OPERATION COSTS IN HIGH-SPEED RAIL TRANSPORTATION

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ABSTRACT

The author puts forward some ideas and drfat methods regarding future HSR in Russia, e.g. proposes a methodology for calculating the annual operating costs per 1 train-kilometer that arise when traffic is organized on Moscow–Kazan high-speed rail, depending on the speed and the main resistivity to train movement. Taking into account the coefficient of comfort and on the basis of the multi-criteria choice for an optimum composition of a train, a composition consisting of 12 cars of four classes (one first class car, two business class cars, four economic and five tourist class) with a capacity of 742 passengers was adopted as author's project suggestion. The dimensions of movement of high-speed trains on HSR are determined, actual data, as well as possible tariffs for fare in cars of various classes, are involved in calculations. The part of conditionally-constant expenses is justified, operational expenses are calculated. The revenue and profits from the sale of tickets were calculated with full mastering of the planned passenger flow. The costs for 1 passenger and 1 passenger-kilometer are shown.

Keywords: *transport, high-speed railways, high-speed trains, traffic organization, operating costs calculation technique, train composition, passenger flow.*

Background. *As foreign experience shows, high-speed rail passenger transportation in the world is developing, and the network of HSR is expanding. The most prominent representatives of HSR are China, Japan, France, Germany, Spain, Italy. The world practices show that, on the one hand, high-speed passenger movement not only increases the prestige of the state, but also offers a completely different level of transport services, stimulates mobility of population, connects remote regions with the center, attracts additional investments in development of the transport sector and helps to build up socio- economic potential of the country. On the other hand, high-speed traffic is specific and, of course, requires the construction of a specialized line, being a very expensive project.*

The fundamental difference between high-speed transportation and traditional ones is train speed, so special attention must be given to the resistance to movement of a high-speed train and the resulting costs. It is high speed of movement that requires the construction of a separate line, otherwise a high-speed train takes a lot of trains from other categories from the train schedule.

No less significant is the cost of high-speed passenger transportation, which determines the tariff (fare) and significantly affects the volume of passenger flows. The final value of the unit cost of transportation is the ratio of operating costs to the volume of transportation in question.

For the future high-speed lines, only an approximate estimate of the cost and operating costs can be given. There is a system of determining the cost of cargo transportation on the projected lines, proposed by domestic specialists, based on a reasonable choice of meters related to the volumes of transportation and the specific costs for each such meter. This system was used until the 80s of the last century to justify the effectiveness of new construction and/or major reconstruction of sections and directions of the railway network [1].

For passenger transportations on HSR in justification of their effectiveness, the degree of uncertainty is significantly higher than for justifying the feasibility of projects for new lines for freight traffic. Therefore, in the pre-project calculations, it is possible to select a system for determining the cost of passenger transportation, based on an enlarged gauge for the dependent part of costs – the operating cost per 1 train-kilometer.

Objective. *The objective of the author is to consider operation costs in high-speed rail transportation.*

Table 1

Composition of a high-speed train at Moscow–Kazan HSR

Number of cars in a train					Number of seats in cars				Capacity of a train a_p, pass.	Coefficient of comfort $k_к$	Revenues from ticket sales, rub.
P	B	E	T	Total	P	B	E	T			
1	2	4	5	12	22	112	228	380	742	4,58	2872100

Table 2

Initial data for calculation of costs per 1 p-km, revenue and profits of the company

Indicator	Indicator value	Indicator	Indicator value	Indicator	Indicator value
Q, t gross	678	T, years	30	e_P, rub./km	15
i_e, %	7,5	P_{comp}, rub.	1191285000	e_B, rub./km	10
L, km	770	$b_{l.br}$, $b_{con.br}$, $b_{m.br}$, $b_{h.br}$	1,25	e_E, rub./km	5
a	0,9	$C_{t\cdot km}$, rub.	33,12	e_T, rub./km	3
K_{stop}	14	C^{l}_{b-h}, C^{con}_{b-h}, C^{m}_{b-h}, C^{h}_{b-h}, rub./hour (averaged)	400		
b_r	0,7	N_{req}	8718		

Table 3

Calculation of operating costs, as well as revenues and profits of the company

V_r, km/h	w_m, N/kN	R_{mech}, t • km	R_{mech}, t • km/km	E_e, rub.	E_v, rub.	E_{tot}, rub.	$E_{t\cdot km}$ rub.
250	13,33	12700,53	16,49	420641,55	65705,42	486346,97	631,62
260	14,19	13298,51	17,27	440446,65	63166,8	503613,45	654,04
270	15,07	13912,77	18,07	460790,94	60777,51	521568,45	677,36
280	15,98	14548,53	18,89	481847,31	58686,89	540534,2	702
290	16,92	15205,8	19,75	503616,1	56596,26	560212,36	727,55
300	17,89	15884,58	20,63	526097,29	54804,29	580901,58	754,41

Methods. *The author uses general scientific methods, mathematical calculations, comparative and economic analysis.*

Results.

1. Determination of the operating expenses, related to the volume of transportation, associated with the organization of movement of high-speed trains.

Operational costs represent the amount of the volume-dependent and conditionally-fixed costs that are not dependent on traffic volumes:

$$E_{year} = E^{d}_{year} + E^{c-f}_{year} . \quad (1)$$

Depending on the volume of transportation costs per train include energy (to overcome resistance to train movement and its displacement) and temporary expenses (salary to the train crew) [2]. Then the dependent costs can be represented in the form of a formula:

$$E_{tot} = E_e + E_v = R_{mech} \cdot C_{t\cdot km} + \frac{L}{\beta_r \cdot V_r} \cdot C_{t-h}, \quad (2)$$

where R_{mech} – mechanical work of a high-speed passenger train, t•km gross; $C_{t\cdot km}$ – rate of expenditure per 1 t•km of mechanical work, rub.; L – length of a direction, km; b_r – coefficient of route speed of passenger trains, depending on the number and duration of stops; V_r – running speed of a train, km/h; C_{t-h} – rate of expenditure per 1 train-hour of a passenger train, rub.

Mechanical work of a train is determined by the formula

$$R_{mech} = Q\cdot(w_m+i_e)\cdot L\cdot 10^{-3} + 3{,}8\cdot Q\cdot(a\cdot V_r)^2\cdot K_{stop}\cdot 10^{-6}, \quad (3)$$

where Q – mass of a train, t gross; w_m – main resistivity of train movement, N/kN; i_e – slope equivalent in mechanical work, %; a – ratio of speed at which braking begins to the running speed; K_{stop} – number of stops of a passenger train.

The main specific resistance to movement of a high-speed train (maximum speed up to 300 km/h) is found according to the formula recommended by VNIIZhT [3]:

$$w_m = 1+0{,}01\cdot V+0{,}00014\cdot(V+15)^2. \quad (4)$$

The first two terms (4) are characterized by mechanical resistance, and the last – aerodynamic resistance (with increasing speed, the aerodynamic resistance increases quadratically) [4]. It is desirable to establish the coefficients before the running speed in the formula (4) according to the results of experiments with a certain type of a high-speed train at an approximate to the real track profile. To date, there is no such data. On the other hand, if the above formula is used in all variants, then when compared with each other, the magnitude of the possible error due to mismatch (4) to the real data remains the same, therefore it is permissible to use the formula.

Expenditure rate per 1 train-hour of a high-speed passenger train:

$$C_{t-h} = C_{comp-h} + 1{,}3\cdot(\beta_{l.br}\cdot C^{l}_{b-h} + \beta_{con.br}\cdot C^{con}_{b-h}\cdot m + \beta_{m.br}\cdot C^{m}_{b-h} + \beta_{h.br}\cdot C^{h}_{b-h}), , \quad (5)$$

where C_{comp-h} – expenditure rate per 1 composition-hour, rub.; 1,3 – a coefficient that takes into account allocations for social needs; C^{l}_{b-h}, C^{con}_{b-h}, C^{m}_{b-h}, C^{h}_{b-h} – expenditure rates of 1 hour of work, respectively, of a locomotive crew, a brigade of conductors, a train electromechanic and a train head, rub./hour; $b_{l.br}$, $b_{con.br}$, $b_{m.br}$, $b_{h.br}$ – coefficients that take into account the time of out-of-train work, respectively, of a locomotive crew, a brigade of conductors, a train electromechanic and a train; m – number of cars in a train, car.

Expenditure rate per 1 composition-hour:

$$C_{comp-h} = \frac{P_{comp}}{T\cdot 8760} , \quad (6)$$

where P_{comp} – cost of a high-speed train, rub.; T – service life of a train, years; 8760 – number of hours per year.

In the formula (2), the dependent costs are calculated for the whole route. If its terms are alternately divided by the length of the route then we get the energy and time costs per 1 train-kilometer, and their amount depends on the cost 1 per train-kilometer:

$$E_{t\cdot km} = \frac{R_{mech}\cdot C_{t-km}}{L} + \frac{C_{t-h}}{\beta_r \cdot V_r} . \quad (7)$$

Having determined the dependent on the volume of transportation costs per train, it is possible to calculate the annual dependent costs:

$$E^{d}_{year} = E_{t-km}\cdot L\cdot N_{req} , \quad (8)$$

where N_{req} – annual number of high-speed trains required.

2. Determination of an optimal composition of a high-speed train.

The planned composition, types of cars and the capacity of a high-speed train are presented in Table 1.

Table 1 shows the composition already accepted and proposed by the author, which was selected from among many other possible [5]. Initially, the compositions varied in the number of cars of each type, but the total number of them in the train was planned to be 12 cars. Among the compositions chosen was the one that allowed to have the largest capacity to assume the maximum profit of the company and the minimum of trains that provide

E^{d}_{year}, mln rub.	E^{c-f}_{year}, mln rub.	E_{year}, mln rub.	B_{year}, mln rub.	P_{year}, mln rub.	E^{pass}_{pr}, rub./pass	$E^{pass-km}_{pr}$, rub./pass-km
4239,97	19326,06	23553,80	25038,97	1485,17	655,45	0,85
4390,5		23703,23		1335,74	678,72	0,88
4547,03		23852,66		1186,31	702,92	0,91
4712,38		24051,9		987,07	728,48	0,95
4883,93		24201,32		837,64	755	0,98
5064,3		24400,56		638,41	782,89	1,02

the given volumes of passenger flows, while the number of cars with the lowest capacity and the most expensive tariffs should be minimal. On the other hand, the composition does not have to consist only of the cheapest and capacious cars, since it is necessary to create for a passenger the possibility of choosing a type of cars and a level of services in accordance with his needs and financial capabilities.

That is, the search for an optimal composition is multicriteria. To select a composition, the author suggests a method based on the coefficient of comfort. The essence of the method consists in the following: each type of cars is assigned points on the comfort scale from 0 to 10 (the most comfortable and expensive type is 10 points), the coefficient of comfort is introduced (as the most suitable, compositions in which it lies in the range from 4,5 to 5 points, below 4,5 – insufficient number of cars of the highest class, more than 5 points – inadequate capacity). Thus, the capacity of one train is 742 passengers, and a composition includes 1 first-class car (P), 2 business class cars (B), 4 economy cars (E) and 5 tourist (T).

Table 1 also indicates the revenue from one train from the sale of tickets, which is calculated on the basis of fares in each type of car (see Table 2).

Using forecast data on the passenger flow for 2019 of the Center for Strategic Research and determining the flow per each section within the route Moscow–Kazan, it can be assumed that the maximum load is expected on Moscow–Vladimir section (6468643 passengers per year) [6]. Then for development of planned passenger flows, the annual required number of high-speed trains is equal to the ratio of the maximum density of the section to the capacity of one train, that is, 8718 trains per year for a given composition of the train.

In addition to the energy and time costs, depending on the volume of traffic, it is necessary to take into account the costs associated with the preparation of trains for a voyage (minor internal repairs, cleaning, sanitary inspection, washing, equipment, internal wet cleaning) and repair costs, maintenance, reformation, gas treatment at the point of registration [7]. The amount of these costs per train can be tentatively adopted taking into account the data of passenger trains on existing routes, for example, on Moscow–St. Petersburg high-speed line. In addition, we must bear in mind the costs associated with servicing passengers at railway stations and on the route (ticket sales, other services). In the calculations given in the article, these expenses in terms of size-dependent movements were not taken into account.

3. Justification of conditionally-fixed expenses on HSR, determination of revenue, profit and reduced costs for 1 passenger and 1 passenger-kilometer.

Conditionally-fixed expenses (E^{c-f}_{year}) include maintenance, repair, amortization of the contact network and power lines, track and permanent devices, signaling, centralization and blocking devices, electric centralization of arrows, HSR, depreciation of HSR and deductions to the reserve for capital repairs of HSR, other expenses [8].

According to the latest official data (for 2017), the cost of building a 770-kilometer HSR Moscow–Kazan is 1288 billion rubles, including the cost of purchasing the required number of rolling stock. In this article, these costs are allocated to the annual depreciation of HSR with a service life of 100 years before major repairs, the rest of the above listed costs are taken as a percentage of annual depreciation (150 %). Thus, annual conditional-fixed costs exceed the annual dependent costs by 3,8 to 4,56 times, depending on the running speed of high-speed passenger trains and amount to approximately E^{c-f}_{year} *= 19326,06 million rubles.*

The annual revenue from the tickets sold will be found according to the formula:

$$B_{year} = N_{req} \cdot L \cdot \sum_{k=1}^{r} a_k \cdot e_k \,, \qquad (9)$$

where a_k – number of passengers in a k-th type car; e_k – fare in a k-type car, rub./km; k – car type in a train; r – number of cars in a train (four of them: P, B, E, T).

Annual profits of the company from the tickets sold:

$$P_{year} = B_{year} - E^{d}_{year} - E^{c-f}_{year} \,. \qquad (10)$$

Reduced costs per one passenger:

$$E^{pass}_{pr} = \frac{E^{d}_{year}}{N_{req} \cdot a_p} \,. \qquad (11)$$

Reduced costs per one passenger-kilometer:

$$E^{pass-km}_{pr} = \frac{E^{d}_{year}}{N_{req} \cdot a_p \cdot L} \,. \qquad (12)$$

The initial data for calculating the costs per 1 train-kilometer, revenue and profit are shown in Table 2.

The results of the calculation, depending on the running speed, are summarized in Table 3.

Conclusions. *With respect to the calculations made, one can expect the company's profit from the sale of tickets. But the calculations represent an approximate quantitative estimate of operating costs in ideal conditions, that is, when the passenger flow of HSR, predicted by the Center for Strategic Development, is fully mastered. In addition, 1 train-kilometer costs are shown for organization of train traffic itself, but also the costs for repairing and*

servicing the rolling stock, for formation and preparation of passenger trains for departure, the costs of servicing at station complexes, the cost of maintenance and repair of the track, the devices of the signal system, the contact network are all part of the dependent costs. In practice, taking into account all the above mentioned clauses, operating costs will be certainly higher, and the possible profit is lower (approximately 20–25 % against the values indicated in Table 3).

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