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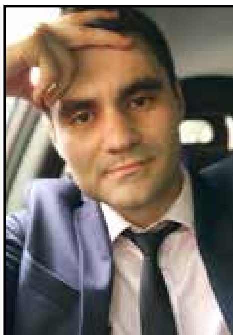
Efficiency of Planning the Reconstruction of Railway Facilities Using BIM



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ABSTRACT

The development of industrial enterprises and the growth of the logistics market require a new approach of planning the construction and reconstruction of railway infrastructure facilities.

For the efficient functioning of the transport system, it is necessary to balance the infrastructure capacity and the needs of the freight and passenger transport market. Uneven growth in traffic volumes applies an extra load to the railway network. Reconstruction of an infrastructure facility can be considered as a phased increase in the production capacity of an enterprise, considering the indicators of net present value (NPV) and labour costs based on the dynamic programming method.

The article analyses the issue of using BIM-modelling in planning the reconstruction of railway infrastructure facilities. The concept of a digital railway is considered as an example since digital railway projects are the main drivers of the economy of many countries.

Reconstruction of railways in the context of a lack of information about the existing infrastructure facility is an urgent problem for the design organization when conducting surveys in difficult conditions, agreeing on the list of engineering networks and linking the infrastructure of the design object with external asset holders.

The objective of the article is to consider the dominant role of BIM for the infrastructure reconstruction projects using a method for economic assessment of investment options based on dynamic programming according to NPV indicator.

Keywords: *reconstruction, transport infrastructure, net present value, labour costs, dynamic programming, BIM-modelling, customer, design, expertise, construction, life cycle management of the reconstruction object.*

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Background.

The railway transport infrastructure can be divided into two groups. The first group integrates main, station and access railway lines, including artificial structures (culverts, drainage ditches, chutes, bridges, retaining walls, etc.). The second group comprises all other objects of railway transport (depots, railway stations, traction substations, equipment, etc.), which represent the infrastructure of the railway track [1].

In Russia, according to Federal Law No. 18-FZ «Charter of Railway Transport of the Russian Federation», the infrastructure of railway transport includes public railway tracks, railway stations, power supply devices, communication networks, signalling, centralization and blocking systems, information systems, traffic control system, and other buildings, structures, structures, devices, and equipment that ensure functioning of the infrastructure [2].

The *objective* of the study is to analyse the effectiveness of the use of BIM-technology in design for the feasibility study of construction options in terms of net present value (NPV) using the methods of dynamic programming and calculation of net present value.

1. Economic assessment of the investment and construction process

The need to increase the capacity of railway transport facilities is due to the growth in the volume of freight and passenger transportation. The economic efficiency of reconstruction of such facilities should be considered with their step-by-step strengthening using both technical and economic indicators. The indicator of net present value (NPV) [1, pp. 125–128] can be used as an economic indicator. For objects owned by private enterprises, such as joint stock companies (JSC), limited liability companies (LLC), NPV indicator during reconstruction of objects is expressed by the relationship [1]:

$$\mathrm{NPV}=\sum_{t=1}^{H_r}\frac{\left(I_t-C_t-HX_t\right)}{\left(1+D\right)^t}-\sum_{t=1}^{H_r}\frac{IC_t}{\left(1+D\right)^t}, \quad (1)$$

where I_t – income (proceeds) of the enterprise in the t-th year;

C_t – costs of the enterprise in the t-th year;

TX_t – taxes in the t-th year;

IC_t – investment costs in the t-th year;

D – discount rate;

H_r – calculation horizon.

When determining NPV according to formula (1) it is necessary to consider property taxes (TX_i) and income taxes (TX_p):

$$TX_t=TX_{it}+TX_{pt}, \quad (2)$$

$$TX_i=\alpha VP_{\mathrm{res}}, \quad (3)$$

where α – property income tax rate;

VP_{res} – residual value of the property.

$$VP_{\mathrm{res}}=VP_{\mathrm{init}}-\Sigma A, \quad (4)$$

where VP_{init} – initial value of the property;

ΣA – accrued depreciation.

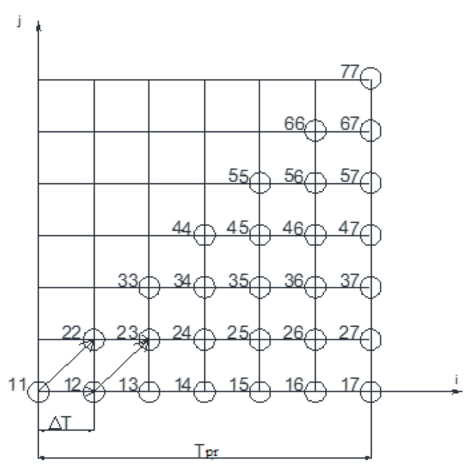
Income tax in the t-th year:

$$TX_{pt}=\beta(I_t-C_t-TX_{it}), \quad (5)$$

where β – interest rate of income tax;

N_{it} – property tax in the t-th year.

The stages of reconstruction of railway infrastructure facilities with an increase in freight traffic and the volume of passenger transportation can be presented in the form of the following diagram (Pic. 1).



Pic. 1. Scheme for selecting possible options for the sequence of reconstruction [compiled by D. A. Boyarinov].

In this diagram, the ordinate axis is j-power of the reconstruction object, the abscissa axis is i-time.

The state of the object is shown as a circle with the number «i–j», for example, «2–4», where: «2» is the second stage of reconstruction of the object, «4» is the state of the object, characterized by its capacity.

The capacity of the object can be expressed, for example, in the number of cars repaired per year, the amount of equipment for locomotives, or in the form of the annual output of the enterprise.

The predicted period H_{pr} is divided into stages, the duration of which ΔT is assigned depending on terms of reconstruction of objects.

According to the property of Pascal's triangle, each number in the triangle is equal to the number of ways to get to it from the vertex, moving either horizontally to the right or diagonally upward. The sum of the *i*-th row of Pascal's triangle is $S_i = 2^i$. Taking the state «1–1» as the zero row, we get that the number of all paths is: $2^6 = 64$.

To reduce the number of analysed variants of object reconstruction, a dynamic programming method based on the Bellman's optimality principle can be used, according to which the original multidimensional problem is replaced by a sequence of problems of a lower dimension. Whatever the state of the system before the next step is, it is necessary to choose the control at this step so that the value (NPV) at this step, together with the optimal income at all subsequent steps, should be the maximum. This makes it possible to reduce the number of analysed options and the time for searching a rational option from an economic point of view during the stage-by-stage reconstruction of railway infrastructure facilities.

Let us consider local variants of object reconstruction from the state «1–1» to the state «2–3» (Pic. 1). There may be 2 local options:

1) from «1–1» to «2–2» (reconstruction is underway) and the transition to «2–3» (operation) is underway;

or

2) from «1–1» to «1–2» (operation), then the reconstruction is carried out during the transition from the state «1–2» to the state «2–3».

Those local variants have a common starting point «1–1» and a common final state «2–3». The continuation of reconstruction options from the state «2–3» will be the same for all analysed local options. Therefore, according to the selected NPV indicator, we can choose one of two considered local options and, in the future, continue analysis only considering that selected option. In this case, the number of options for reconstruction of railway infrastructure facilities required for analysis can be expressed by the following definition:

$$A_i^j = \frac{i!}{(i-j)!}.$$

With $i = 6, j = 2$ we get 5:

$$A_i^j = \frac{6!}{(6-2)!} = 30 < S_i = 64.$$

The number of analysed options to identify an effective solution is reduced by:

$\frac{S_i}{S_i^j} = \frac{64}{30} = 2{,}1$ times.

Comparison of local options is carried out by maximizing NPV. In the first option NPV is determined according to the dependence:

$$NPV_1 = \sum_{t=T_0}^{H_r} \frac{\left(\Delta I_{t_1} - \Delta C_{t_1} - \Delta TX_{t_1}\right)}{(1+D)^t} - K_{r_1} + \sum_{t=H_r}^{t=2\Delta T} \frac{\left(\Delta I_{t_2} - \Delta C_{t_2} - \Delta TX_{t_2}\right)}{(1+D)^t}. \quad (6)$$

For the second local NPV:

$$NPV_2 = \sum_{t=T_0}^{t=\Delta T+H_r} \frac{\left(\Delta I_{t_2} - \Delta C_{t_2} - \Delta TX_{t_2}\right)}{(1+D)^t} - \frac{IC_{r_2}}{(1+D)^{\Delta T}} + \sum_{t=\Delta T+H_r}^{t=2\Delta T} \frac{\left(\Delta I_{t_2} - \Delta C_{t_2} - \Delta TX_{t_2}\right)}{(1+D)^t}, \quad (7)$$

where in these dependencies:

ΔI_{t1}, (ΔI_{t1}) is an increase in the enterprise's income after the analysed stage of reconstruction of the object according to the first local option (according to the second) in the *t*-th year;

ΔC_{t1}, (ΔC_{t2}) is an increase in costs in the *t*-th year after reconstruction, due to an increase in the volume of work according to the first local option (according to the second);

ΔTX_{t1}, (ΔTX_{t2}) are changes in taxes after this stage of reconstruction of the object;

H_r is period of reconstruction of the object;

IC_{r1}, (IC_{r2}) –are costs of reconstruction as per options.

A rational version of reconstruction of the object will be found during the transition to the final state of the object «*i*–*j*».

To increase reliability of choosing a rational option for the phased reconstruction of an object, it is advisable to check the selected option according to the criterion of minimizing labour costs. In this case, the criterion for selection of local options when using dynamic programming is the minimum of labour costs during reconstruction and operation of the object [7].

Total labour costs in case of reconstruction and operation of the object are determined according to the following dependence:

– for the first one among above considered local options:

$$T_1 = \sum_{t=0}^{T_r} \frac{T_{t_1}}{(1+E_T)^t} + T_{r_1} + \sum_{t=T_r}^{t=2\Delta T} \frac{T_{t_1}}{(1+E_T)^t}; \quad (8)$$

– for the second local option:

$$T_2 = \sum_{t=0}^{t=\Delta T+T_r} \frac{T_{t_2}}{(1+E_T)^t} + \frac{T_{r_2}}{(1+E_T)^{\Delta T}} + \sum_{t=\Delta T+T_r}^{t=2\Delta T} \frac{T_{t_2}}{(1+E_T)^t}, \quad (9)$$

where T_1, T_2 are total labour costs as per the first and the second options;

T_{t1}, T_{t2} are labour costs when operating objects as per the first and the second local options;

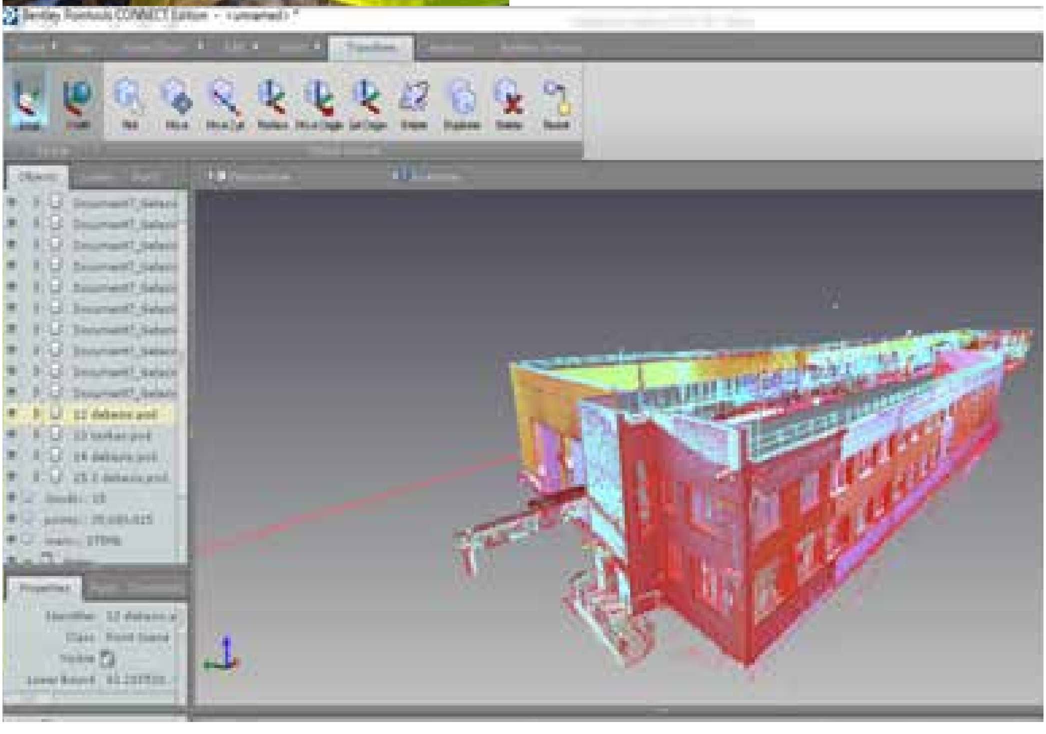
T_{r1}, T_{r2} are labour costs when reconstructing the object;

E_T is labour cost discount factor as determined in accordance with the change in wages over time.

If the selected option according to the *max NPV* criterion coincides with *min T* criterion, then this option is accepted for implementation. Otherwise, additional analysis is required while giving preference to *max NPV* indicator. When developing options for construction (reconstruction) of infrastructure objects, it is often necessary to make changes to design and estimate documentation.

2. Digital railway concept

When implementing infrastructure projects for railway transport, automatic programming software systems based on Building Information Modelling (BIM) technology should be used. BIM aims to make construction projects more cost-effective, sustainable, and punctual [5]. Some researchers even talk about the BIM model, adding a lifecycle object management dimension, but this requires a clear connection with business processes [4; 13], agreeing on the list of engineering networks and linking the infrastructure of the design object with external asset holders [e.g., 3]. Digital railway projects are the main drivers of the economy of many countries [6].



Pic. 2. Creation of a 3D information model of the reconstructed object in Bentley software [6].

So, the main goals and objectives of using BIM in construction and reconstruction of railway infrastructure is the analysis of the architectural and urban planning situation, making space-planning decisions, the technical and economic comparison of the options for promising solutions for an investment project at the stage of developing the main design solutions. The integration of geographic information networks and BIM technologies will help make high-quality decisions on business processes [3; 13].

An important step in using BIM in infrastructure reconstruction projects is creation of a 3D point cloud model. Pic. 2 shows a stage of work in Bentley software package, in which a cloud of physical points forming geometric half-spaces and figures are part of the physical building of the depot being reconstructed. This information model combines the results of a terrestrial laser scanner and close-range photogrammetry. Reliable information and project's team work based on BIM methodology ensures efficient procedures and prevents the most significant problems typical of renovation projects, which are implemented in the traditional way and without the use of information modelling and other digital technologies. The integrated use of modern computer tools and BIM is the best solution for reconstruction of infrastructure objects [9–11].

Conclusion. The use of the dynamic programming method together with the use of BIM technology will increase the efficiency of technical and economic assessment of investment projects in terms of net present value (NPV) by reducing design time and drawing up a consolidated estimate (CE), will improve quality of planning and implementation of measures for renewal of railway infrastructure objects, increase the life cycle of an object, reduce the costs of reconstruction, as well as of operation of an object [8]. This approach can be used to optimize reconstruction of other transport facilities.

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