ESTIMATING THE FEASIBILITY OF TUNNELS: THEORETICAL ASPECTS

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ABSTRACT

The article substantiates the motives and significance of construction of new tunnels within strategic development of the network of Russian railways. The classification of railway tunnels based on the purposes of their creation and the types of generated effects is proposed. Approaches to assessment of feasibility of tunnels, which allow the «straightening» of the existing railway communication, improving its quality characteristics and efficiency, are considered. Based on the logical-analytical method, the spectrum of potential effects arising thanks to the construction of such tunnels at both the sectoral and macro levels is determined. Particular attention is focused on the choice of the calculation horizon and the discount rates. It is concluded that the construction of a railway tunnel can be considered expedient even with a long payback period of capital investments (15–20 years) in the case of a significant net discounted effect for the chosen calculation horizon.

Keywords: *railway tunnels, theory, construction, reconstruction, classification, feasibility assessment, discounting, remote effects.*

Background. *The first railway tunnel was built in England on Liverpool–Manchester line in the years 1826–1830, its length was 1190 meters. In 1861, Kovno (now Kaunas) Tunnel (1285 m), one of the first two railways tunnels built in the Russian Empire, was opened for movement at St. Petersburg–Warsaw Railway. At the end of 19th century a large number of tunnels appeared in the Caucasus, Crimea and Siberia. At the beginning of 20th century, there was a «peak» of their construction in the Far East.*

The emergence of this type of artificial structures has opened up fundamentally new opportunities for development of the railway network, growth of speed and reduction in the cost of railways, and has become the basis for creation of a new sub-sector of transport construction – railway tunnel construction. Therefore, in accordance with the classification of innovations in the field of railway transport, proposed in [1], tunnels should be considered as a basic innovation related to the group of disruptive (macro) innovations.

Objective. *The objective of the authors is to consider theoretical aspects of feasibility of tunnels' construction.*

Methods. *The authors use general scientific methods, comparative analysis, mathematical, economical, logical methods.*

Results.

Economic features

Railway tunnels are characterized by extremely high capital intensity and a significant construction time. Both of these factors lead to an increase in losses from «freezing» of capital in the newly constructed facility.

In addition, the considerable duration of tunnel construction postpones the effects of their operation, which means that these effects are relatively reduced taking into account the discounting [5, 6] and worsen the economic parameters of the respective projects.

A significant time horizon for economic evaluation of tunnel construction also leads to an increase in uncertainty and risks associated with unsecured estimated efficiency. An illustrative example is construction of a railway and automobile tunnel under the English Channel, which, after commissioning in the mid-1990s, was unprofitable because of a threefold deviation of the actual volume of rail traffic from the forecast.

At the same time, the construction of railway tunnels is an example of implementation in the industry of devious methods of transport production [8], which, due to lengthening of the production period and increase in capital intensity, lead to an increase in its efficiency. Considering the normative service life of tunnels, which is 100 years long, their construction can be justified in the case of generation of long-term (century-long) socio-economic effects, the presence of which in rail transport is shown in [5].

With this in mind, the construction of railway tunnels requires a system assessment, which must be based on their scientific classification, depending on the purpose of construction and the types of generated effects.

Classification of railway tunnels

Using the logical-analytical method [9], it is possible to propose the following classification of railway tunnels for the purposes of construction and the types of generated effects:

1. Tunnels, making possible the opening of a new railway communication:

a) tunnels through mountain barriers;

b) tunnels through water barriers.

2. Tunnels, which make it possible to straighten the existing railway communication, improve its quality characteristics and increase the efficiency.

Effects from construction of tunnels belonging to the first group, i. e. which are an integral part of larger projects for organization of a new railway route, should be considered in the context of the general economic classification of planned railway lines proposed in [10]. This classification is shown in Table 1.

A line may have signs of two or of all three categories. For example, it can increase the return on private investment, and stimulate social development.

The principal difference between the presented classification and the traditional one is that categorization of lines is performed exclusively on economic grounds, without the use of technical and technological characteristics. Accordingly, this classification covers only the lines that form certain economic and social (ultimately, also economic) effects. Its use, therefore, makes the presence of such effects justifying investments in the construction of railway lines mandatory and «cuts off» the possibility of building economically unjustified lines.

Estimating the effectiveness of construction of tunnels

The efficiency of construction of tunnels belonging to this group is evaluated in the framework of complex projects for a new railway route using standard methods, set out in particular in [11–13]. At the same time, technical and technological features [14] and risks [15] should be taken into account.

If it is necessary to overcome water obstacles (rivers, straits), as a rule, a dilemma arises: to build a tunnel or bridge for this?

From the economic point of view, this issue should be solved using the indicators of comparative economic efficiency [13, pp. 183–185; 16], which allow one to identify the advantages of implementing one variant in comparison with another. At the same time, it is important to take into account the technical aspects of construction of a tunnel or a bridge crossing, which undoubtedly affect the economic characteristics of a particular option, but also have an independent significance.

It is necessary to mention specially the feasibility of constructing tunnels belonging to the second group,

Table 1

Classification of planned railway lines

Category of lines	Source (mechanism) of financing
1) Lines providing increased return on private investment (i. e. forming effects for non-transport business)	Public-Private Partnership
2) Lines accelerating social development and contributing to the value of the human capital of the country (i. e. forming social and macroeconomic effects)	Budgetary funds
3) Lines whose costs are covered with revenue from transportation services (i. e. ensuring efficient management of transport business)	Private investment in the railway industry

that is, enabling the existing railway route to be «straightened», improving its qualitative characteristics, and improving its efficiency (the example is the North-Muya Tunnel at the Baikal-Amur Railway).

The construction of such a tunnel is advisable if the capital investments in its construction are compensated in an acceptable time by the effects generated by the operation of the tunnel.

The following problems occur:

– determination of a full list of arising effects (branch-wise and macroeconomic) and an estimation of a value of each of them;

– determination of the overall calculation horizon, an acceptable payback period for capital investments and the choice of the discount factor to measure the costs and effects that arise during different time periods.

Of course, a full list of effects arising from construction of a railway tunnel and estimation of their values can be obtained only in real conditions with the help of technical and economic calculations. But a typical list of such effects can be formed on the basis of a logical-analytical method.

In general, after building a tunnel that straightens out the existing railway route and improves its quality and economic characteristics, the following effects can occur.

First of all, cheapening of freight transportation by reducing the route of the goods on the direction served by the tunnel, from l_0 to l_1. For cargo owners it can be roughly estimated by the formula:

$\Delta D = d \cdot P \cdot (l_0 - l_1)$,

where d is income rate for carriage of goods per 1 ton•km;

P – volume of freight transportation on this route.

For rail transport, this figure will be a reduction in revenue for transportation. But the operating costs of the industry will also decrease by an amount

$\Delta C = c/c \cdot P \cdot (l_0 - l_1)$,

where c/c is cost price of freight transportation on this route.

In the general case (on average over the network), the revenue rate for freight transportation is higher than their cost price. However, in specific sections, especially difficult to operate (in the mountainous terrain, etc.), the cost of transportation often exceeds the yield rate, which is formed on the basis of the average network tariff. In this option, the cost savings can be greater than the decline in income. But even if this is not the case, as a result of the tunnel construction, railway transport, as a rule, gets a reduction in the cost of transportation $\Delta c/c$ due to the increase in weight and speed of trains. Estimating the cost of transportation as a result of increasing the weight and speed of trains is presented in [17, 18].

Reducing operating costs as a result of cost reduction will be:

$\Delta C_1 = \Delta c/c \cdot P \cdot l_1$.

Thus, the total savings in operating costs of rail transport will be:

$\Delta C_{tot} = \Delta C + \Delta C_1$.

By reducing the distance and increasing the speed of transportation, the time for delivery of goods in the direction in question will be shortened, let us denote this value as Δt_d. Here, another effect is reduction in losses from freezing of working capital embodied in the goods being transported. In accordance with the methodology outlined in [19], it can be estimated as:

$$\Delta K_{tot} = P \cdot \overline{\Pr} \cdot \Delta t_d \cdot i,$$

where P is volume of transportation;

$\overline{\Pr}$ – average price of 1 ton of transported cargo;

i – interest rate.

Cost reduction and acceleration of carriage lead, with other things being equal, to an increase in demand. The growth in demand should be evaluated in specific conditions on the basis of marketing research, but in general, average network's elasticity coefficients of demand can be used to estimate it. As shown in the study [20, pp. 117–140], the price elasticity of demand for freight transportation can be taken at the level of 0,5, and the non-price elasticity, depending on the level of the quality of transportation (the term of delivery of cargo is deemed to be the key indicator of the quality of transportation) – at a single level. Having designated the additional demand for transportations as ΔP, the incomes of railway transport from these additional transportations can be calculated by the formula:

$D = d \cdot \Delta P \cdot l_1$.

But the increase in demand for transportation will be formed, at least in part, due to an increase in the volume of industrial and agricultural production. As grounded in [21], the increase in industrial and agricultural production in similar cases can amount to:

$\Delta P = \Delta P \cdot Pr \cdot (1 - \alpha)$,

where α is a share of the additional cargo traffic generated due to the attraction of goods from other modes of transport.

Effects, largely similar in nature to those listed, will also arise in the sphere of passenger transportation.

Thus, the construction of railway tunnels causes a wide range of economic effects at both the sectoral and macro levels, which should be taken into account when assessing the feasibility of constructing a tunnel.

When choosing a calculation horizon for assessing the feasibility of construction of railway tunnels, a contradiction arises. On the one hand, the overall life cycle of the tunnel, including the time of its construction and operation, which is more than 100 years, can theoretically be accepted as the calculation horizon. On the other hand, the larger is the calculation horizon, the greater is the uncertainty in estimating the remote effects. In addition, as shown in [5], using the generally accepted discount rates, the discounted effects from the operation of infrastructure objects beyond the 20-year horizon of calculations tend to zero.

The solution may be a reduction in the discount rate in more remote years, the validity of which is justified in the same work. At the same time for a horizon of calculation of 25 years and more, discounting is associated with intergenerational distribution of effects from investments. According to some scientists [22, pp. 308–309], in these cases, discounting cannot be carried out, since each dollar for the future generation will have the same «social value» as for the present one. In addition, it is impossible to abandon the time preference, which is a ground for discounting, and which is «categorically inseparable from human activity» [23, p. 451].

A detailed examination of this dilemma goes beyond the scope of the published paper. In our opinion, a palliative solution is to minimize the discount rate outside the 20–25-year period to a level close to zero, but still different from zero.

This should make it possible to retain the significance of even distant economic effects from operation of the tunnel, and in this case there are certain grounds for using ultra-long-term calculation horizons close to the lifetime of the tunnel or even equal to it.

That is, construction of a tunnel can be considered expedient if there is a significant net discounted effect for the chosen calculation horizon even with a significant estimated payback period of capital investments (15–20 years or more).

Conclusion.

The theoretical foundations for assessing the feasibility of construction of railway tunnels proposed in the article can be the basis for developing methodological tools for making managerial decisions on construction of tunnels within the framework of the implementation of the Transport Strategy of the Russian Federation.

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