ISSUES OF OPTIMIZING THE SPEED OF PASSENGER TRAINS ON ROUTES

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Abstract: This article focuses on the issues of determining the optimal size and speed of freight and passenger trains. In developing the current methodology, research was conducted based on previous scientific research. Currently, one of the pressing issues in railway transport is the problem of soil movement in windy areas, especially in desert areas. It is important to study the negative effects of wind on railway infrastructure and provide scientifically based solutions in this area. For this purpose, the effects of wind on the stability of rolling stock were studied.

Keywords: Freight and passenger trains, optimal speed, optimal mass, minimize, empty containers, wind gusts, wind speed, aerodynamic pressure, sand drift, obstacles.

Let's consider the issues of determining the optimal speed of the train. The forward objective is to distribute the speed of freight and passenger trains in such a way that the minimum costs are achieved along the main line. The economic and mathematical model in question takes into account the time spent on effort and energy resources to overcome the main resistance, depending on the speed of the train [1-10]. To calculate the Optimal speed, it is proposed to take into account the change in a number of parameters of the transport process by directions, in particular, the axle load, the size of the train and the proportion of empty cars in the train. Defined mean

when calculating the optimal speed using train-clock speed, the magnitude of the relative error was studied. One of the main directions for improving the organization of the transportation process in modern conditions is the optimization of the speed of freight and passenger trains, which largely determines the economic indicators of the Uzbek railway. In particular, an increase in the speed of movement will lead to an increase in energy costs for pulling and repairing trains, but maintenance of the rolling stock will reduce the costs associated with train working personnel, etc., and with additional measures will reduce the specific fuel consumption for pulling trains and increase the overall efficiency of the transportation process [11-15].

The study of train speed optimization and the search for optimal solutions was carried out in close connection with existing economic and technical factors. Thus, the costs associated with pulling cars, 10,000 tons of km of brutto, should be calculated according to individual calculations of mechanical work for pulling a train, and not at the average rates of fuel (electricity) consumption. In general, the dependence of costs on train speed is described by the following looking equation:

$$E = e_{p \cdot ch} \frac{S}{v_{uch}} + e, A \qquad (1)$$

Here: $e_{v.ch}$ - train-clock price; som;

S - area length, km;

V_{uch} - passenger train has a local speed of, km / h;

e_e - 1 kWh, working Price;

The energy consumption for pulling an A-train is calculated and it is defined as:

$$A = \frac{(P+Q)g}{3600\eta} (w_0 + i_e) S \qquad (2)$$

Here: R - is the locomotive mass, t;

Q - is the mass of the train, t;

g - free fall acceleration, m/s2;

3600 - conductor coefficient (Dj kW per hour);

η - useful coefficient of work of a locomotive;

w_0 - main comparative resistance to train traffic, N / kN;

i_e - equivalent slope,‰.

The main comparative resistance to the movement of wagons on roller bearings ($q_o > 6$ t) is determined according to the following basic dependence:

$$w_0'' = a_{gr} \frac{b_{gr} + c_{gr} v + d_{gr} V^2}{q_0} \qquad (3)$$

Here: a_{gr}, b_{gr} , C_{gr}, d_{gr} - are empirical coefficients depending on the type of road surface;

q_o - is the weight on the wheel pair axle, t.

For empty wagons on roller bearings (q0 < 6 t),

$$w_0'' = b_{por} + c_{por} v + d_{por} v^2 \qquad (4)$$

Here: b_{por}, c_{por}, d_{por} - are empirical coefficients established experimentally.

The resistance to the movement of a train consisting of loaded and empty wagons is determined in the following manner:

$$w_0 = \alpha_p w_0^n + \alpha_p w_0^{gr} \qquad (5)$$

Here: a_p, a_{gr} - the percentage of empty and non-empty wagons in the train, respectively;

$a_p + a_{gr} = 1$.

After some modifications, we have the following expression:

$$w_0 = A' + B'v + C'v^2 \qquad (6)$$

Here: A', B', C' - are the calculation coefficients.

An important conclusion follows from expression (6) that, if the train consists of empty and loaded wagons, the resistance to movement is described by a parabolic relationship.

Let us write the basic specific resistance to train movement as follows:

$$w_0^n = A + B_v + Cv^2 \qquad (7)$$

Here, the above coefficients are determined as follows:

$$A = \frac{QA' + Pa_l}{Q+P}; \qquad (8)$$

$$B = \frac{QB' + Pb_l}{Q+P} \qquad (9)$$

$$C = \frac{QC' + Pc_l}{Q+P} \qquad (10)$$

Substituting the above expressions into the expression for basic operating costs, the following equation was obtained:

$$E = e_{p\cdot ch}\frac{S}{v\beta_{uch}} + e,\frac{(P+Q)g}{3600\eta}\cdot(A + Bv + Cv^2 + i)S \qquad (11)$$

Here: βuch - is the ratio of local speed to technical speed.

Expression (6) does not take into account the costs of energy resources to overcome additional resistance from the curves. In the current "rules of traction calculations for train operation", these costs do not depend on the speed of movement and therefore they are excluded in this economic and mathematical model.

To find the minimum value, function (11) is differentiated:

$$\frac{\partial E}{\partial v} = -\frac{e_{p\cdot ch}S}{v^2\beta_{uch}} + \frac{e_e(P+Q)gS(B+2Cv)}{3600\eta} \qquad (12)$$

$$\frac{2e_e(P+Q)gCS\beta_{uch}}{3600\eta}v^3 + \frac{e_e(P+Q)gBS\beta_{uch}}{3600\eta}v^2 - e_{p\cdot ch}S = 0 \qquad (13)$$

After a series of substitutions and modifications of expression (13), we obtain an incomplete cubic equation:

$$x^3 + px^2 + q = 0 \qquad (14)$$

The solution to such an equation can be found using Cardano's formula:

$$x = \sqrt[3]{-\frac{q}{2} + \sqrt{\frac{q^2}{4} + \frac{p^3}{27}}} + \sqrt[3]{-\frac{q}{2} - \sqrt{\frac{q^2}{4} + \frac{p^3}{27}}} \qquad (15)$$

The optimal speed of the train that minimizes total travel costs is:

$$v_{opt} = \sqrt[3]{-\left(\frac{B^3}{216^3} + \frac{1800\eta e_{p\cdot ch}}{2e_e(P+Q)gC\beta_{uch}}\right) + \left(\frac{B^3}{216C^3} + \frac{1800\eta e_{p\cdot ch}}{2e_e(P+Q)gC\beta_{uch}}\right)^2 + \left(\frac{B^2}{36C^2}\right)^3} + + \sqrt[3]{-\left(\frac{B^3}{216^3} + \frac{1800\eta e_{p\cdot ch}}{2e_e(P+Q)gC\beta_{uch}}\right) - \left(\frac{B^3}{216C^3} + \frac{1800\eta e_{p\cdot ch}}{2e_e(P+Q)gC\beta_{uch}}\right)^2 + \left(-\frac{B^2}{36C^2}\right)^3} - \frac{B}{6C} \qquad (16)$$

To estimate the train-hour cost parameter in the proposed model, it is determined not by calculating the average road speed, but by calculating the following train-km units: wagon-kilometer, wagon-hour, moving wagon-hour, diesel (electric) locomotive-kilometer, diesel (electric) locomotive-hour, locomotive crew-hour, gross ton-kilometers of wagons and locomotives, kilograms of conditional fuel, and costs associated with auxiliary linear travel are included in the locomotive costs (Table 1).

Table 1

Calculation of the cost rate per 1 train km when operating a locomotive

Measurement	Consumption rate, soums. Calculation formula for the cost of the meter	Consumption rate, soums. Calculation formula for the cost of the meter
Wagon-kilometer	8.4	T
Wagon-hour	942,0	m/v_{uch}
Locomotive-kilometer	1145,0	$1+K$
Locomotive-hour	5842,0	$1/v_{uch}+K$
Locomotive team-hour	17677,0	$1/v_{uch}+1.5$

As an example, the results of the study (Table 2) show that the structure of the wagon flow with electric and diesel traction has significant differences in even and odd directions.

Table 2

Initial data and results of optimization calculations performed for individual regions

Options	U-Kh		Kh-U	
	odd direction	pair way	odd direction	pair way
Train-hour, price sum	618319	618319	680032	680032
1 kW/h, price s.	130	130	130	130
Technical speed, km/h	69,48	68,11	45,16	44,23
Area speed, km/h	68,6	67,93	42,14	39,22
Train mass, t	3860	2170	4125	2165
Cargo per unit, t/uq	16,07	9,15	17,38	8,56
The proportion of empty wagons in the composition	0,148	0,758	0,232	0,726
The share of freight wagons in the composition	0,852	0,242	0,768	0,274
Number of wagons in the composition is wagon.	60,1	66,6	59,3	63,3

Regional velocity coefficient	0,987	0,997	0,933	0,887
Optimal technical speed, km/h	63,49	60,51	62,38	63,67
Estimated price of a train hour, soums	779700	521682	849660	510660
Calculated optimal speed, km/h	69,36	56,37	68,04	56,57
Relative error in determining the optimal speed based on the average train hourly rate costs, %	8,5	7,3	8,3	12,6

As seen in Table 2, the average train-clock consumption rate calculated optimally rarely corresponds to the optimal speed. This is because the composition of railcars by region is significantly different, and bringing all indicators to the average by road results in significant inaccuracies in the calculations. It can be argued that due to the low energy density of Transportation on electrified lines, the greatest faults are observed in friction areas with a locomotive driven on diesel fuel.

Analysis of the behavior of the optimal train speed function in changing the parameters of the transportation process, such as the number of cars in the train and the load on the axle, in particular, allows you to draw the following conclusions:

1. The dependence of Optimal speed on train mass is illustrated by a parabola (Figure 1).

2. When trains maintain a traffic flow (empty wagon share and average axle load), an increase in train mass from Meyer will, as expected, lead to an increase in transport costs, but the minimum cost of the cost function, depending on the speed. it is achieved at a certain technical speed relative to the train. Thus, its change in value with the calculated train-hour speed does not exceed 5 km/h when the weight of the train increases more than twice (See Figure 1, a, curve v2). The use of the average track rate results in a sharp decrease in the amount of optimal speed, which is overestimated for trains with a small mass and weighing more than 3,000 tons (Figure 1 shows that curve a, v1 can reach 17% of train mass depending on the error).

3. By keeping the constant value of the content in the direction, an increase in mass (up to a certain limit) is achieved due to an increase in the proportion of wagons loaded in the composition and, accordingly, an average load on the axle. At the same time, an increase in train mass leads to an increase in the cost of movement, but the minimum level of cost function is achieved with an increase in technical speed, the change of which is characterized by a parabolic dependence. Figure 1, 2, shows from the V2 curve that an increase in content mass from 2,000 to 5,000 tons indicates the need to increase the technical speed of the train from 61 to 95 km/ oat with a constant content equal to 60 cars. This results in a relative calculation error of 14% if used in train-clock speed optimization [15-24].

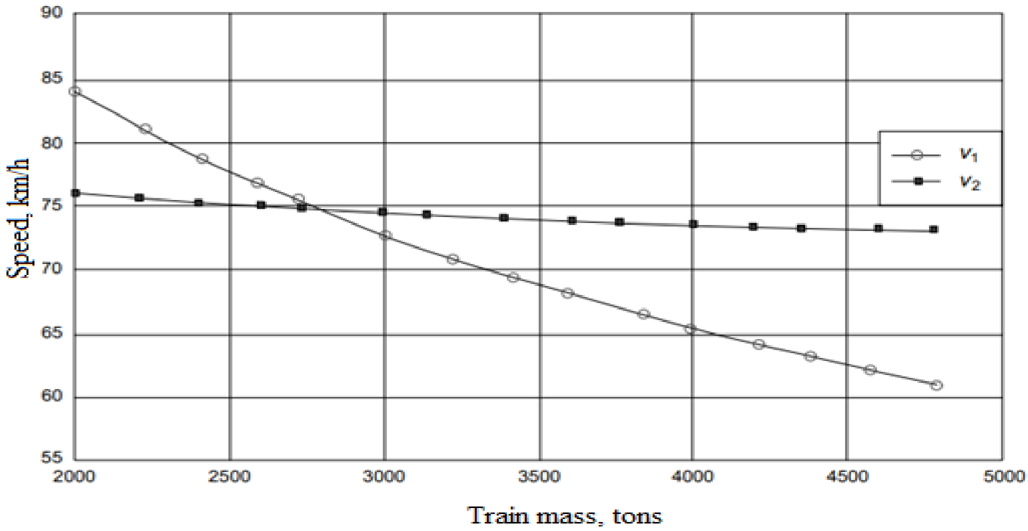

Figure 1. The dependence of the optimal speed on the mass of the train is depicted by a parabola

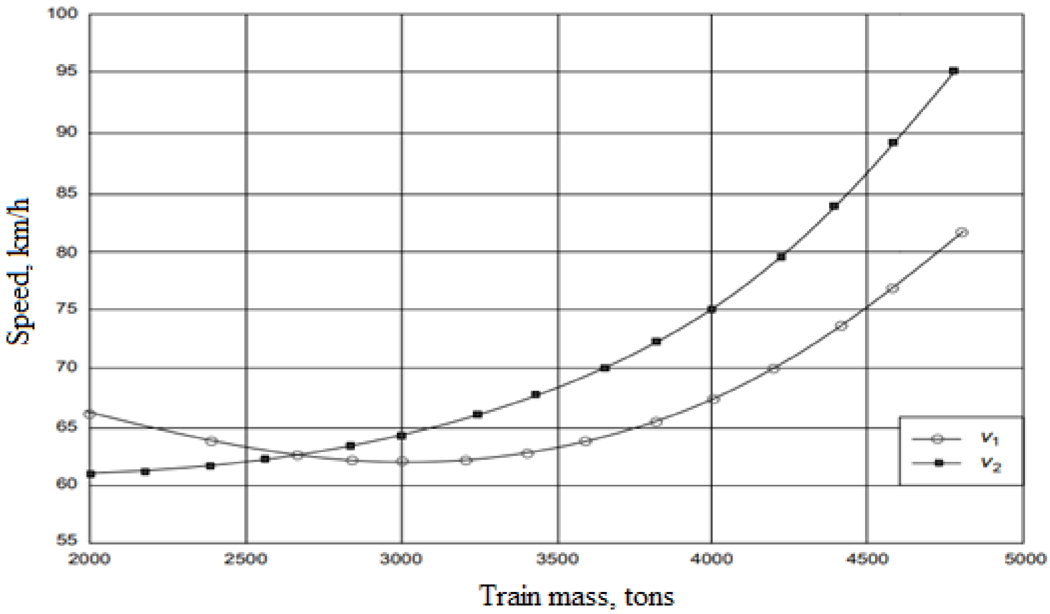

Figure 2. Dynamics of changes in the optimal speed of a freight train

V_1- by the average train-hour speed of the train; V_2- by the calculated train-hour speed of the train:

1 - the increase in the mass of the train is associated with an increase in the number of wagons with a constant axle load in its composition;

2 - the increase in the weight of the train is associated with an increase in the axle load of wagons with a constant composition size.

4. Analysis of the behavior of the optimal function allows us to conclude that the dependence of the optimal speed on the mass of the passenger train on the speed of the train is also described by a parabola. In this case, an increase in the mass of the train, as expected, leads to an increase in the cost of movement, but the minimum level of the cost function, depending on the speed of the train, is achieved by reducing a certain technical speed (within 5 km/h). The recommended optimal speed of movement varies

from 93 km/h (region U-Kh, consisting of 13 wagons) to 98 km/h (Kh-U, long-distance trains, consisting of 17 wagons) in different regions according to the calculation rates of passenger trains. In this case, the relative error of calculating the optimal technical speed by the existing method will be from 0,3% to 3%.

Currently, studies are being conducted to optimize train speeds and find optimal solutions, taking into account the fact that many parameters of the transport process affect the main specific resistance to movement, in particular, axle load [9-14].

The optimization of the speed and mass of passenger trains is based on determining the minimum total economic costs associated with changing these parameters. The total current annual costs are determined as the sum of the previously discussed step-by-step costs:

$$\mathrm{f(Q, vx)} = \frac{v_x^2}{Q} + D_3 v_x^2 \qquad (17)$$

As can be seen from equation (17), the costs of the national economy depend on two variables: the mass and speed of passenger trains ΣE=f(Q, V_x). Taking the value of Q as a variable, differentiating in partial derivatives the condition (17) and setting the result to zero, we find the minimum of the reduced costs ΣE=f(Q):

$$\frac{\partial E}{\partial Q} = -\frac{B_1}{v_x Q^2} - \frac{B_2}{Q^2} - \frac{G_1}{v_x Q^2} - \frac{G_3}{Q_2} + \frac{(x_1 + y v_x)(z v_x + x_2)}{(z v_x Q + x_2 Q)^2} -$$

$$- \frac{DR(a + i_e + b v_x + c v_x^2)}{Q^2} - \frac{F_2}{v_x^2 Q^2} + \frac{F_2}{v_X Q^2} - \frac{F_3}{Q_2} + P + W + D - D_2 \frac{v_x^2}{Q^2} = 0 \qquad (18)$$

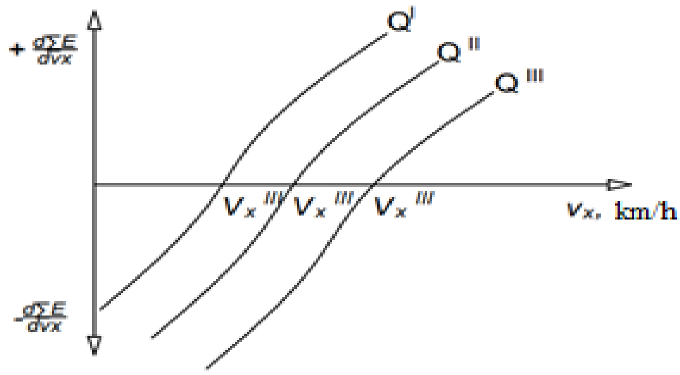

Figure 3. Curves characterizing the average speed of passenger trains for different masses

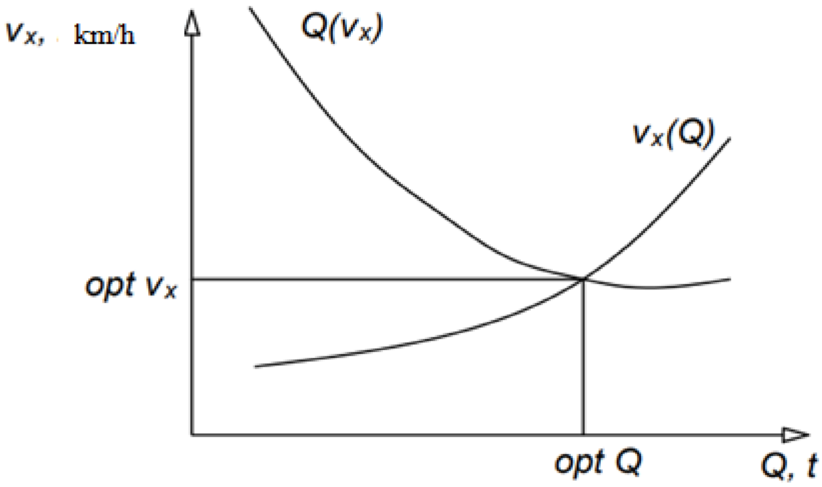

Figure 4 - Curves for determining the optimal mass and average speed of passenger trains

The optimal mass of a passenger train would be:

$$Q = \sqrt{\frac{\frac{B_1}{v_x} + B + \frac{G_1}{v_x} + G_3 + \frac{(x_1 + yv_x)(zv_x + x_2)}{(zv_x + x_2)^2} + \frac{\Phi_1}{v_x^2} -}{P + W + D}} \rightarrow$$

$$\rightarrow \frac{-\frac{\Phi_2}{v_x} + \Phi_3 + DR(a + i_e + bv_t + cv_x^2) + D_2 v_x^2}{P + W + D} \qquad (19)$$

We differentiate condition (19) with respect to vx and, after reformulation, we obtain the following expression:

$$\frac{\partial E}{\partial v_x} = -\frac{B_1}{Qv_x^2} - \frac{V}{v_x^2} - \frac{G_1}{v_x^2} - \frac{G_2}{v_x^2} + D\left(1 + \frac{P}{Q}\right)b + 2cD\left(1 + \frac{P}{Q}\right)v_x +$$

$$+ \frac{1}{Q}\frac{x_2 y - zx_1}{(zv_x + x_2)^2} + \frac{F_2}{Q_x^2} - \frac{Z}{v_x^2} - \frac{J}{v_x^2} + \left(2\frac{D_2}{Q} + 2D_e\right)v_x = 0 \qquad (20)$$

Substituting the value of Q in condition (20) into condition (19), we obtain an equation with one unknown variable V_x. It can be approximated by the Lobachevsky method or by solving transcendental equations, which can be achieved by determining individual real roots. The current task can be determined by the exact average speed of movement and a simple graphical-analytical method.

The determination of different values of Q is carried out by the method of graphically solving the condition. For this, different values of Q are substituted into condition (19) and curves are drawn on the basis of these values in the coordinate system. The value of V_x for different Q is determined at the points of intersection with the x-axis. In this regard, firstly, from condition (20), different masses of trains Q', Q'', etc. are determined for different values of V_x. According to the values in the figure, the curve v=f(Q) is constructed in the coordinate system V'_x, V''_x, V'''_x etc. At the intersection point of the curves $Q=f(V_x)$ and $x=f(Q)$, optimal values for the mass and average speed of passenger trains are found based on minimal economic costs. The accuracy of the optimal values of the average speed and mass of passenger trains depends on the step of variables adopted when solving conditions (20) or (19) [11].

$$E_{ost} = 3{,}6(P+Q)(\alpha_T l v_x)^2 \frac{L_n}{l_{ost}} \frac{g}{1+y} c_e \frac{Aqbr}{a_0 Q} 10^{-6} \cdot 2 \cdot 365 = D_3 \frac{v_x^2}{Q} + +D_3 v_x^2 \qquad (21)$$

Here: l_{ost} - average distance between passenger train stops, km.

$$D_2 = \frac{27243\alpha_T^2 C_e A q_{br} L}{a_0 l_{ost} \cdot 10^{-6}}; \qquad (22)$$

$$D_3 = \frac{2724\alpha_T L A c_e q_{br}}{a_0 l_{ost} \cdot 10^{-6}}. \qquad (23)$$

Based on the above expressions, it is possible to determine the optimal mass and speed for any train set (train).

References:

1. Bozorov R. Sh. Aerodynamic impact of the high-speed electric train «Afrosiyob» on opposite trains. Journal of Transsib Railway Studies, 2022, no. 2 (50), pp. 96-107 (In Russian).

2. Bozorov R.S., Rasulov M.X., Masharipov M.N. Investigation of mutual aerodynamic influence of high-speed passenger and freight trains moving on adjacent tracks. Journal Innotrans Scientific-and-nonfiction edition, 2022, no. 2(44), pp. 42-48. DOI:10.20291/2311-164X-2022-2-42-48

3. "EN 14067 Railway applications – Aerodynamics – Part 2: Aerodynamics on open track", ed: CEN/TC 256, 2010.

4. "EN 14067 Railway applications – Aerodynamics – Part 4: Requirements and test procedures for aerodynamics on open track", ed: CEN/TC 256, 2010.

5. Lazarenko Y.M., Kapuskin A.N. Aerodynamic impact of the «Sapsan» high-speed electric train on passengers on platforms and on oncoming trains when crossing. Bulletin of the Research Institute of Railway Transport, 2012, no. 4, pp.11-14 (In Russian).

6. Raghu S. Raghunathan, H. D. Kim, T. Setoguchi. Aerodynamics of high-speed railway train / Progress in Aerospace Sciences 38 (2002) 469-514.

7. Baker C., Quinn A., Sima M., Hoefener L., and Licciardello R. Full-scale measurement and analysisof train slipstreams and wakes. Part 1: Ensemble averages. Proceedings of the Institute of mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 2013. p. 453-467.

8. Baker C., Quinn A., Sima M., Hoefener L., and Licciardello R. Full scale measurement and analysis of train slipstreams and wakes: Part 2 Gust analysis.

Proceedings of the Institute of mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 2013. p. 468-480.

9. Katsuyuki M., Kazuaki I., Tsutomu H., Jin'ichi O., Kei H. and Atsuyushi H. Effect of train draft on platforms and in station houses. JR East Technical Review No. 16, 2010. p. 39-42.

10. Hong Wu, Zhi-jian Zhou. Study on aerodynamic characteristics and running safety of two high-speed trains passing each other under crosswinds based on computer simulation technologies. Journal of Vibroengineering, Vol. 19, Issue 8, 2017, p. 6328-6345.

11. Tian Li , Ming Li, Zheng Wang and Jiye Zhang. Effect of the inter-car gap length on the aerodynamic characteristics of a high-speed train. Journal of Rail and Rapid transit, Issue 4, September 20, 2018, p. 448-465.

12. Chris Baker, Terry Johnson, Dominic Flynn, Hassan Hemida, Andrew Quinn, David Soper, Mark Sterling. Train Aerodynamics fundamentals and applications. Book Butterworth-Heinemann London 2019, p. 151-179. ISBN 978-0-12-813310-1, https://doi.org/10.1016/B978-0-12-813310-1.00008-3

13. Bozorov R.Sh., Rasulov M.Kh., Bekzhanova S.E., Masharipov M.N. Methods for the efficient use of the capacity of sections in the conditions of the passage of high-speed passenger trains.Journal Railway transport: Topical issues and innovations, 2021, no. 2, pp. 5-22. (In Russian).

14. Shukhrat Saidivaliev, Ramazon Bozorov, Elbek Shermatov. Kinematic characteristics of the car movement from the top to the calculation point of the marshalling hump. E3S Web of Conferences 264, 05008 (2021) https://doi.org/10.1051/e3sconf/202126405008

15. Rasulov, M., Masharipov, M., Sattorov, S., & Bozorov, R. (2023). Study of specific aspects of calculating the throughput of freight trains on two-track railway sections with mixed traffic. In E3S Web of Conferences (Vol. 458, p. 03015). EDP Sciences. https://doi.org/10.1051/e3sconf/202345803015

16. Bozorov R.Sh. About absence of theoretical base of the formula for determination of height of the first profile site of the marshalling hump / Bozorov R.Sh., Saidivaliev Sh.U., Djabbarov Sh.B. –Text : immediate // Innovation. The science. Education. 2021, №34. pp. 1467–1481. (In Russian).

17. Bozorov R. S., Rasulov M. X., Masharipov M. N. Research on the aerodynamics of high-speed trains // Universum: технические науки: электрон. научн. журн., 2022, № 6 (99).

18. Marufdjan Rasulov, Masud Masharipov, S. E. Bekzhanova and Ramazon Bozorov. Measures of effective use of the capacity of twotrack sections of JSC "Uzbekistan Railways". E3S Web of Conferences 401, 05041 (2023) https://doi.org/10.1051/e3sconf/202340105041

19. Andrzej Zbieć. Aerodynamic Phenomena Caused by the Passage of a Train. Part 2: Pressure Influence on Passing Trains. Problemy Kolejnictwa. Issue 192, September 2021, p. 195-202. http://dx.doi.org/10.36137/1926E

20. NB JT ST 03-98. Safety standards for railway transport. Electric trains. – M.: VNIIJT, 2003. – 196 p.

21. UIC 566 Leaflet: Loadings of coach bodies and their components, 3rd edition of 1.1.90

22. Saidivaliev, Sh.U. A new method of calculating time and speed of a carriage during its movement on the section of the first brake position of a marshaling hump when exposed headwind / Sh.U. Saidivaliev, R.Sh. Bozorov, E.S. Shermatov // STUDENT eISSN: 2658-4964. 2021, №9.

23. Bozorov R.Sh., Saidivaliev Sh.U., Shermatov E.S., and Boboev D.Sh. Research to establish the optimal number of platforms in a container. Transport: science, technology, management. Scientific information collection. Issue 5, 2022, p. 24-28. https://doi.org/10.36535/0236-1914-2022-05-5 (In Russian).

24. Rasulov, M., Masharipov, M., & Ismatullaev, A. (2021). Optimization of the terminal operating mode during the formation of a container block train. In E3S Web of Conferences (Vol. 264, p. 05025). EDP Sciences. https://doi.org/10.1051/e3sconf/202126405025