Information modeling of the construction process (the case study of the construction of a civil building pit)

Vadim Kabanov

1Moscow State University of Civil Engineering, Moscow, Russian Federation
E-mail: kabanovvn@yandex.ru

Abstract. The paper studies approaches to information modeling of construction processes. The technology of earthworks production is fully mechanized. This feature simplifies construction information modeling procedures. As an example, the construction of a civil building pit is considered. The purpose of the work: to develop a sequence of formation and selection of technological solutions with a minimum cost. Combinatorics and numerical methods were applied. The quantitative values of the source data (productivity and cost) are set by the standards of the Russian Federation. The cost and duration of work were used as the selection criteria. The values of the source data and criteria are given in relative units (relative to the minimum value in the array of source and calculated data). As a result of the research, we obtained sets of machines (excavator and dump trucks) with a minimum cost. A graphic image of the duration and cost for each technological solution of earthworks production, which can be formed using the Russian estimation standards, is obtained.

Key words: earthworks, ditch, excavator, dump truck, duration, cost.

1 Introduction

The use of information technologies for architectural and structural design is not surprising. Information modeling of construction work production processes is one of the unsolved problems [1, 2]. Information modeling of construction processes (technology-oriented BIM technologies [3]) should provide a link with construction management processes (for example, compatibility of BIM and CDM technologies [4]). The cost of implementing information technologies should be covered by the economic effect of using BIM technologies [5].

Information models of technological processes of construction are considered as the result of interaction of participants in the investment process [6] or as the interaction of material, technical, labor and financial resources. To describe the interaction of resources in construction, use:
- decomposition method [7];
- multidimensional modeling [8];
- nomograms [9] and multi-criteria evaluation [10] for choosing the best solution;
- mathematical modeling [11], including neural networks [12], the Monte Carlo method [13], the Bayesian model and Markov chains [14].

The author considers the main result of information modeling of construction processes to be the calculation of the duration and cost of work. The example of pit construction is not chosen by chance. Modern production technology of excavation virtually eliminates manual labor. The technology of soil development by an excavator consists of a leading (excavator operation) and auxiliary (soil transportation by dump trucks) processes. This technology can easily be represented as an information model.
A visual representation of the information model of the construction process is a graph (network or Gantt diagram) of work production. Plans for the consumption of material, labor, and financial resources are formed depending on the schedule of construction and installation work. The main quantitative indicators of the work schedule must have a high degree of reliability.

To plot the construction schedule for a civil building pit, the duration of the main machine (excavator) should be taken into consideration. To ensure continuous operation of the excavator, the number of auxiliary machines (dump trucks) is determined. This approach simplifies the process of developing an information model of the construction process in comparison with the latest research results. For example, it is proposed to use video surveillance [15], adaptive control algorithm EMFAC-TD [16], Newton - Euler method [17], laser scanners [18], optimal calculation of the digging trajectory [19], remote control [20] in the work on modeling the excavator operation. All these works are intended for specific brands of excavators. The proposed approaches cannot be used to select an excavator based on the criteria of cost and duration of work.

The proposed estimation of preferences by data fusion methods and the MULTIMOORA method [21] can be applied at the stage of acquisition of the excavator into ownership. It is not possible to use the proposed approach when estimating the cost of construction work. The AHP method is more suitable for estimating the cost of an excavator [22].

In Russia, the estimated cost of operating an excavator is set by estimated standards. State budget standards significantly simplify the formation of initial data for information modeling of construction processes. The use of standards in calculating the duration and cost of construction work leads to the use of elementary algebra methods.

Published results of variant design of earthworks production processes could not be found. The construction of a scraper selection model [11] cannot be applied to excavators. This conclusion is based on a comparison of technological operations in the development of soil with an excavator and scraper.

Determining the number of dump trucks to service the excavator is a simple task. This may explain the lack of publications on this topic. For example, to complicate the problem of determining the number of dump trucks, the production of earthworks in high-density urban development [23] should be considered. Another example is the formation of a fleet of dump trucks for working in a quarry [24].

These publications do not describe the procedures for selecting a set of machines (excavators and dump trucks) for the construction of ditches in civil buildings. On this basis, the purpose of the work is formulated: the development of design procedures for sets of machines (excavators and dump trucks) for the construction of pits of civil buildings. To achieve this goal, the following tasks have been completed:

- initial data for the design of technological processes for the production of earthworks is systematized;
- a mathematical apparatus for calculating the duration and cost of each option for the construction of a pit of civil buildings is obtained;
- options with the lowest cost and duration of construction of the pit for civil buildings are identified;
- the dependence of the cost on the duration of construction of the pit is obtained.

2 Materials and methods

Combinatorics methods were used to form variants of construction of a civil building pit. This method of mathematics provides the formation and consideration of all feasible options for the production of earthworks. Using this mathematical method, the initial data for conducting a numerical experiment are formed. Numerical experiment is used for many fields of science, for example, for earthworks-modeling of soil compaction [25].

The initial data is formed from the values of estimated standards for Russia. Conditions for the construction of a civil building pit are described by the properties of the soil (volume weight, internal friction angle) and the distance of soil transportation (this value was considered as a variable).
For the criteria for evaluating sets of machines, the values of the duration and cost of earthworks were used. The relationship between the criteria was determined by standard methods of mathematical statistics (regression and correlation analysis) with a confidence score based on the Fisher and student criteria.

In contrast to the virtual representation of earthmoving equipment [26], the results of the numerical experiment obtained the main technical characteristics of earthmoving equipment, which provides a minimum cost or minimum duration of construction of a pit for a civil building.

When calculating the cost of work, relative units are used. The calculated value of relative units is obtained by dividing the cost of operating a construction machine by the value of the minimum cost. To get the value of the minimum cost, you need all the machines that can be used to perform the work. The use of relative units of value removes the question of whether they need to be indexed. In this work, the values given in the Russian estimation standards were applied.

### 3 Results

For the formation and evaluation of options for earthmoving equipment for the construction of the pit, it is necessary to establish:

- productivity and cost of operation of the excavator;
- load capacity and cost of operation of a dump truck.

The Russian estimation standards significantly simplify the search and justification of the reliability of the source data. Quantitative values for calculating the duration and cost of earthworks are shown in table 1 (for excavators) and table 2 (for dump trucks).

#### Table 1. Characteristics of excavators for multi-variant design of technological processes of earthworks production.

| Resource code | Bucket volume, \(v\), \(\text{m}^3\) | Performance, \(W_e\), \(\text{m}^3/\text{h.}\) | Cost per hour, \(C_e\), \(\text{FEP}\) | Relative unit |
|---------------|--------------------------------|---------------------------------|----------------|---------------|
| 91.01.05-106 (E1) | 0.25 | 01-01-018-04 | 19 | 91.01.05-106 | 1.28 |
| 91.01.05-084 (E2) | 0.40 | 01-01-018-01 | 24 | 91.01.05-084 | 1.00 |
| 91.01.05-085 (E3) | 0.50 | 01-01-019-01 | 30 | 91.01.05-085 | 1.82 |
| 91.01.05-086 (E4) | 0.65 | 01-01-020-01 | 35 | 91.01.05-086 | 2.10 |
| 91.01.05-087 (E5) | 1.00 | 01-01-021-01 | 45 | 91.01.05-087 | 2.24 |

#### Table 2. Characteristics of dump trucks for multi-variant design of technological processes for earthworks production.

| Resource code | Load capacity, \(q\), \(\text{tons}\) | Cost per hour, \(C_e\), \(\text{FEP}\) | Relative unit |
|---------------|--------------------------------|----------------|---------------|
| 91.14.03-001 | 7 | 91.14.03-001 | 1.63 |
| 91.14.03-002 | 10 | 91.14.03-002 | 1.60 |
| 91.14.03-003 | 15 | 91.14.03-003 | 2.07 |
| 91.14.03-004 | 30 | 91.14.03-004 | 3.70 |

1. SEE 81-02-01-2017 State element estimates for construction and special construction work. Collection 1. Earthwork. Approved by the order of the Ministry of construction of Russia from 30.12.2016 N 1038 / PR.

2. Federal estimated prices for the operation of construction vehicles and motor vehicles FEP 81-01-2001, approved by the Order of the Ministry of construction of Russia from 30.12.2016 N 1039 / PR.
Calculation of the duration of construction of a pit for a civil building is performed by the value of the productivity of the excavator:

\[ T = \frac{V}{W_e} \]  

(1)

where \( T \) – is the duration of work, hour.;
- \( V \) – volume of earthworks on the project, m\(^3\);
- \( W_e \) – productivity of the excavator from the gesn tables, m\(^3\) hour.

The cost of work consists of the cost of the excavator and the cost of operating dump trucks:

\[ C = (C_e + nC_d)T \]  

(2)

where \( C \) is the cost of earthworks;
- \( C_e \) – the cost of operating the excavator per unit of time, Rel. ed.;
- \( n \) – number of dump trucks in the mechanized complex, pieces;
- \( C_d \) – the cost of operating a dump truck per unit of time, Rel. ed.;
- \( T \) – duration of work (calculated by Eq. 1), hour.

The calculation of the number of dump trucks (n) depends on the bucket capacity of the excavator and the distance of soil transportation:

\[ n = 1 + \frac{l}{\frac{v}{W_e} + t_u} \]  

(3)

where \( n \) – is the number of dump trucks for continuous operation of the excavator, pieces.;
- \( l \) – distance of soil transportation by car-dump truck, km.;
- \( v \) – the speed of the dump truck is set in Russia: for urban conditions-24 km / h, outside the city-50 km / h);
- \( t_u \) – the duration of unloading the soil by a dump truck (determined by the formula \( t_u = 3 + q \)), hour.;
- \( q \) – load capacity of the dump truck, tons;
- \( W_e \) – excavator capacity m\(^3\) per hour;
- \( \rho \) – soil density, t/m\(^3\);
- \( v \) – the volume of excavator bucket, m\(^3\);

Eq. (3) is obtained as a result of algebraic transformations of analytical expressions that are used to determine the duration of the technological cycle of a dump truck.

Eq. (1-3) are a mathematical device for calculating the duration and cost for each feasible combination of an excavator with dump trucks. Mathematical expressions (Eq. 1-3) can be easily programmed, for example, in the Excel environment. To facilitate programming procedures, a flowchart is provided (figure 1).

According to table 1 and 2 twenty alternative technological solutions can be formed. Each technological solution consists of an excavator and dump trucks. The excavators differ in the volume of the bucket. Dump trucks capacity and quantity (the number of dump trucks is calculated using Eq. 3). The duration of the work depends on the volume of the bucket of the excavator. The cost of each set of mechanization tools depends on the load capacity, the number of dump trucks, and the distance of transportation.

The results of calculating the duration and cost for the option with the minimum and maximum cost are shown in the graph (figure 2). The cost of developing a single volume of soil will depend on the distance of transportation. As a result of a numerical experiment, we were able to find an option with a minimum cost. The composition of the set of vehicles varies depending on the distance of soil transportation.
Source data

| Source data | Performance | Cost per hour |
|-------------|-------------|---------------|
| Excavator   | \( W_e \)   | \( C_e \)     |
| Dump truck  | \( q \)     | \( C_d \)     |

Formation of an organizational structure-technological solution

Calculating duration and cost

The calculation of the duration

\[
T = \frac{V}{W_e}
\]

Determining the number of dump trucks

\[
n = 1 + \frac{l}{v} + \frac{1}{qW_e} \rho v^2
\]

Calculating the cost

\[
C = (C_e + nC_d)T
\]

Ranking and selection procedures based on cost and duration criteria

Table of symbols:

- \( E_1 \) to \( E_5 \): excavators with a bucket volume of 0.25, 0.4, 0.5, 0.65, 1 m³
- \( D_1 \) to \( D_4 \): dump trucks with a load capacity of 7, 10, 15, 30 tons.

Figure 1. The block diagram of formation of organizational and technological solutions of the numerical method (numerical simulation).

When transporting up to 8 km, the minimum cost shows a set of an excavator with a bucket of 0.4 m³ (resource code-91.01.05-084) and a dump truck with a load capacity of 10 tons (resource code – 91.14.03-003).

With a range of soil transportation from 8 to 20 km, the best option consists of an excavator with a bucket of 0.4 m³ (resource code-91.01.05-084) and a dump truck with a load capacity of 15 tons (resource code – 91.14.03-003).

It was not possible to find an adequate dependence of the cost on the duration of work. The dependence is described by a complex multiparametric algebraic function. For example, the cost depends on the distance of soil transportation (figure 2). To do this, it is enough to substitute Eq. (3) instead of \( n \) in Eq. (2). The duration of construction of the pit is inversely proportional to the productivity of the excavator, which depends on the volume of the bucket Eq. (1). A graphical representation of the cost and duration values for all 20 options is shown in figure 3.

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Table of symbols:
A solid line and round dots are the minimum cost of earthworks.
Dotted lines and square dots represent the maximum cost of earthworks

Figure 2. The dependence of the cost of construction of the pit on the distance of soil transportation.

Table of symbols:
E 1-E4 – excavators corresponding to column 1, table 1.

Figure 3. The cost depends on the duration of construction of the pit at a distance of soil transportation l = 10 km.

4 Discussions
Modern methods of information modeling [6-14] are used for a given set of machines (excavator and dump truck). The estimation of the economic efficiency of the excavator [21] cannot be applied when forming a set of machines taking into account the construction conditions. The AHP method [22] does not take into account the joint operation of excavators and dump trucks. It is not correct to use the selection method [11] because the technological process of excavating soil is very different from the work of a scraper. The method of forming a fleet of dump trucks for working in a quarry [24] can not be used when modeling earthworks for the construction of a pit of civil buildings (a small volume of pits). The influence of dense urban development on the speed of dump trucks [23] is taken into account by the standard speed value, which is set in Russia.
As a result of a simple analysis of the cost and duration for all variants of work production, it can be concluded that the minimum duration does not always require maximum funding (vertical corresponding to "E1", figure 3). It can be argued that the minimum cost does not always correspond to the maximum duration.

5 Conclusions
1. A numerical method for solving the problem of multivariate design of construction processes always allows to find an option that corresponds to extreme values of the cost and duration of work.
2. For mechanized earthworks, it is always possible to allocate options with a minimum cost and duration.
3. The use of a numerical method for evaluating all feasible solutions provides high reliability of the calculated values of the duration and cost of excavation. The accuracy of calculations depends only on the reliability of the initial values (productivity and cost of construction equipment).
4. The higher the efficiency of variant design, the more types of construction equipment (for example, excavators and dump trucks) are involved in the calculations.

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