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Technique for Determination of Rational Boundaries in Combining Construction and Installation Processes Based on Quantitative Estimation of Technological Connections

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Abstract. The problems of the existing methods for the determination of combining and technologically interlinked construction processes and activities are considered under the modern construction conditions of various facilities. The necessity to identify common parameters that characterize the interaction nature of all the technology-related construction and installation processes and activities is shown. The research of the technologies of construction and installation processes for buildings and structures with the goal of determining a common parameter for evaluating the relationship between technologically interconnected processes and construction works are conducted. The result of this research was to identify the quantitative evaluation of interaction construction and installation processes and activities in a minimum technologically necessary volume of the previous process allowing one to plan and organize the execution of a subsequent technologically interconnected process. The quantitative evaluation is used as the basis for the calculation of the optimum range of the combination of processes and activities. The calculation method is based on the use of the graph theory. The authors applied a generic characterization parameter to reveal the technological links between construction and installation processes, and the proposed technique has adaptive properties which are key for wide use in organizational decisions forming. The article provides a written practical significance of the developed technique.

1. Introduction

The construction of the various facilities is a complex and time-consuming task, characterized by high dynamism, i.e., constantly changing work conditions. No doubt the fact that for the successful solution of this problem effective organization of the works that is the linkage system works in time and space, the system of supply and use of resources is necessary.

The integration of all construction, installation and special works in terms of their beginnings and endings with the possibility of their combined execution is the main procedure of drawing up the calendar plan of the object. Given the sequence and duration of individual processes of construction,

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in linking the timing of the processes are adjusted and thus the option schedule becomes more adapted to the actual progress of works.

In the linkage process are guided by the principle of combination, i.e. the simultaneous execution of multiple processes on different seizures of object or simultaneous execution of multiple processes on one seizure or any other part of general scope of work [1, 2]. The implementation of this principle allows us to reduce the total duration of construction even with some increased timing of individual processes of construction. For maximum overlapping of operations, according to the principle of threading are organized the leading process making full use of the scope of work and are highlighted the processes that are performed simultaneously with the leading, and processes that have the same leading in rhythm and are performed reciprocally.

Construction experience shows that any set of works, in principle, can be made by different methods with different combination of works in time and in space, with a different value of technical and economic indicators. Therefore, it is necessary to develop different models of work organization in each of the possible methods for their comparison and choice the most rational for the specific production conditions.

The ways and methods of work organization are determined by the specific conditions of construction, nature of the linking works in their technological sequence, in time and space. Creating the organizational and technological scheme of construction is a daunting task, requiring certain qualifications of designers. You can cite a lot of examples of construction practices, indicating the need of considering in addition to the main and optional auxiliary work and this speaks to the highly individual nature of the development of the model of work organization.

In the work [3] the options of methods of work organization are presented, according to the design methods of work organization are determined by the following: invariance of structure and principles, which are formed the methods of work organization; the level of combination of different composition of work; level of parallelism of performance of the same scope of work; level for smooth execution of work; level indicator constant intensity; the level of alternative variants of performance of works; the level of the ability to determine deadlines and spread of relations; the duration of execution of works lying on noncritical paths, etc.

According to this classification, the degree of combining different types of work and the parallelism of similar works, which are the main criteria (these two criteria reflect the fact of the simultaneity of execution of those or other works) that define the general nature of the work organizational methods, the main varieties of these methods are:

- consistent types, fronts, grades;
- parallel;
- parallel-to-serial;
- flow;
- parallel-flow.

But due to the complexity of construction works on erection of buildings and structures, using modern technologies of production of construction works there are problems linking them with traditional types of work assignment to one of the options listed above organizational works on the construction of the facility. From this point of view, this task is urgent and requires solution. Therefore, the problem statement is formulated as the development of an indicator combining the construction processes and activities that reflect organizational and technological decisions under modern conditions of construction of buildings and structures.

In solving the stated problem, it is reasonable to proceed from the results of the analysis of existing methods of determining the degree of alignment of construction processes and activities.

2. The analysis of existing methods of combining construction processes

The combination, as well as continuity, smoothness, rhythm and intensity of the erection of buildings and structures belongs to the second group of indicators (for evaluation of schedules) techno – economic assessment of organization of production [4]. Basically a combination of construction processes (threads) defines some of the most diverse in composition and methods of calculating indicators, as a combination of works, calendar density, specific work duration.

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Performance (COP) and the degree (S) combination is considered in [4-7]. The definition of a measure (COP) change different formulas that use such parameters as: the time interval from beginning of installation to the start of other works; the duration of the installation of the underground part; the duration of the combined works; duration of construction; the duration of all processes; the maximum duration of the process flow; number of processes, etc.

The degree of alignment (S) are determined by the formula:

$$S = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n} t_{ij}}{\sum_{j=1}^{m}\sum_{i=1}^{n} t_{ij} + \sum_{j=1}^{m}\sum_{i=1}^{n} t_{oij}} \tag{1}$$

where $\sum_{j=1}^{m}\sum_{i=1}^{n} t_{ij}$ – the total value of the durations of all teams on seizure (sites), days; $\sum_{j=1}^{m}\sum_{i=1}^{n} t_{oij}$ – the total value of.

The durations of the organizational breaks between the works of teams days. Analysis of these formulas shows that for determining the alignment processes there is no single approach, and the degree of alignment of the processes is evaluated by the relative ratio combining.

The need to create scope of work for subsequent interrelated process requires an organizational relationship between the processes. When you run processes in the construction of buildings, the volume of these processes are unevenly distributed, forcing you to design the volume of work fronts at various sites, exceeding the terms of their performance potential downtime. Quantitative assessment of increased downtime scope of work is given in this figure is defined as the ratio of the total downtime of the scope of work on all sites for the duration of the process taking into account downtime [8].

The next sort of indicator of alignment is an indicator of a calendar of the flux density (α). This figure is described in [8] and is given by:

$$\alpha = \frac{T}{mR} \tag{2}$$

$$T = R\,(m + n - 1) \tag{3}$$

where m - the number of seizures (plots); R – the rhythm of the flow; n - the number of processes.

Given the indicator is a characteristic of the share of each of the processes in the duration object stream, which changes from mR to mnR, with $1 \le \alpha \le n$.

The calendar indicator of the flux density follows the duration of construction, but in this calculation the figure is defined only for rhythmic flow. To determine the duration of flow by the formula:

$$T = \alpha m R \tag{4}$$

are accepted in works [7,9] for the starting premise for assessing the level of organization of construction.

The value of the specific indicator of the duration of processes is shown in [8] it is determined by the formula:

$$K = \frac{t_i}{T} \tag{5}$$

where t_i - the duration of a process performed at the facility.

The formula shows that the larger the index of specific duration, the more duration of processes at a given time of the facility, and, accordingly, the more evenly resources are being consumed. The use of the maximum duration of processes at a given date of completion of facility to select the optimum organization and an estimation of its level is given in [10].

Thus, as seen from the above analysis, the rate of combination has different ways of defining and represents the relative magnitude by which is difficult to judge the depth of the alignment processes. Therefore, it is necessary to develop the most generic method of determining the measure of alignment, allowing to describe dependence of continuous, flux and parallel execution of processes, and reflecting optimal range of overlapping processes. The versatility of this method can be achieved using the method of common parameter characterizing the nature of the interaction between any technologically interconnected construction processes and works [11]. To determine such a parameter will conduct studies of technologies of construction of buildings and structures.

3. Research technology of construction

The process of constructing facilities of any complexity is characterized by the involvement for the construction of a substantial number of construction and industrial enterprises of various kinds of specialization, the use of a large number of materials, designs, products, with various constructive and technological properties. Manufacture of works on construction of buildings involves the implementation of a large number of technological processes and operations with specific indicators and parameters. In addition, during the construction it is necessary to consider the fact that construction and installation work is affected by factors such as climate, weather and regional conditions; the level of skills of workers and managerial personnel; the use of performers when performing work different by design, technical equipment, logistical means [12].

It is therefore necessary in the first place in technology of construction of buildings and structures to consider the degree of interaction of related simple and complex processes that make up the technology of construction of buildings and structures, their internal relationships and coherence in space and time to perform the functional purpose of technology of construction of buildings and structures on the construction of objects of different purposes. The result of previously conducted similar studies was the establishment of a technological sequence of works on object and graphic design in the form of arrow diagrams, topology, network diagrams and other forms of construction models of the object [1]. For example, in [13], following the procedure for the development of a schedule for the construction of the object:

1. Make a list (nomenclature) works.
2. In accordance with it on each type of work shall be determined by the volume.
3. Produce the choice of methods of production of major works and leading machines.
4. Expect regulatory engineering and complexity.
5. Determine the composition of the brigades and units.
6. Identify technological sequence of works.
7. Establish shift work.
8. Determine the length of individual works and their combination among themselves; at the same time according to this adjusted number of workers and shifts.
9. Make the estimated duration with a standard and introduce necessary amendments.
10. Based on the plan develop schedules of resource requirements and their provision.

As can be seen, the task of the technology of construction of buildings and structures and to develop a calendar plan is limited only by the establishment of technological sequence of works and processes, on this technology of construction of buildings and structures is over.

Studies of the characteristics of technology of construction of buildings and structures from the point of view of sound planning multiple interactions between the construction process and the work of the most perfect example for these purposes, the network models has yielded the following results.

Improving network models of construction, ranging from the simplest deterministic network models to networks related to a specific class of a node deterministic temporal models from the point of view of improving the reliability and adequacy of the actual course of construction of the facility is based on the hardening of the closeness of the relationship between technologically interconnected. The achievement of this goal is based on the introduction of additional relations, namely, the quantitative relations between the amount of work that offer opportunities to develop effective institutional arrangements.

In the framework of this trend also the results of other studies in this area are stacked. For example, the development of the model of object technological addictions was the result of further theoretical studies in the determination of quantitative relationships between related works [14,15].

The basis of this model is technological dependencies between activities. The principle of its construction is based on "... qualitative and quantitative estimation of technological connections between works which determine the possibility of planning of volumes at the beginning and end of the work depending on the previous status" [14,15]. With this principle, a qualitative assessment reflects the execution of any works relative to the preceding works. In turn, the quantitative assessment can judge the technology based on the beginning of the subsequent works since the beginning of the preceding and technological dependence the end of the next work from the end of the preceding activities. Quantification gives an idea of the volume ratios between technologically related works.

The result of above study is the following. Technology erection of buildings and structures is a set of construction processes in the construction of buildings and structures, the degree of technologically related combination of them depends on the adequacy of the real course of construction. Therefore, for the organization of construction, i.e. to establish an effective procedure for the interaction of these construction processes should be used its qualitative and quantitative assessment. If the qualitative assessment reflects the execution of any works relative to the preceding works, it can be used in the formation of organizational and technological scheme of construction. Whereas the quantitative assessment that reflects the volume ratio between technologically related works, reflects the depth of interaction and can be used to determine the numerical values of the overlapping processes and activities.

The definition of rational combination of field construction processes and activities.

Previously conducted research in the area of construction allowed to identify the auto-RAM article the trend of using the evaluation of the relationship between the technological processes involved in solving the issues of formation of organizational solutions in the construction of various facilities [14,15]. The method of determining the quantitative evaluation of the relationship of technological processes is the amount of the minimum technologically necessary volume of the previous process and allows you to plan and organize the execution of subsequent technologically interconnected process and is the basis for modeling the rational area of overlapping processes [16,17].

When forming a model area of overlapping processes need to consider directed graph $G = \{X, Y\}$ consisting of a nonempty set of vertices X and Y of the set of arcs [18,19]. The elements of the set Y are the pairs $\{x, y\}$, $x \in X$, $y \in Y$. If each vertex of the graph corresponds to the process j, then the arcs of the graph indicate the necessary continuity of the results of these processes. In relation to a separate vertex x of the graph adjacent vertex y which is the end of an arc $\{x, y\}$, will be considered to be adjacent and denoted by $x+$. Adjacent to x vertex y, which is the beginning of the arc $\{y, x\}$ will be referred to as reverse adjacent and denoted by x^-.

In this case:

$$y = x+ = j+, \; if \; \{x, y\} \int Y, j + \int G[j] \tag{6}$$

$$y = x^- = j^-, \; if \; \{y, x\} \in Y, j^- \in G^*[j] \tag{7}$$

where *G[j]* is the set of processes *j*+ performed directly after process *j*; *G*[j]* is the set of processes j^- directly premarching process *j*.

If the graph is viewed as an unfolding in time of the processes in the direction from the initial start to the final, then any subsequent process is at the same time previous to other processes. Therefore, the count may be represented by a sequence of nodes from the process and processes preceding him:

$$\varnothing \to j1, j1^- \to j2 j1^- \to j3, \left(j1^-, j2^-, j3^-\right) \to j4, \left(j2^-, j4^-\right) \to j5 \tag{8}$$

where the sign → indicates a relationship of the process *j* with the preprocession j^-.

In General, the directed graph is written in the following form:

$$G^*[j] \to j, \; (j = 1, \iota) \tag{9}$$

For $G^*[j] = \varnothing$ (the empty set), the process *j* is the source.

Thus can be described any directed graph with one or more of the initial and final processes. In the description of the graph in a similar way the processes are represented as points, but in reality the process is extended in time and their relative positions can be different. As you know, communication between processes can be direct or inverse, to take place at the beginning (NN), the end (CC), at arbitrary points of their execution (a, b), at the end of the previous and the beginning of the process in the order of their execution (CN), at the beginning and the end, combined with the implementation of the processes (NN, CC), not how many arbitrary points (NN, $a_1 b_1, a_2 b_2$, ..., CC) [18,19]. Knowing these relationships, you can build different directed graphs. Therefore, to build a graph of processes should be known to a certain process (*j*), the set of processes j^- immediately preceding process j (*G**[*j*]) and the type of communication.

Many *G*[j]* is an alternative, as it can be represented by a different set of processes j^- preceding process *j*, it is permissible and in fact implemented in emergency situations. In this case, *G*[j]* ϵ *M*, i.e. is a subset of *M* processes j^-, which may be preceded by *j*. The list of types of processes *j*, indicating the many possible variants of the preceding process j^- and the types of relations form the basis of reference data solutions to the task of forming the graph – model of process execution. The method of constructing a directed graph were the basis for constructing the model construction processes with known link types and data values of the offsets in these relations [19]. The calculation of the offsets of the beginning and end of the work j and j - under the condition of continuity of reference is as follows [19]:

$$\Delta t^{нн}_{p_{\min(jj-)_n}} (jj-)_n = \max \left\{ \begin{array}{c} \Delta t^{нн}_{p_{\min(jj-)_{n-1}}} \\ \sum_{i=1}^{n} t_{ij-} - \sum_{i=1}^{n} t_{ij} + \Delta t^{kk}_{\min(jj-)_n} \end{array} \right\} \tag{10}$$

$$\Delta t^{kk}_{p_{\min(jj-)_n}} (jj-)_n = \Delta t^{нн}_{p_{\min(jj-)_n}} - \sum_{i=1}^{n} t_{ij-} - \sum_{i=1}^{n} t_{ij} \tag{11}$$

$$\Delta t^{нн}_{p_{\max(jj-)_n}} (jj-)_n = \min \left\{ \begin{array}{c} \Delta t^{нн}_{p_{\max(jj-)_{n-1}}} \\ \sum_{i=1}^{n} t_{ij-} - \sum_{i=1}^{n} t_{ij} + \Delta t^{\infty}_{\max(jj-)_n} \end{array} \right\} \tag{12}$$

$$\Delta t^{kk}_{p_{\max(jj-)_n}} (jj-)_n = \Delta t^{нн}_{p_{\max(jj-)_n}} - \sum_{i=1}^{n} t_{ij-} - \sum_{i=1}^{n} t_{ij} \tag{13}$$

where $\Delta t^{нн}_{p_{\min(jj-)_n}}(jj-)_n$, $\Delta t^{kk}_{p_{\min(jj-)_n}}(jj-)_n$ – the calculated minimum offset accordingly start and end of the processes j и j- when in carrying out them on n sites (seizures); $\Delta t^{нн}_{p_{\max(jj-)_n}}(jj-)_n$, $\Delta t^{kk}_{p_{\max(jj-)_n}}(jj-)_n$ - the calculated maximum offset accordingly start and end of the processes j и j- when in carrying out them on n sites (seizures).

4. Conclusion

Method of determining the optimal and rational boundaries of the alignment processes based on quantitative assessment of technology- related processes allows to determine the actual range of the combination of interrelated processes, acting as an additional parameter in the development of organizational solutions for construction of facilities. Due to the development of methods to determine optimal and efficient frontiers of combining the processes of quantitative assessment in the form of minimum technologically necessary volume of the preceding process, having the flexibility characteristics of the interaction of all technology-related processes and activities, regardless of the variant of the organization of works on construction of the object, this method has the properties of wide adaptability

The practical significance of the proposed methodology lies in its suitability for construction and design organizations in the formation of the schedule of construction of various facilities for the proposed scheme. The essence of this scheme is the dismemberment of the entire calendar into separate components, in each of them without violating technological relationships between processes and activities are determined a set of processes and activities.

Many works that are scheduled to execute in a certain planning period in such a scheme, in most cases, belongs to different participants of the construction. For the successful implementation of the planned processes and activities by all executors fully and as scheduled it is necessary that the scope of work created by previous executors was enough for the next ones. This goal is achieved through the use of such a selection of quantitative evaluation as in the form of minimum technologically necessary volume of works (Figure 1).

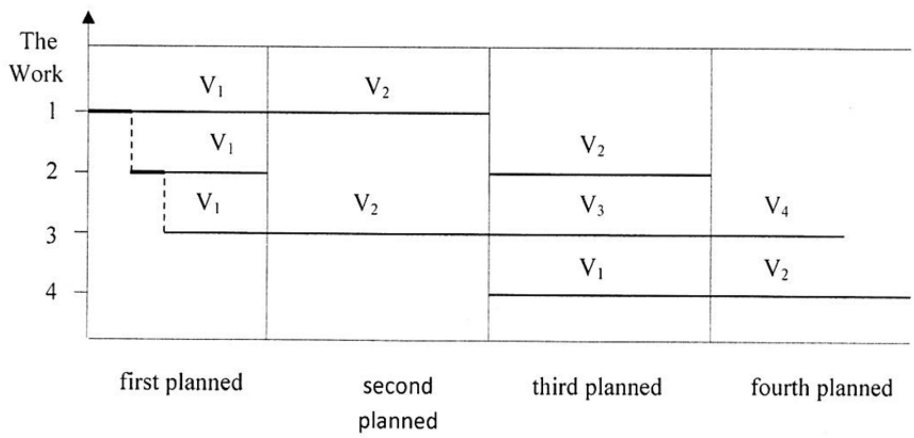

Figure 1. Example of the distribution of the amount of work in the plan periods.

For example, in figure 1, in the plan period I is produced a set of technology-related works 1, 2, 3. These works are in the technological relationships for the commencement of further work is necessary and sufficient to create the front in the form of minimum technologically necessary volume of works (shown in bold below), which allows with the use proposed by the methodology to determine the estimated minimum and maximum displacement, respectively, the start and end of construction and installation processes according to the formulas (12) and (13). Selection of such set of works has been implemented using the methodology of rational combination of works and allows to solve tasks like the execution of the planned feasibility physical volume at this stage and compliance with the deadlines due to the variation in the range of combination of construction processes and activities.

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