Optimization of the construction project in complex geomechanical conditions

Vasilii Komolov¹, Tatyana Simankina², Konstantin Kuzmin³, Tatyana Kuzmina⁴

¹Saint-Petersburg Mining University, 2, 21st Line, 199106, St Petersburg, Russia
²Peter the Great St. Petersburg Polytechnic University, 29, Polytechnicheskaya, 195251, St. Petersburg, Russia
³Moscow State University of Technology and Management. K. G. Razumovsky (Smolensk branch), Lenin street 77, 215100, Vyazma, Smolensk region, Russia
⁴Moscow State University of Civil Engineering 26, Yaroslavskoye Shosse, Moscow, 129337, Russia

E-mail: talesim@mail.ru

Abstract. The purpose of the study is to optimize the construction project of a residential complex. The paper considers the mechanism for optimizing the construction of a residential building and a quarterly road network. The study was carried out in several stages and includes the breakdown of the complex into specialized types of work, the preparation of matrices of work volumes, the calculation of construction duration, the calculation of methods for organizing work in different order, and the calculation of the estimated cost of objects. The calculation and selection of the work organization method was carried out by the method of continuous use of resources, continuous development of work fronts and the critical path method. Next, statistical modeling of the deviation of the project duration from the planned value was performed in the Microsoft Project software package. The first step was to perform a regression analysis. The second step is a correlation analysis, which allowed us to determine the degree of reliability of the project. The third step is to analyze the effectiveness of the project. In conclusion, a conclusion is made regarding the relevance of the unified estimated standards for this project.

1. Introduction

In our time, an urgent problem for expanding megacities, in particular St. Petersburg, is the issue of rational and economically attractive reconstruction and development of abandoned industrial zones located in the historical center. For many years, the Northern Capital was built up unevenly, industrial blocks were built surrounded by residential areas, cultural and architectural monuments, but today most enterprises are no longer functioning, are in a state of disrepair, and are often not subject to restoration [1, 2].

An excellent example of a solution to this problem is the planned reconstruction of the territory of the military industry plant named after M. I. Kalinin, which was founded in 1869. It is planned to build a modern residential complex "Samotsvety" on the territory of the enterprise, which will not only give a new impetus to development, but also decorate the panorama of the Vasileostrovsky district (Figure 1) [13].
The Samotsvety residential complex consists of four 10-storey buildings constructed using modern brick-and-monolithic technology, which improve the surrounding landscape without violating the General principle of development laid down by Peter I. The facades painted in different colors will enliven it, and the non-standard shape of the buildings will allow them to accommodate 2015 apartments of various sizes and layouts [3-6]. Future residents will be offered small studios, one-, two-, three-room and spacious four-room apartments. The project also includes underground parking for 1,654 cars.

The residential complex consists of 4 buildings:
- Building 1-10 floors, 13 sections, 113 apartments;
- Building 2-10 floors, 13 sections, 310 apartments;
- Building 3 – 10 floors, 11 sections, 153 apartments;
- Building 4-10 floors, 4 sections, 141 apartments;

This article offers a variant of optimization of the construction project of the residential complex "Samotsvety". The study includes a breakdown of complex specialized types of work, drawing up a matrix of quantities, the calculation of the duration of construction, calculation methods of organization of work in different sequence, the calculations of the estimated cost of objects. A qualitative risk analysis of the project was carried out.

2. Methods
Software products like Bentley Systems Inc, Autodesk, SmartPlant 3D are useful for creating a BIM-model. They could also support BIM-technology. During the use of traditional design tools, buildings are usually found in the finished state [2]. At the same time, as a result, one of the main limitations of 3D models is their inability to display the exact state of the progress of construction [3]. In addition, traditional construction planning tools, such as schedules and diagrams, don't facilitate the visualization of the process and require the creation of a mental representation of the construction [4].

The addition of the time attribute to a 3D (x, y, z) environment results in what it is broadly known as 4D (x, y, z, t) environment. This extra feature provides the model with more dynamism in terms of representing the behaviour of the building elements along time, extending in this way its usage for other purposes. [5-6]

The study was conducted in the following sequence.
1. the complex was divided into specialized types of work:
   1) Preparatory work;
   2) Zero cycle;
   3) installation of the frame;
   4) Engineering networks;
5) Finishing works;
6) Landscaping.

Table 1 contains estimated data on the estimated cost of construction.

Table 1. Complex stream - residential complex "Samotsvety».

| Object     | Area, m² | Number of storeys | Cost, thousand rubles |
|------------|----------|-------------------|-----------------------|
| Building 1 | 56 060,68| 11                | 3 462 195,475        |
| Building 2 | 56 479,9 | 13                | 3 488 085,664        |
| Building 3 | 74 264,1 | 12                | 4 586 402,288        |
| Building 4 | 26 757,98| 11                | 1 652 519,329        |
| Total area | 213 562,66|                  | Total cost: 13 189 202,76 |

2. The matrix of quantities is described in (table 2) [7].

Table 2. Matrix of work volumes.

| Labor per 1 worker | Preparator y work 3% | Zero cycle 10% | Installation of the frame 36% | Engineering networks 15% | Finishing works 30% | Landscaping 6% | Engineering networks 15% |
|--------------------|----------------------|----------------|-----------------------------|------------------------|-------------------|----------------|------------------------|
| RUB / shift        | 1600                 | 1900           | 3200                        | 2300                   | 1000              | 1200          |
| thousand rubles    |                      |                |                              |                        |                   |               |
| person-shift       | 103 865              | 346 219        | 1 246 390                   | 519 329                | 1 038 658        | 207 731       |
| Building 1         |                      |                |                              |                        |                   |               |
|                      | 64 916               | 182 220        | 389 497                     | 225 795                | 1 038 658        | 173 109       |
|                      | 104 642              | 348 808        | 1 255 710                   | 523 212                | 1 046 425        | 209 285       |
|                      | 65 40                | 183 583        | 39 240                      | 227 483                | 1 046 425        | 174 404       |
| Building 2          |                      |                |                              |                        |                   |               |
|                      | 137 592              | 458 640        | 1 651 104                   | 687 960                | 1 375 920        | 275 184       |
|                      | 85 995               | 241 389        | 515 970                     | 299 113                | 1 375 920        | 229 320       |
|                      | 49 575               | 165 251        | 594 906                     | 247 877                | 495 755          | 99 151        |
| Building 3          |                      |                |                              |                        |                   |               |
|                      | 30 984               | 86 974         | 185 908                     | 107 772                | 495 755          | 82 625        |

3. The calculation of the duration of capital construction based on the cost in accordance with [3].

Where: \( T = A_1 \times C^{A_2} \), \( A_1 = 9.96, A_2 = 0.27, k=203.42 \) – correction coefficient from 13.02.2017 no. KC / 2017-02tii "on indices of changes in the estimated cost of construction for Federal districts and regions of the Russian Federation for FEBRUARY 2017" VAT=1.18

The resulting calculation data is presented in table 3.
4. Determining the optimal method of organizing work based on the criterion of minimizing the duration.

Based on the data in Table 3, a duration matrix is obtained (Table 4).

**Table 5. Duration Matrix calculated using the continuous resource use method.**

| Preparatory work | Zero cycle | Installation of the frame | Engineering networks | Finishing works/Landscaping | Engineering networks | T. days |
|------------------|------------|---------------------------|----------------------|-----------------------------|----------------------|---------|
| Building 1       | 15         | 50                        | 178                  | 74                          | 148                  | 30      |
|                  | 0          | 15                        | 65                   | 65                          | 243                  | 1090    |
| Building 2       | 15         | 50                        | 178                  | 74                          | 148                  | 30      |
|                  | 15         | 30                        | 65                   | 115                         | 243                  | 901     |
| Building 3       | 16         | 54                        | 192                  | 80                          | 160                  | 1120    |
|                  | 30         | 46                        | 613                  | 679                         | 759                  | 1182    |
| Building 4       | 13         | 41                        | 146                  | 61                          | 121                  | 1206    |
|                  | 46         | 59                        | 613                  | 759                         | 820                  | 1182    |
Table 6. Duration Matrix calculated by the method of continuous development of work fronts.

|        | Preparatory work | Zero cycle | Installation of the frame | Engineering networks | Finishing works/Landscaping | Engineering networks |
|--------|------------------|-------------|---------------------------|----------------------|-----------------------------|---------------------|
| Building 1 |
| 15     | 15               | 50          | 178                       | 74                   | 148                         | 30                  |
| 0      | 15               | 50          | 65                        | 243                  | 243                         | 317                 |
| 15     | 178              | 193         | 243                       | 193                  | 231                         | 178                 |
| Building 2 |
| 0      | 15               | 50          | 178                       | 74                   | 148                         | 30                  |
| 15     | 178              | 193         | 243                       | 193                  | 231                         | 178                 |
| 16     | 54               | 192         | 243                       | 193                  | 231                         | 178                 |
| Building 3 |
| 13     | 16               | 54          | 192                       | 243                  | 243                         | 317                 |
| 351    | 16               | 54          | 192                       | 243                  | 243                         | 317                 |
| Building 4 |
| 13     | 41               | 146         | 61                        | 792                  | 792                         | 792                 |
| 592    | 605              | 646         | 646                       | 792                  | 792                         | 792                 |

Table 7. The matrix of the duration calculated by the critical path method.

|        | Preparatory work | Zero cycle | Installation of the frame | Engineering networks | Finishing works/Landscaping | Engineering networks |
|--------|------------------|-------------|---------------------------|----------------------|-----------------------------|---------------------|
| Building 1 |
| 15     | 15               | 50          | 178                       | 74                   | 148                         | 30                  |
| 0      | 15               | 50          | 65                        | 243                  | 243                         | 317                 |
| 15     | 178              | 193         | 243                       | 193                  | 231                         | 178                 |
| Building 2 |
| 0      | 15               | 50          | 178                       | 74                   | 148                         | 30                  |
| 15     | 178              | 193         | 243                       | 193                  | 231                         | 178                 |
| 16     | 54               | 192         | 243                       | 193                  | 231                         | 178                 |
| Building 3 |
| 13     | 16               | 54          | 192                       | 243                  | 243                         | 317                 |
| 30     | 115              | 192         | 231                       | 243                  | 243                         | 317                 |
| Building 4 |
| 13     | 41               | 146         | 61                        | 792                  | 792                         | 792                 |
| 46     | 169              | 613         | 613                       | 759                  | 759                         | 759                 |

The results of calculations showed that the minimum duration was obtained by calculating the critical path method (hereinafter MCP). The total duration of the project’s capital construction was 998 days.

5. The estimated cost of construction of four buildings of the residential complex "Samotsvety" was calculated. It showed that the total cost of construction was 6.1 billion rubles.

As a result of the calculation, it was found that the estimated norms and prices are not perfect in the case of capital construction in complex geological conditions and conditions of dense urban development and distort the real cost of construction of the object [6-9]. Such objects must be calculated using specially developed individual estimated standards that take into account all the features of construction.

3. Results
In the Microsoft Project software package, statistical modeling of the deviation of the project duration from the planned value was performed. The first step was to perform regression analysis, a method of statistical data processing that allows you to measure the relationship between one or more causes (factor features) and the effect (result feature). The generator was operated under the condition that the base cost is less than zero, and the percentage of delay is 15% of the base duration.

Unexpected deviations gave a spread over the statistical duration from 428.45 to 927.11, taking into account the yield period (Figure 2). Based on the basic plan of the method for determining the probabilistic values of durations, taking into account the acceleration or delays in the project, depending on unforeseen factors, 30 variations of work durations were obtained, and monetary damages were determined for each of these options.
Based on the basic plan, the method of determining the probabilistic values of the duration, taking into account the acceleration or delay in the project, depending on unforeseen factors, 30 variants of the duration of work were obtained, and the monetary damage for each of these options was determined. Monetary damages were divided into 7 intervals with a step of 20,000,000, and static duration values were divided into 6 intervals with a step of 100 days (Figure 3).

Figure 3. Distribution of monetary damage values by intervals.

Statistical modeling is performed, which consists in constructing and evaluating the adequacy of the probabilistic model of the capital construction process. Statistical construction durations (days) are taken for $x_i$, the number of $y_i$ measurements in which the values of $x_i$ are observed and the relative frequencies of $t$ are determined.

The following values are obtained:
- mathematical expectation of a random variable $M(x)=626.66$ days
- variance of a random variable $D(x)=14455.56$ days.
- Standard deviation $\sigma=\sqrt{120.23}$, shows the dispersion of values of a random variable (duration) relative to its mathematical expectation.

A correlation analysis was performed and a regression equation was compiled. The purpose of correlation analysis is to determine the strength of the relationship between random variables—duration and loss, which characterize the construction process. We accept statistical duration (days) for $X$, and losses (rubles) for $Y$.

The following values are defined:
- Sample averages:
  $\bar{x} = 624.6$ days and $\bar{y} = 60730903.07$ days
- Sample variances:
  $S_x^2 = 13412.64; S_y^2 = 1190635792751810$
- Standard deviation:
  $S_x = 115.81; S_y = 34505590.75$

As a result, the value of the correlation coefficient is obtained $r_{xy}=0.82$. This value shows that the relationship between statistical duration and loss is high. On a scale of Chedoke value falls within the interval from 0.7 to 0.9. ($0.7 < r_{xy} < 0.9$).
A regression equation has been compiled: \( y = 243114.34 \cdot x + (-91130063.67) \).

The coefficient \( a = 243114.34 \) shows the average change in the effective indicator (in rubles) with an increase or decrease in the value of factor \( x \) (duration) per unit of measurement. It turns out that with an increase of 1 unit, \( y \) increases by an average of 243114.34.

The coefficient \( b = -91130063.67 \) formally shows the predicted level of \( y \), but only if \( x = 0 \) is close to the sample values.

The relationship between \( y \) and \( x \) determines the sign of the regression coefficient \( b \). If \( b > 0 \) is a direct link, \( b < 0 \) is a feedback link. In this project, the relationship is reversed.

Figure 4 shows a value distribution graph showing that the points are distributed around the reference value.

The correlation analysis and the obtained correlation value allow us to conclude that the degree of tightness of the connection between days and monetary damages is high, which indicates the reliability of the capital construction project of the Samotsvet complex in the historical center of the city in complex geological conditions.

7. The project effectiveness analysis was performed.

Figure 5 shows the cash flow chart, which shows that the main costs appear at the first stages of the project, then there is a reduction in costs. This dynamic is due to the purpose of the project: capital construction in difficult conditions involves large investments of funds at the first stages.

Analysis of the cash flow statement showed that the cost period begins in the 1st quarter of 2017 and ends in the 4th quarter of 2018, the total cost is 5,054,197,945 rubles.

To analyze the effectiveness of the project, you need to set a discount rate - this is the interest rate used to convert future revenue streams into a single amount of current value. It consists of a risk-free
rate that is equal to the rate of the Central Bank of the Russian Federation (6.77%) and a risk-based part.

Among the risks that affect the setting of the discount rate, you can identify: - the risk of default; - the financial condition of the company; - industry affiliation (risks inherent in the construction industry); - the degree to which the company's activities are subject to inflation and exchange rates - country risk.

Taking into account the above factors, the discount rate in this project is assumed to be equal to E=10%.

After calculating the performance indicators, the following results were obtained: NPV =12,099,279,372. 89; PI=2.24 >1; IRR =19.76%; PBP=2.18 years.

A positive value of net discounted income, an index of profitability greater than one, a value of the internal rate of return exceeding the discount rate by 9.76%, and a short payback period allow us to conclude that investment in the capital construction project of a residential complex is effective "Samotsvety" is located in the historical part of Saint Petersburg.

4. Conclusions

Analysis of the efficiency of construction of the residential complex "Samotsvety" showed that the developed development project is effective and attractive for investment.

However, it was concluded that the estimated norms and prices are imperfect in the case of a planned reconstruction of industrial territories with the further construction of a residential complex, they distort the real estimate of the cost of the project. Such objects must be calculated using specially developed individual budget standards that take into account all the features and degree of complexity and uniqueness of this project.

References

[1] Romanovich M, Vilinskaya A 2016 Web of Conferences Ser. International scientific conference Week of science in SPBU-civil engineering, SPbWOSCE 2015 01052
[2] 1991 Calculation indicators for determining the duration of construction. Calculation indicators (graphs) for determining the duration of construction of enterprises, buildings and structures (M.: APPL Association "Stroynormirovanie" TSNIOMTP gosstroya SSSR) p 80
[3] Braila N, Barinov S 2017 IOP Conference Series: Earth and Environmental Science 90(1) doi:10.1088/1755-1315/90/1/012219;
[4] Khazieva L, Braila N, Staritcyna A 2017 Magazine of Civil Engineering 6 70 doi: 10.18720/MCE.74.7
[5] Vakhrusheva S, Martynenko E, Braila N, Kisel T 2017 IOP Conference Series: Earth and Environmental Science 90(1) doi:10.1088/1755-1315/90/1/012030
[6] Melović B, Mitrović S, Zhuravlev A, Braila N 2016 MATEC Web of Conferences 86 DOI: 10.1051/matecconf/20168605029
[7] Ardzinov V D 2006 Pricing and cost estimating in construction (Saint Petersburg: Piter) p 240
[8] Nguyen T T, Karasev M A, Vilner M A 2020 Lecture Notes in Civil Engineering 383-388
[9] Demenkov P A, Belakov N A, Ochkurov V I 2016 International Journal of Applied Engineering Research 11(21) 10698 ISSN 0973-4562
[10] Khaibullina K S, Sagirova I R, Sandyga M S 2020 Periódico Tchê Química 17(34) ISSN 2179-0302
[11] Maksarov V V, Keksin A I, Filipenko I A 2020 Key Engineering Materials 836 71
[12] Goldobina L A, Demenkov P A 2019 Journal of Mining Institute 239 583
[13] Demenkov P A, Trushko O V, Komolov V V 2019 Izvestiya Tula state University, earth science 2 300