Formation of optimal performance of works during establishment of the complex of objects optimal sequence of establishing objects complex building

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Abstract. In the complex development of urbanized areas, construction objects differ in spaceplanning and design solutions, construction volume, total area, and cost of construction. In this regard, in the construction of a facility complex, an important factor is the rational choice of the sequence of facility construction to ensure the optimal duration of construction of the entire complex. This problem is solved by the method of organizational and technological modeling, taking into account the availability of a sufficient amount of resources necessary for the parallel construction of several objects simultaneously. The erection of the construction object includes the underground part, the above-ground part, roofing and finishing construction work, which can be organized into rhythmic specialized flows at individual worksites. This allows you to reduce the duration of the construction of each facility and complex as a whole, as well as to determine the temporary reserves and use them to reduce construction time and optimal provision of material and financial resources. The methods of organizational and technological modeling solve the problem of choosing the optimal sequence of work during the construction of a facility complex to reduce construction time. With limited resources, there is an alternative to attracting additional resources or increasing the overall construction time.

1. Introduction

One of the priority tasks of organisational and technological design during the construction of a complex of construction objects is to determine the optimal sequence of their construction, accounting the most significant technical and economic indicators. It includes the timing of object construction and estimated cost [1-2].

Specialities of the construction of a facility complex are the differences in their space-planning and structural solutions, construction volume, total area and, as a consequence, the estimated cost of the facilities.

The method of organisational and technological modelling solves the problem of determining the optimal sequence of work at the facility, which allows to ensure the minimum duration of work [3-5].

2. Methods

Facility construction complex provides the construction of 7 buildings of various functional purposes, space-planning and structural solutions, construction volume, area and cost [6].
The area of the construction object \((m^2)\) and the estimated cost in conventional units \((cu)\) were taken as the most significant indicators to form the priority program for the construction of objects (Table 1).

### Table 1. Estimated technical and economic parameters of objects.

| Name of the object | Square, \(m^2\) | Estimated cost, \(cu\) |
|--------------------|-----------------|----------------------|
| Object number 1    | 5535            | 46143                |
| Object number 2    | 10121           | 84375                |
| Object number 3    | 12325           | 102748               |
| Object number 4    | 6742            | 56205                |
| Object number 5    | 19776           | 164864               |
| Object number 6    | 24359           | 203071               |
| Object number 7    | 19669           | 163972               |

In addition, the construction of the construction site itself is cyclical. As a rule, the underground part, the aboveground part, roofing and finishing construction work are distinguished in separate stages of construction. Their sequence is determined, first of all, by the safety of the work, and inside the stages themselves specialized flows can be organized that rhythmically develop on individual fronts or areas of work and can reduce the duration of the construction of each individual object as a whole [7-10].

Decomposition of the full cycle of construction of a building object into separate works allows not only to determine temporary reserves and use them to reduce construction time, but also to build a system of optimal provision of material and financial resources. For this, it is necessary to take into account both the cost of the materials themselves, which can be varied in a certain range, and the cost of construction and installation works, operation of machines and mechanisms, as well as the attraction of highly qualified working personnel.

The use of innovative technologies is justified in cases where they replace traditional ones with the aim of resource minimization and without exceeding the established duration of the construction of the facility provide a reduction in material and financial costs [11,12].

The data on the estimated cost for certain types of construction and installation works (in \(cu\)) of all objects included in the production program are presented in table 2.

### Table 2. Decomposition of the construction work cost by type at the objects.

| Name of work            | Estimated cost (\(cu\)) of facilities |
|-------------------------|---------------------------------------|
|                         | \(\#1\)   | \(\#2\)   | \(\#3\)   | \(\#4\)   | \(\#5\)   | \(\#6\)   | \(\#7\)   |
| Underground part        | 46143     | 84375     | 102748    | 56205     | 164846    | 203071    | 163972    |
| Building frame          | 3230      | 5906      | 7192      | 3934      | 11539     | 14215     | 11478     |
| Filling openings        | 15689     | 28688     | 34934     | 19110     | 56048     | 69044     | 55750     |
| Roofing                 | 5076      | 9281      | 11302     | 6183      | 18133     | 22338     | 18037     |
| Flooring                | 4153      | 7594      | 9247      | 5058      | 14836     | 18276     | 14757     |
| Finishing works         | 5046      | 9281      | 11302     | 6183      | 18133     | 22338     | 18037     |
| Domestic plumbing       | 5537      | 10125     | 12330     | 6745      | 19782     | 24369     | 19677     |
| Internal electrical work| 3691      | 6750      | 8220      | 4496      | 13188     | 16246     | 13118     |
| Beautification          | 2769      | 5063      | 6165      | 3372      | 9891      | 12184     | 9838      |

The duration of all types of work at each facility is shown in table 3. The arrangement of objects in the stream is presented in the form of a network diagram in Figure 1. The top of the network diagram is work. Changes in the arrangement of objects in the stream can lead to a change in the total duration of work for the entire complex of objects.
Table 3. Duration of all types of work at the facilities.

| Name of work            | №1 | №2 | №3 | №4 | №5 | №6 | №7 |
|-------------------------|----|----|----|----|----|----|----|
| Underground part        | 65 | 119| 145| 79 | 132| 186| 131|
| Building frame          | 172| 315| 383| 210| 214| 257| 311|
| Filling openings        | 88 | 161| 196| 107| 214| 287| 213|
| Roofing                 | 45 | 82 | 100| 55 | 161| 198| 160|
| Flooring                | 91 | 166| 203| 111| 225| 200| 123|
| Finishing works         | 153| 208| 241| 186| 205| 173| 144|
| Domestic plumbing       | 105| 192| 234| 128| 175| 162| 207|
| Internal electrical work| 93 | 107| 137| 113| 132| 209| 130|
| Beautification          | 21 | 38 | 47 | 26 | 35 | 42 | 35|

Figure 1. Network graphic.

The corresponding values are indicated on the arcs connecting the vertices of the network diagram in Figure 1. In the upper half of the vertex, the object number is indicated according to table 1, and in the lower half, the duration of the work in months.

3. Results and Discussion
Determining the optimal sequence of work when the dependencies of the recommendation type.

Using the data shown in Figure 1, we set the task of determining the optimal sequence of work at the facilities included in the production program of the enterprise, so that the entire duration of the work is minimal.

For this purpose, we apply the following algorithm $t_1=11$, $t_2=16$, $t_3=12$, $t_4=12$, $t_5=17$, $t_6=18$, $t_7=15$.

2. We consider each vertex of the network diagram and determine its index.

The vertex index is $1 - \lambda_1 = 11$.

For vertex 2 the index can be defined as follows: only one arc enters the vertex. Consequently, only two options are possible: the dependence represented by this arc is fulfilled or this dependence is violated. We will evaluate both of these options. For the first, it is necessary that work 1 be completed and then work 2. The total duration will be $t_2 = 11 + 16 = 27$.

In case of violation of the dependence $t_2 = 16 + 12 = 28$. So the new vertex index will be $\lambda_2 = \min(27, 28) = 27$. 


Define the index of the vertex 3. Two arcs enter this vertex: (2,3) and (6,3). This gives four possible options:

Option 1: All dependencies are not fulfilled. Then \( t_3 = 12 + 12 + 16 = 40 \)
Option 2: All dependencies are fulfilled. In this case, we obtain \( t_3 = 12 + \max(27.18) = 39 \)
Option 3: Dependence (2,3) is not satisfied, and dependence (6,3) is satisfied. This gives the following value \( t_3 = 12 + 12 + 18 = 42 \)
Option 4: Dependence (6,3) is not satisfied, and dependence (2,3) is satisfied. Then \( t_3 = 12 + 27 + 16 = 55 \)

New index for vertex 3 is \( \lambda_3 = \min(40,39,42,55) = 39 \).

Therefore, the vertex index has not changed.

Consider vertex 5. Three arcs enter this vertex: (2,5), (4,5), (6,5). This leads to the need to consider eight possible options of implementation the recommended dependencies.

Option 1: All dependencies are not fulfilled. Then \( t_5 = 17 + 17 + 15 + 14 = 63 \)
Option 2: All dependencies are fulfilled. In this case, we obtain \( t_5 = 17 + \max(27.18) = 44 \)
Option 3: Dependence (2,5) is satisfied, but the rest are not. Then \( t_5 = 17 + 27 + 15 + 14 = 73 \)
Option 4: Dependence (4,5) is satisfied, but the rest are not. Then \( t_5 = 17 + 17 + 25 + 14 = 73 \)
Option 5: Dependence (6,5) is satisfied, but the rest are not. In this case, we have: \( t_5 = 17 + 17 + 15 + 18 = 67 \)
Option 6: Dependencies (2,5) and (4,5) are satisfied, but the rest are not. Then \( t_5 = 17 + \max(27.25) + 14 = 58 \)
Option 7: Dependencies (2,5) and (6,5) are satisfied, but the rest are not. In this case, we get: \( t_5 = 17 + \max(27,18) + 15 = 59 \)
Option 8: Dependencies (4,5) and (6,5) are satisfied, but the rest are not. This gives: \( t_5 = 17 + \max(25,18) + 17 = 59 \)

As a result, the new index of vertex 5 will be determined by the relation

\[ \lambda_5 = \min(63,44,73,73,67,58,59,59) = 44 \]

Similarly, the indices of the vertices 6 and 7 are found.

\[ \lambda_6 = 18 \quad \lambda_7 = \min(15 + 27.15 + 27 + 14,15 + 13 + 18.15 + 13 + 14) = 42 \]

Make an adjustment of the vertex indices of the network in the same order, which means take the third step.

3. Consider the vertex 1. The new index of the vertex is \( \lambda_1 = 11 \). Vertex 2 includes only one job. Therefore, the vertex index is determined from the relation

\[ \lambda_2 = \min(\tau_2 + d_{12},\tau_2 + \lambda_1) = \min(16 + 12,16 + 11) = 27 \]

Thus, the vertex index has not changed.

Define the index of the vertex 3. Two arcs enter this vertex: (2,3) and (6,3). This gives you four possible options.

Option 1: All dependencies are not fulfilled. Then \( t_3 = 12 + 12 + 16 = 40 \)
Option 2: All dependencies are fulfilled. In this case, we obtain \( t_3 = 12 + \max(27.18) = 39 \)
Option 3: Dependence (2,3) is not satisfied, and dependence (6,3) is satisfied. This gives the following value \( t_3 = 12 + 12 + 18 = 42 \)
Option 4: Dependence (6,3) is not satisfied, and dependence (2,3) is satisfied. Then \( t_3 = 12 + 27 + 16 = 55 \)

New index for vertex 3 is \( \lambda_3 = \min(40,39,42,55) = 39 \).

Therefore, the vertex index has not changed.

Consider vertex 5. Three arcs enter this vertex: (2,5), (4,5), (6,5). This leads to the need to consider eight possible options of implementation the recommended dependencies.

Option 1: All dependencies are not fulfilled. Then \( t_5 = 17 + 17 + 15 + 14 = 63 \)
Option 2: All dependencies are fulfilled. In this case, we obtain \( t_5 = 17 + \max(27.25,18) = 44 \).
Option 3: Dependence (2.5) is satisfied, but the rest are not. Then $t_5 = 17 + 27 + 15 + 14 = 73$.

Option 4: Dependence (4.5) is satisfied, but the rest are not. Then $t_5 = 17 + 17 + 25 + 14 = 73$.

Option 5: Dependence (6.5) is satisfied, but the rest are not. In this case, we have: $t_5 = 17 + 17 + 15 + 18 = 67$.

Option 6: Dependencies (2.5) and (4.5) are satisfied, but the rest are not. Then $t_5 = 17 + \max(27,25) + 14 = 58$.

Option 7: Dependencies (2.5) and (6.5) are satisfied, but the rest are not. In this case, we get: $t_5 = 17 + \max(27,18) + 15 = 59$.

Option 8: Dependencies (4.5) and (6.5) are satisfied, but the rest are not. This gives: $t_5 = 17 + \max(25,18) + 17 = 59$.

As a result, the new index of vertex 5 will be determined by the relation: $\lambda_5 = \min(63,44,73,67,58,59,59) = 44$.

Similarly, the indices of the vertices 6 and 7 are found.

$\lambda_6 = 18 \quad \lambda_7 = \min(15 + 27.15 + 27 + 14.15 + 13 + 18.15 + 13 + 14) = 42$.

Note that the vertex indices of the network under consideration have not changed which indicates that the iterative solution procedure is complete. By removing dependencies that are broken, we get the network diagram shown in figure 2.

![Network Diagram](image)

**Figure 2. Optimized network graphic.**

The formation of optimal resource support for the construction of an object is associated with the correct decomposition of construction work within each stage since excessive detail does not lead to a significant change in the result. However, aggregation of work within each stage without taking into account their specifics and allocation to specialized flows can lead to a violation of the rhythmic and
uninterrupted resource provision. The research performed earlier is based on the proposed typed decomposition of construction works during the construction of construction objects [13,14].

4. Conclusion
Such a solution is an optimal interpretation of the production situation, according to which it is assumed that the work at the facilities 2, 4 and 6 will be executed in parallel. It turns out that in order to take advantage of the results obtained, it is necessary to have the technical ability to carry out work at three sites at the same time, for this it is necessary to have the appropriate personnel, technical and material support in appropriate volumes, which will make it possible to implement the work in parallel [15-18].

Using the proposed models of organisational and technological design of constructional production has significantly reduced the duration of construction.

Practical implementation of the proposed models of organisational and technological design of constructional production in a specific building organisation allows us to form the optimal sequence of construction and installation works during the construction of a facility complex [18-20].

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