9364(2006)132:7(697)
6. Caldas C.H., Soibelman L. Automating Hierarchical Document Classification for Construction Management Information Systems. *Automation in Construction*, 2003, vol. 12 (4), pp. 395–406. DOI: 10.1016/S0926-5805(03)00004-9
7. Ma G., Wang A., Li N., Gu L., Ai Q. Improved Critical Chain Project Management Framework for Scheduling Construction Projects. *Journal of Construction Engineering and Management*, 2014, vol. 140 (12), p. 04014055. DOI: 10.1061/(ASCE)CO.1943-7862.0000908
8. Mincks W., Johnston H. *Construction Jobsite Management*. 3th ed. Cengage Learning. 2010, 480 p.
9. Lyapina A.R., Borodin S.I. Use of Building Information Modelling (BIM) in Construction: the State Expert Inspection of Construction Projects in Russia. *Proceedings of Universities. Investment. Construction. Real Estate*, 2018, vol. 8, no. 2, pp. 11–17. DOI: 10.21285/2227-2917-2018-2-11-17
10. Gusakov A.A. *Sistemotekhnika stroitel'stva* [Systems and Techniques for Construction]. Moscow, Stroyizdat Publ., 1983. 368 p.
11. Gusakov A.A. *Organizatsionno-tekhnologicheskaya nadezhnost' stroitel'nogo proizvodstva* [Organizational and Technological Reliability of Construction Operations]. Moscow, Stroyizdat Publ., 1974. 252 p.
12. Baldwin A., Bordoli D. *Handbook for Construction Planning and Scheduling*. UK, John Wiley & Sons, 2014. 408 p. DOI: 10.1002/9781118838167
13. Kothari C.R. *Research Methodology: Methods and Techniques*. New Delhi, New Age International, 2004, 401 p.
14. Halpin D.W. *Construction Management*. 4th ed. John Wiley & Sons, 2011. 448 p.
15. Voropaev V.I. *Modeli i metody kalendarnogo planirovaniya v avtomatizirovannykh sistemakh upravleniya stroitel'stvom* [Scheduling Models and Methods within Automated Control System]. Moscow, Stroyizdat Publ., 1975. 232 p.
16. Gusev E.V. *Tekhnologicheskoye modelirovaniye i sbalansirovannoye planirovaniye stroitel'no-montazhnykh rabot* [Technological Dependence and Balanced Planning of Construction Works]. Chelyabinsk, Redaktor Publ., 1990. 147 p.

Received 25 May 2019

УПРАВЛЕНИЕ ПРОИЗВОДСТВОМ РАБОТ НА ОСНОВЕ МОДЕЛИРОВАНИЯ ТЕХНОЛОГИИ СТРОИТЕЛЬСТВА ОБЪЕКТА

Е.В. Гусев

Южно-Уральский государственный университет, г. Челябинск, Россия

В статье подчеркивается важность календарного планирования в системе управления строительным производством. Календарный план и его составная часть, график строительства, служат основным источником информации для решения задач логистического и инженерного характера. Проведен анализ порядка разработки календарного плана строительства объекта. Выявлено, что в применяемых методиках разработки графиков строительства отсутствуют количественные ограничения при: а) определении минимальной продолжительности строительства объекта; б) максимального совмещения производства технологически взаимосвязанных работ; в) моделировании строительства объекта.

Приведено описание модели объектных технологических зависимостей (МОТЗ), которая отражает технологию строительства объекта. Основными параметрами МОТЗ являются:

- 1) количественные оценки технологических связей между работами;
- 2) временная область выполнения работы;
- 3) точки критичности каждой работы;
- 4) продолжительность строительства объекта;
- 5) максимальное количество ресурсов типа мощности, которое можно использовать на работах.

На основе МОТЗ определяется технологически возможная минимальная продолжительность строительства.

Математическое описание методики привязки технологически взаимосвязанных работ во времени дает возможность решить задачу их максимального совмещения.

Ключевые слова: модель объектных технологических зависимостей (МОТЗ), календарный план, технология производства работ, организационно-технологические модели.

Литература

1. Polesie, P. *Implementing Standardisation in Medium-Sized Construction Firms: Facilitating Site Managers' Feeling of Freedom through a Bottom-up Approach* / P. Polesie, M. Frödell, P.E. Josephson // *Proceedings for the 17th Annual Conference of the International Group for Lean Construction. Taipei, Taiwan, 15–17 July 2009.* – P. 317–326.

2. Бородин, С.И. *Понятие и функции застройщика на рынке жилищного строительства* / С.И. Бородин // *Экономика строительства.* – 2011. – № 3. – С. 50–53.

3. Gusev, E.V. *Construction and assembly works planning: optimization or search for solutions* / E.V. Gusev // *3-rd International Conference on Industrial Engineering (ICIE-2017). SHS Web Conf.* – 2017. – Vol. 35. DOI: 10.1051/shsconf/20173501147

4. *A review of methods and algorithms for optimizing construction scheduling* / J. Zhou, P.E. Love, X. Wang et al. // *Journal of the Operational Research Society.* – 2013. – Vol. 64 (8). – P. 1091–1105. DOI: 10.1057/jors.2012.174

5. Galloway, P.D. *Survey of the construction industry relative to the use of CPM scheduling for construction projects* / P.D. Galloway // *Journal of Construction Engineering and Management.* – 2006. – Vol. 132 (7). – P. 697–711. DOI: 10.1061/(ASCE)0733-9364(2006)132:7(697)

6. Caldas, C.H. *Automating hierarchical document classification for construction management information systems* / C.H. Caldas, L. Soibelman // *Automation in Construction.* – 2003. – Vol. 12 (4). – P. 395–406. DOI: 10.1016/S0926-5805(03)00004-9

7. *Improved critical chain project management framework for scheduling construction projects* / G. Ma, A. Wang, N. Li et al. // *Journal of Construction Engineering and Management.* – 2014. – Vol. 140 (12). – P. 04014055. DOI: 10.1061/(ASCE)CO.1943-7862.0000908

8. Mincks, W. *Construction jobsite management* / W. Mincks, H. Johnston. – 3th ed. – Cengage Learning, 2010. – 480 p.
9. Lyapina, A.R. *Use of building information modelling (BIM) in construction: the state expert inspection of construction projects in Russia* / A.R. Lyapina, S.I. Borodin // *Proceedings of Universities. Investment. Construction. Real Estate.* – 2018. – Vol. 8, no. 2. – P. 11–17. DOI: 10.21285/2227-2917-2018-2-11-17
10. Гусаков, А.А. *Системотехника строительства* / А.А. Гусаков. – М.: Стройиздат, 1983. – 368 с.
11. Гусаков, А.А. *Организационно-технологическая надежность строительного производства* / А.А. Гусаков. – М.: Стройиздат, 1974. – 252 с.
12. Baldwin, A. *Handbook for construction planning and scheduling* / A. Baldwin, D. Bordoli. – UK, John Wiley & Sons, 2014. – 408 p. DOI: 10.1002/9781118838167
13. Kothari, C.R. *Research methodology: Methods and techniques* / C.R. Kothari. – New Delhi: New Age International, 2004. – 401 p.
14. Halpin, D.W. *Construction management* / D.W. Halpin. – 4th ed. – John Wiley & Sons, 2011. – 448 p.
15. Воропаев, В.И. *Модели и методы календарного планирования в автоматических системах управления строительством* / В.И. Воропаев. – М.: Стройиздат, 1975. – 232 с.
16. Гусев, Е.В. *Технологическое моделирование и сбалансированное планирование строительно-монтажных работ* / Е.В. Гусев. – Челябинск: Редактор, 1990. – 147 с.

Гусев Евгений Васильевич, д-р техн. наук, профессор кафедры прикладной экономики, Южно-Уральский государственный университет, г. Челябинск; gusevev@susu.ru.

Поступила в редакцию 25 мая 2019 г.

ОБРАЗЕЦ ЦИТИРОВАНИЯ

Gusev, E.V. Using Object Construction Model for Implementation Building Works Management / E.V. Gusev // Вестник ЮУрГУ. Серия «Компьютерные технологии, управление, радиоэлектроника». – 2019. – Т. 19, № 3. – С. 147–155. DOI: 10.14529/ctcr190314

FOR CITATION

Gusev E.V. Using Object Construction Model for Implementation Building Works Management. *Bulletin of the South Ural State University. Ser. Computer Technologies, Automatic Control, Radio Electronics*, 2019, vol. 19, no. 3, pp. 147–155. DOI: 10.14529/ctcr190314
