Study of specific aspects of calculating the throughput of freight trains on two-track railway sections with mixed traffic

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Abstract. The article shows a study of the influence of the high-speed train "Afrasiab" on the throughput of stations, which was determined by analyzing the change in the coefficient of displacement of freight trains from the schedule when high-speed trains “Afrasiab” pass to the sections of JSC "Uzbekiston temir yullari". In addition, the article discusses in detail the issues of reducing the interval of arrival of freight and high-speed passenger trains at the points of division in a row and increasing the maximum number of freight trains that can pass through the section based on the connection technology of high-speed passenger trains. Key words. High-speed trains, “Afrasiab” electric train, throughput, in one direction, in the dependent direction, displacement factor, freight trains.

1 Introduction

Along with improving the quality of passenger service, timely and high-quality delivery of goods is one of the main tasks of railway transport. It has been observed that an increase in consumption due to an increase in population leads to a proportional increase in the volume of demand for additional freight and passenger transportation. This, in turn, requires the development of measures to introduce additional innovative technologies in the field of transport. In particular, over the years of operation of the joint-stock company "Uzbekiston temir yullari" the number of passengers sent by rail increased by 88% compared to 2007, the number of transported goods increased by 35%, but the speed of movement of the section on average decreased by 3% (Fig.1). Of course, taking into account the above significant changes in freight and passenger traffic, it is necessary to develop additional measures to increase the throughput of railway transport sections, the speed of sections and the locomotive fleet.

In this regard, increasing the throughput of freight trains in areas with mixed traffic is one of the urgent tasks. To do this, in addition to calculating the reserve throughput of freight trains on double-track sections with mixed traffic of Uzbekistan Temir Yollari JSC and studying the factors affecting it $\left(\Delta N_{reserve} = f\left(\Delta t,\ N_{high-speed}\right)\right)$, the coefficient of displacement of freight trains from the schedule is calculated based on the number of high-speed passenger trains sent in one direction to separation points, it is required to study and

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analyze the dependence of the time interval $\left(\varepsilon = f\left(\Delta t, N_{high-speed}, I_{passin.arrival}\right)\right)$ for the departure of freight and high-speed trains, the total parking time (stay) of freight trains at separation points for the passage of high-speed passenger trains, as well as to search for mathematical patterns of ways to reduce delays.

Based on the current recommendations [1], the throughput of railway sections is divided into calculated and required. Estimated train throughput is understood as the maximum number of freight and passenger trains of a certain weight and length passing through a given section per unit of time (day), in accordance with the track profile, technical equipment and the method of organizing train traffic. The required throughput is usually less than the design throughput and the displacement of freight trains by other types of trains must be taken into account. Required throughput - the number of trains per day required to fulfill the transportation plan.

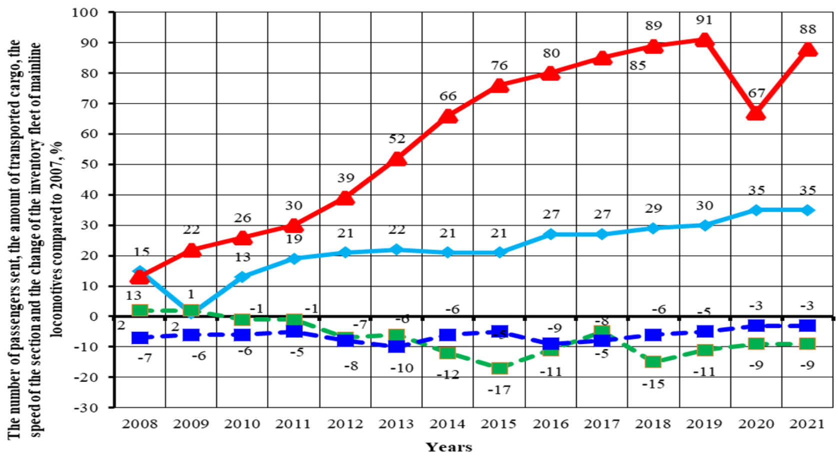

Fig. 1. Dynamics of changes in the main indicators of the Joint Stock Company "Uzbekiston Temir Yollari" in comparison with 2007, %

2 Materials and methods

At present, analytical, graphic-analytical and simulation modeling are widely used to determine the throughput of a computational train. Undoubtedly, the factor of displacement of freight trains from the schedule has a great influence on the throughput of trains. To do this, it is necessary to analyze the factors influencing the coefficient of displacement of freight trains according to the schedule.(Figure 2).

Based on the above analysis, in accordance with the processes of organizing the movement of trains in JSC "Uzbekiston temir yullari", the throughput of freight trains on existing sections and the coefficient of shift from the schedule is explained by the following functions. [1-3, 12, 13, 21-22]:

$$\begin{cases} N = f\left(A, S, Q, L, I_{high-speed}, N_{high-speed}, q_1\right) \rightarrow \max \\ \varepsilon = f\left(I, \Delta, N_{high-speed}, I_{high-speed}, \vartheta_f, \vartheta_{high-speed}, q_2\right) \rightarrow \min \end{cases} \quad (1)$$

here, A - number of tracks at stations and sections; S - haul length, km; Q - Technical equipment of railway sections; L - thrust type; Δt - time interval between successive high-speed passenger trains, min; $N_{high-speed}$ - number of high-speed passenger trains, train; I - time interval between successive freight trains, min; Δ - the ratio of the time of movement of high-speed passenger and freight trains on certain sections; ϑ_f, $\vartheta_{high-speed}$ - determination of the speed of freight and high-speed passenger trains on separate sections, km/h; q_1, q_2 - other conditions.

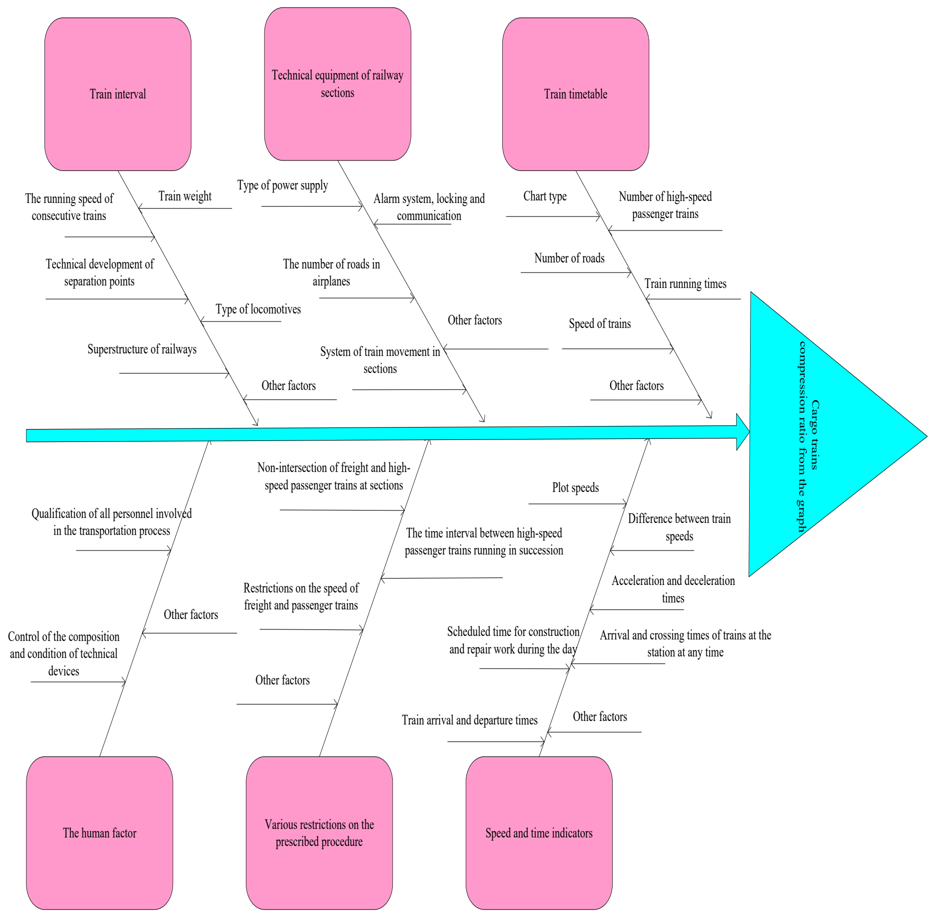

Fig. 2. Analysis of the Factors Affecting the Coefficient of Freight Train Displacement on Schedule

For the above objective functions, the following boundary conditions must be satisfied:

$$\begin{cases} 2 \le A \le A_{\max};\ S_{\min} \le S \le S_{\max};\ 0 \le I_{YT} \le I_{YT}^{\max} \\ 1 \le N_{high-speed} \le N_{high-speed}^{\max};\ I_{\min} \le I \le I_{\max};\ \vartheta_f^{\min} \le \vartheta_f \le \vartheta_f^{\max} \\ \vartheta_{high-speed}^{\min} \le \vartheta_{high-speed} \le \vartheta_{high-speed}^{\max};\ \Delta^{\min} \le \Delta \le \Delta^{\max};\ q_{1,2}^{\min} \le q_{1,2} \le q_{1,2}^{\max} \end{cases} \quad (2)$$

To date, a number of scientists have carried out scientific research to determine the displacement coefficient of freight trains on double-track sections according to the schedule and solve the above problems, and in particular A.A. Abramov, G.M. Groshev, B.M. Maksimovich, F.P. Kochnev, A.K. Ugryumov (tab.1) [4, 5, 6, 20].

Table 1. Methodology for determining the coefficient of displacement of freight trains from the schedule on double-track sections

Methodology for determining the coefficient of displacement	the coefficient of displacement of freight trains, ε
B.M. Maksimovich	$\varepsilon = \frac{(0{,}25 + 0{,}7 \cdot j) \cdot (1 - \Delta) \cdot t_f}{I} + 1{,}3 \cdot \Delta + 0{,}5$
F.P. Kochnev	$\varepsilon = \frac{t_f \cdot (1 - \Delta) + I_{pass in arrival.} + I_{pass in departure} + t_{sl.} + t_{ov.}}{I} + 0{,}2$
A.K. Ugryumov	$\varepsilon = \frac{t_f \cdot (1 - \Delta) + I_{pass in arrival.} + I_{pass in departure} + t_{sl.} + t_{ov.} - I}{I} + \frac{I - 1}{2 \cdot I}$
A.A. Abramov A.N. Goliguzova	$\begin{cases} \varepsilon = \frac{t_f \cdot (1-\Delta) \cdot (0{,}8 - 0{,}005 \cdot N_{hig-s}) \cdot}{I} + 2{,}5 - 0{,}01 \cdot N_{hig-s} - \Delta \cdot (0{,}85 - 0{,}011 \cdot N_{hig-s}) \\ \Delta = \frac{t_{hig-s}^{running}}{t_f^{running}} \end{cases}$
According to the instruction	$\varepsilon_2 = \frac{(T_f + I_{hig-s}) \cdot (1 - \Delta)}{2 \cdot I_{hig-s}} - \frac{T_f \cdot (1 - \Delta)}{2 \cdot (I_{pass in arrival.} \cdot (1 + \gamma) + t_{sl.})} + 1{,}5$

Based on methodological recommendations [1] and scientific research [2, 3, 14], the estimated capabilities of freight trains and their maximum number are expressed as follows:

$$\begin{cases} N_{available} = \frac{(1440 - t_{tech}) \cdot \alpha_n}{I} \\ N_{required} = (N^f \cdot k + N_{pass.}^{hig-s} \cdot \varepsilon_{pass}^{hig-s} + N_{pass.} \cdot \varepsilon_{pass} + N_{pass}^{sub..} \cdot \varepsilon_{pass}^{sub..} + N_{fast}^f \cdot \varepsilon_{fast}^f + N_{prefab}^f \cdot \varepsilon_{prefab}^f) \cdot (1 + \beta) \\ \Delta N_{reserve} = N_{available} - N_{required} \\ N_{\max}^Y = N_{available} - N_{pass.}^{hig-s} \cdot \varepsilon_{pass}^{hig-s} - N_{pass.} \cdot \varepsilon_{pass} - N_{pass}^{sub..} \cdot \varepsilon_{pass}^{sub..} - N_{fast}^f \cdot (\varepsilon_{fast}^f - 1) - N_{prefab}^f \cdot (\varepsilon_{prefab}^f - 1) \end{cases} \quad (3)$$

here, t_{tech} - break time allotted for the repair and construction work planned during the day, min; α_n - coefficient taking into account the reliability of technical devices; k - volume mismatch ratio (1,1); β - reserve ratio (15%); $\varepsilon_{pass}^{hig-s}, \varepsilon_{pass}, \varepsilon_{pass}^{sub..}, \varepsilon_{fast}^f, \varepsilon_{prefab}^f$ - compression ratios for high-speed passenger, other passenger, popular, accelerated freight and thermal trains, respectively; $N_{pass.}^{hig-s}, N_{pass.}, N_{pass}^{sub..}, N_{fast}^f, N_{prefab}^f$ - the number of high-speed passenger, other passenger, mass, accelerated freight and thermal trains, pairs of trains/day, respectively.

In the above expressions, it is necessary to take into account the order of placing high-speed passenger trains in the schedule of trains available in the Joint Stock Company "Uzbekistan Railways". In particular, taking into account that the movement of high-speed passenger trains is partially carried out in a packet method, the coefficient of displacement of freight trains from the graph is described in scientific research [4, 16, 19] as follows:

$$\begin{cases} N_{available} = \dfrac{(1440 - t_{tech}) \cdot \alpha_n - \left(\dfrac{\sum_{i=1}^{k} (t_{pl.}^{if} + t_{pl.}^{ihig-s})}{k} - 1 + I_{hig-s} \cdot (N_{pass}^{hig-s} - 1) + t_{ov.} + t_{sl.} + \tau_n^{pr} + \tau_{sk} \right)}{I} \\ \varepsilon_{pass}^{hig-s} = \dfrac{1}{i \cdot N_{pass}^{hig-s}} \cdot \left((c_1 \cdot i + c_2) \cdot \left(\dfrac{t_{pl.}^{f} - t_{pl.}^{hig-s} + I_{passinarrival.} + I_{passindeparture} + t_{sl.} + t_{ov.}}{I} - n_{\max}^{T_0} - 1 \right) + \dfrac{c_2 \cdot (i-1) \cdot I_{hig-s}}{I} \right) \end{cases} \tag{4}$$

In the above researches, when determining the calculated train throughput and finding the maximum number of freight trains, the number of high-speed trains was reduced by half, and when calculating the coefficient of compression of freight trains, only the compression of trains in one direction was taken into account, and the compression of trains in the dependent direction was not considered. The problems of reducing the time interval between trains ($I_{high-speed}$) and the arrival times of consecutive high-speed passenger trains following freight trains ($I_{passinarrival.}$) and the total waiting time at freight train separation points on the Tashkent-Yangi Yangier double-track section equipped with an auto-blocking system were partially addressed. In order to study the above issue, the procedure for placing high-speed passenger trains in the train schedule was studied (Fig. 3.).

$$\begin{cases} \tau_2 - \tau_1 = I_{passindeparture} \\ \tau_4 - \tau_2 = t_{running}^{f} + t_{ov.} + t_{sl.} \\ \tau_5 - \tau_3 = t_{running}^{high-s} \\ \tau_5 - \tau_4 = I_{passinarrival} \end{cases} \Rightarrow \tau_3 - \tau_1 = I_{passindeparture} + t_{running}^{f} + t_{ov.} + t_{sl.} + I_{passinarrival.} - t_{running}^{high-s} \tag{5}$$

is considered, then the following equality is formed:

$$I_{high-s} = I_{passindeparture} + t_{running}^{f} + t_{ov.} + t_{sl.} + I_{passinarrival.} - t_{running}^{high-s} \tag{6}$$

This parity may only be able to send freight trains between bursts when the time interval between high-speed passenger trains is equal to or greater than a given value. If the time interval between high-speed passenger trains is less than a given value, freight trains cannot be placed between bursts, and in this schedule, high-speed trains are sent in a partially burst fashion. [4, 7, 10, 11].

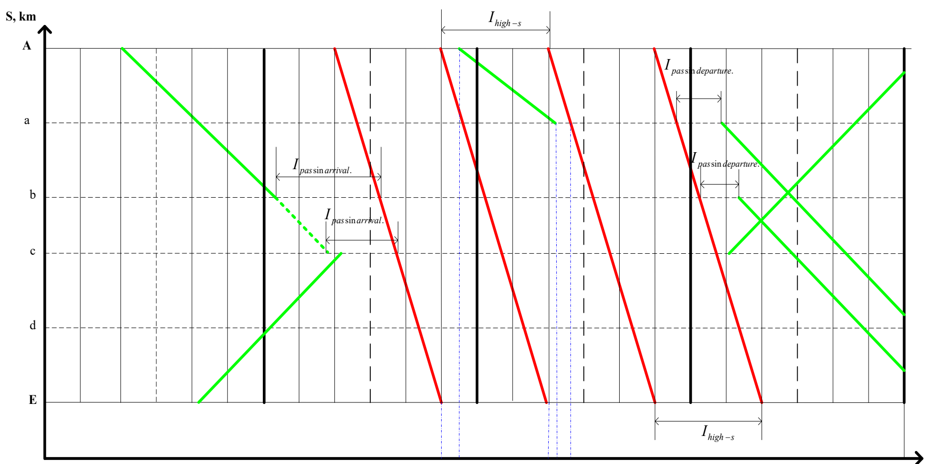

Fig. 3. The procedure for placing high-speed passenger trains on the graph

The arrival times of successive freight and high-speed passenger trains at the separation points and the downtime when crossing trains are analyzed. To determine the minimum exposure time value, the following graph is used: (Fig. 4.).

Based on the graph above, when trains are sent sequentially, the minimum time for them to stop when overtaking a freight train at the separation point is:

$$T^{\min}_{simple} = I_{passindeparture} + I_{passinarrival.} + I_{high-s} \cdot (N^{high-s}_{pass.} - 1) \tag{7}$$

If such a situation occurs when trains cross at separation points, then it is defined as follows:

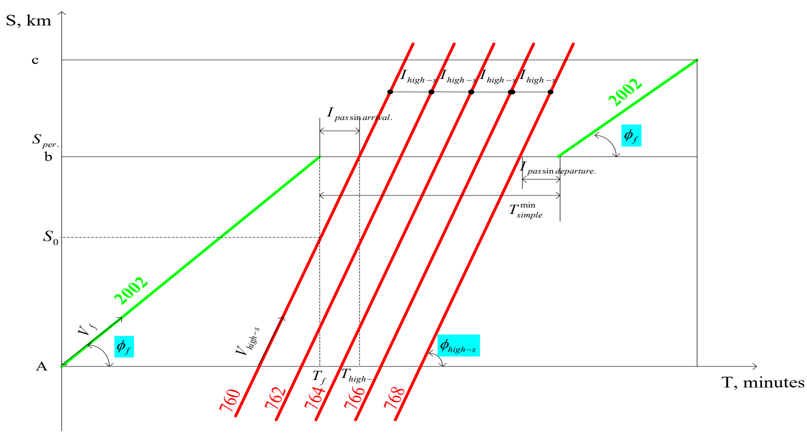

Fig. 4. Freight train standing time during overtaking

$$T^{\min}_{simple} = \tau_{arrival} + \tau_{cross} + I_{high-s} \cdot (N^{high-s}_{pass.} - 1) \tag{8}$$

Along the way, the time of successive arrivals of freight and high-speed passenger trains to the separation points is recorded. In this case, when high-speed passenger trains move at speeds up to 250 km/h, the route must be prepared 10 minutes before reaching the separation point, and the distance of the train approach to the station must be at least three block sections (Fig. 5. and Fig. 6.) [1, 8, 9, 15].

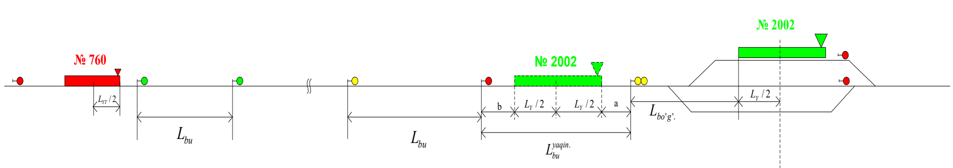

Fig. 5. Technological scheme of freight and high-speed passenger trains arriving sequentially along the route to the separation points

$$I_{passinarrival.} = t^{reserve}_{marsh.} + 0{,}06 \cdot \frac{(L_{nec.} + L^{y.}_{bu} - \mathrm{b})}{(\mathrm{V_f}/2)} + 0{,}06 \cdot \frac{(L_{nec.} + n \cdot L_{bu} + (L_f/2 + L_{high-s}/2))}{\mathrm{V_{high\text{-}s}}} \tag{9}$$

here, $t_{marsh.}^{reserve}$ - sum of route preparation time and additional reserve for a high-speed passenger train arriving in one direction, min.; $L_{nec.}$ - throat length separation point, m .; $L_{bu}^{y.}$ - length of the section of the first block in the area of the place of separation, m; V_f , $V_{high\text{-}s}$ - speed of freight and high-speed passenger trains, respectively, in km/h; n - number of block plots; b - distance between insulated rails and traffic lights, m; L_f , $L_{high\text{-}s}$ - length of freight and high-speed passenger trains, respectively, m; L_{bu} - length of block sections, m.; ($L_{bu} = 1000 \div 2200$ м.).

3 Result and discussion

As a result of calculations performed using the MatLab programming language, we create the following graphs:

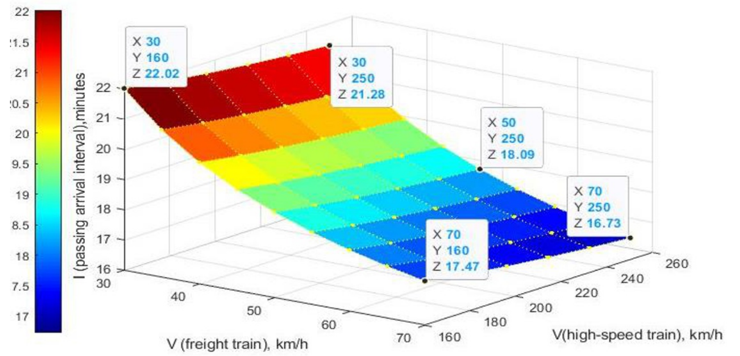

Fig. 6. Graph of the arrival time interval of successive high-speed passenger trains traveling in the same direction after freight trains at separation points, depending on the speed of the trains

Similarly, the dependence of the total delay time of freight train No. 2002 as a result of the passage of high-speed trains, on the time interval of the successive arrival of $N_{pass.}^{high-s}$ several fast trains at the separation point, is displayed. (Fig. 7.).

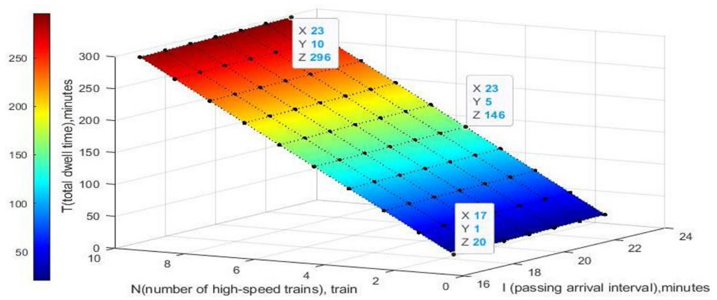

Fig. 7. A plot of the total dwell time of freight trains as a result of passing high-speed passenger trains at the separation point, as a function of the time interval of consecutive track arrivals

In general, on the basis of the technology of connecting high-speed trains, the mathematical model of the total waiting time at the points of separation of freight trains when sending them in a partial package in a graph depends on the number of destination stations of high-speed passenger trains. (Fig. 8.) [1, 17, 18]:

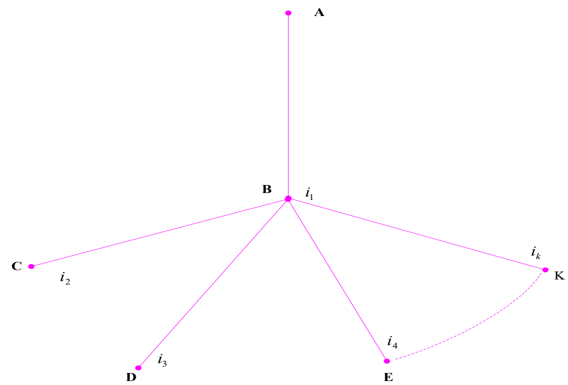

Fig. 8. Technology to dispatch high-speed passenger trains in a connected manner based on destinations

$$T^{\min}_{simple}(N^{h-s}_{pas.}, \mathrm{V}_{\text{h-s}}, \mathrm{V}_{\text{f}}) = \begin{cases} N^{h-s}_{pas.} = 2 \cdot n \Rightarrow I_{pass\,in\,departure} + I_{pass\,in\,arrival.} + I_{h-s} \cdot (\frac{N^{h-s}_{pas.}}{2} - 1) \\ N^{h-s}_{pas.} = 2 \cdot n \pm 1 \Rightarrow I_{pass\,in\,departure} + I_{pass\,in\,arrival.} + I_{h-s} \cdot \frac{(N^{h-s}_{pas.} - 1)}{2} \\ i \in \{1,2,3,...,k\}; \quad n \in \forall N \end{cases} \quad (10)$$

here - $\mathrm{V}_{\text{f}}, \mathrm{V}_{\text{high-s}}$ - speed of freight and high-speed passenger trains, respectively, km/h; $N^{high-s}_{pass.}$ - number of high-speed passenger trains, train; n - any set of natural numbers; i - the number of destination stations to which trains are intended to go; $I_{pass\,in\,departure}$ - time interval of consecutive arrival of freight and high-speed passenger trains to the separation points, min.; $I_{pass\,in\,arrival.}$ - time interval of high-speed passenger and freight train departures from the separation points in a row, min.; I_{high-s} - time interval between high-speed passenger trains in partial package dispatch, min .

On fig. 9 it is shown the result for an even and odd number of trains.

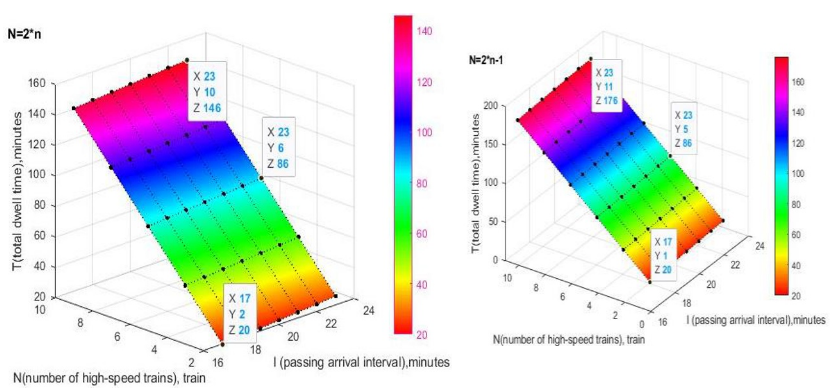

Fig. 9. Waiting time for freight trains at the separation point based on high-speed passenger train connection technology

As a result of applying the technological methods proposed above, based on mathematical models, changes in the displacement coefficient of freight trains according to the schedule and their maximum number that can be passed through certain sections were analyzed (Fig. 10 and Fig. 11).

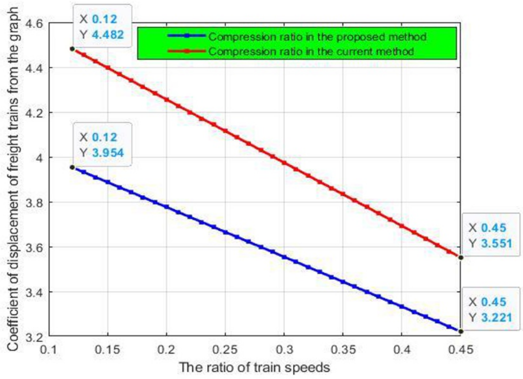

Fig. 10. Comparative analysis of the displacement factor of freight trains according to the schedule

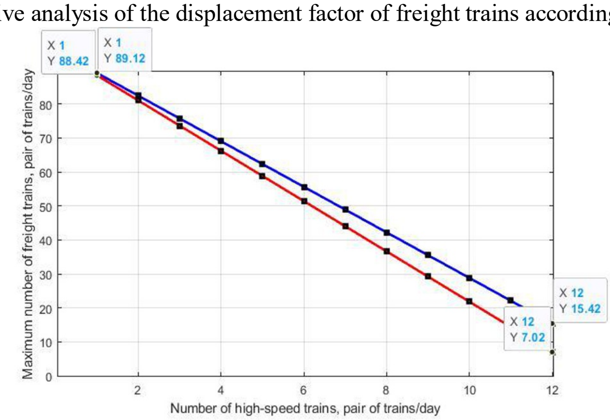

Fig. 11. The graph of the relationship of the maximum number of freight trains that can be passed through a certain section during the day, to the number of high-speed passenger trains

4 Conclusion

Taking into account the urgency of increasing the throughput of freight trains of sections with mixed traffic, we can say that the following results have been achieved based on the above proposed methods: the arrival time of freight and high-speed passenger trains arriving at the separation points consecutively in one direction is reduced from 30 minutes to 17÷23 minutes according to the speed of the trains. , that is, an average reduction of 33%; Based on train connection technology, the total waiting time at freight train separation points is reduced from 153 minutes to 86 minutes for partial packets (5 trains in an average packet), i.e., an average reduction is 43.8%; The coefficient of displacement of freight trains from the schedule, in turn, depending on the speed of trains (70/160) will decrease by an average of 9.3%. The proposed methods will increase the maximum number of freight trains that can be passed from the site during the day, up to 24.1% with the number of high-speed passenger trains 10 pairs of trains/day.

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