Measures of effective use of the capacity of two-track sections of JSC "Uzbekistan Railways"

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Abstract. The article first presents the analysis of the complete structure of all two-track sections of JSC "Uzbekistan Railways" with mixed traffic, and then the proposals of local and foreign scientists regarding the determination of the coefficient of displacement of freight trains from the graph on two-track sections in conditions of mixed traffic of trains are described in detail. In addition, the factors affecting the displacement coefficient of freight trains from the graph were analyzed, as well as the reduction of the time interval of the arrival of freight and high-speed passenger trains that arrive at the separation points in a row in the track direction, and as a result of the organization of train movement based on the technology of connecting, increasing the maximum number of freight trains in the sections suggestions were made regarding the issues.

1 Introduction

Currently, a series of measures are being implemented to accelerate the transport-transit potential of our Republic, including the creation of new transport corridors (Trans-Afghan, China-Kyrgyzstan-Uzbekistan, etc.), acquisition of new power plants, etc. Undoubtedly, these measures will create a basis for increasing cargo flows and the number of transit freight trains in the future. In this case, due to the increase in the number of freight and high-speed passenger trains on sections with a mixed traffic system, there will be more delays of freight trains, a decrease in the throughput capacity of the section, an increase in delivery times of goods, and an increase in various cases of damage due to the delay of goods. Therefore, it is necessary to avoid the occurrence of disputed situations between the railway and customers. Increasing the throughput capacity of freight trains on double-track sections with a mixed traffic system is one of the pressing issues to prevent such situations.

The Joint-Stock Company "Uzbekistan Railways" has launched the high-speed passenger train "Afrosiyob" on routes between Tashkent-Samarkand, Samarkand-Karshi, and Samarkand-Bukhara. The plan is to begin running this train on sections of the Bukhara-Mishken route. In addition to ensuring the safe operation of high-speed passenger trains on

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these routes, the issue of accommodating freight trains is also crucial. To calculate the train-passing capacity of sections, it is necessary to analyze the technical indicators of each section. The Tashkent-Samarkand section consists of 31 stations, the Tashkent-Yangi-Yangier and Jizakh1-Samarkand sections are double-track, and the Yangi Yangier-Jizakh1 section consists of a separate high-speed mainline and tracks for freight trains [8, 10, 13, 21].

The railway section between Samarkand and Marakand is double-track, while the Marakand-Karshi section is single-track. The Samarkand-Karshi section consists of 10 sections, with a length of 16.5 km for the Samarkand-Marakand section and 139.8 km for the Marakand-Karshi section. The Samarkand-Navi section, which is 156 km long, is a double-track railway consisting of 11 stations. The Navi-Bukhara-1 section is 91.9 km long and is a single-track railway consisting of 6 stations. As can be seen from the analysis above, the Tashkent-Yangi-Yangier, Yangi-Yangier-Jizakh-1, Jizakh-1-Samarkand, and Samarkand-Navai sections are double-track sections where high-speed passenger trains run. The structure of these sections is presented in Fig.1 [8, 10, 13, 21].

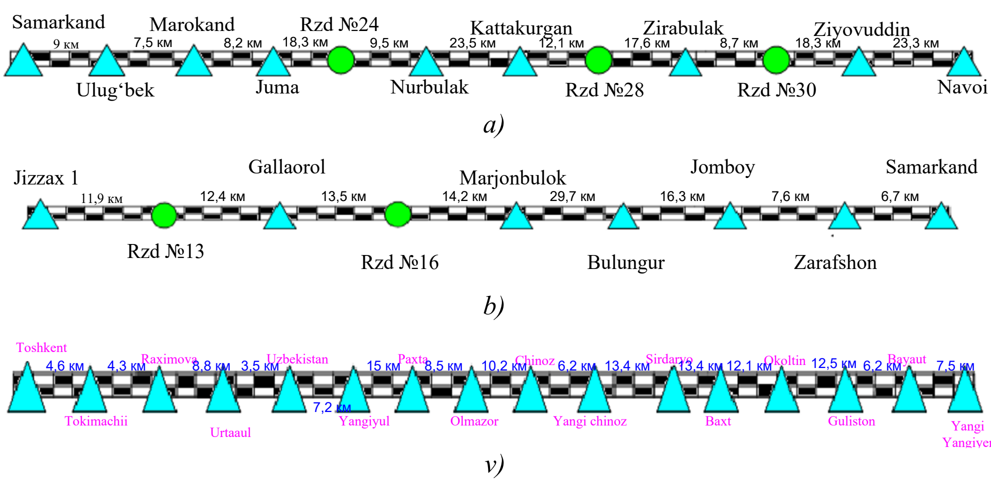

Fig.1. Technical parameters of double-track sections with high-speed traffic at JSC "Uzbekistan Railways": double-track section Samarkand-Navoi; b-double-track section Jizzakh-1-Samarkand; v-double track section Tashkent-Yangi Yangier

In terms of technical specifications, the length of tracks capable of high-speed movement is 748.2 km. Despite only accounting for 10.1% of the total railway length, these sections handle the majority of freight traffic.

2 Materials and Methods

Therefore, it is necessary to study and analyze the dependence of the time interval $\left(\Delta N_{reserve} = f\left(\Delta t,\, N_{high-speed}\right)\right)$ between sequentially arriving freight and high-speed trains, the total travel time of freight trains at separation points to accommodate high-speed passenger trains, and to find mathematical patterns for reducing travel time. To calculate the capacity reserve for freight trains on double-track sections with mixed traffic of the Joint-Stock Company "UZBEKISTAN RAILWAYS" and to study the factors affecting it $\left(\varepsilon = f\left(\Delta t,\, N_{high-speed}, I_{passin.arrival}\right)\right)$ such as the displacement coefficient of freight trains from the schedule due to consecutive high-speed passenger trains sent on their way to separation points.

Overall, according to the guidelines [1], the train capacity of railway sections is differentiated into calculated and actual. The calculated train capacity is determined as the maximum number of freight trains (pairs of trains) of a given weight and length that pass through a given section in a unit of time (day), in accordance with the technical equipment of the railway station and the train traffic organization method. The required capacity is usually less than the calculated capacity, taking into account that different classes of trains displace freight trains. The demand capacity is the number of trains per day required to fulfill the transportation plan.

Currently, analytical, graph-analytical, and simulation modeling methods are widely used to determine the capacity of a computational train. Of course, the displacement factor of freight trains from the schedule has a significant impact on train capacity. To do this, it is necessary to analyze the factors influencing the displacement coefficient of freight trains from the schedule (Figure 2).

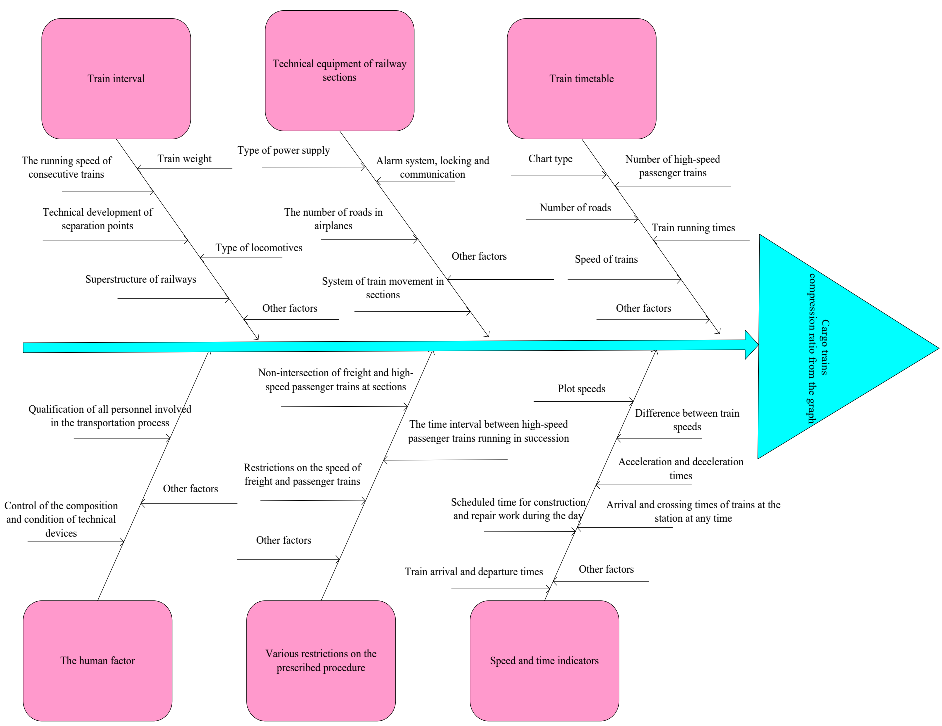

Fig. 2. Analysis of factors affecting the displacement coefficient of freight trains according to the schedule

Based on the analysis, in accordance with the conditions for organizing the movement of trains in “UZBEKISTAN RAILWAYS” JSC, the possibility of passing freight trains on existing sections and the shift coefficient from the schedule were explained by the following functions [1-3, 12-13].

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

Here, A - the number of tracks at stations and sections; S - haul length, km; Q - Technical equipment of railway sections; L - type of traction; Δt - time interval between successive high-speed passenger trains, min; Δt - 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 in certain sections; ϑ_f, $\vartheta_{high-speed}$ - the given speed of freight and high-speed passenger trains on separate sections, km/h; q_1, q_2 - other conditions.

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

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

Up to the present time, a multitude of scientists have carried out scientific investigations and submitted their recommendations for calculating the coefficient of displacement of cargo trains on double-track sections as per the established timetable and resolving the aforementioned issues. Notable researchers in this regard include Abramov A.A., Volkov G.M., Groshev B.M., Maksimovich F.P., Kochnev A.K., and Ugryumov A.K. (As presented in Table 1 and supported by references [4, 5, 6, 20]).

Table 1. Method for determining the coefficient of displacement of freight trains according to the schedule on double-track sections

Displacement ratio determination method	Freight train displacement ratio 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	$\varepsilon = \frac{t_f \cdot (1-\Delta) + I_{passinarrival.} + I_{passindeparture} + t_{sl.} + t_{ov.}}{I} + 0.2$
A.K. Ugryumov	$\varepsilon = \frac{t_f \cdot (1-\Delta) + I_{passinarrival.} + I_{passindeparture} + t_{sl.} + t_{ov.} - I}{I} + \frac{I-1}{2 \cdot I}$
A.A. Abramov A.N. Goliguzova	$\left[\begin{array}{l} \varepsilon = \frac{t_f \cdot (1-\Delta) \cdot (0{,}8 - 0{,}005 \cdot N_{hig-s}) \cdot}{I} + 2.5 - 0.01 \cdot N_{hig-s} - \Delta \cdot (0.85 - 0.011 \cdot N_{hig-s}) \\ \Delta = \frac{t_{hig-s}^{running}}{t_f^{running}} \end{array} \right.$
According to instructions	$\varepsilon_2 = \frac{(T_f + I_{hig-s}) \cdot (1-\Delta)}{2 \cdot I_{hig-s}} - \frac{T_f \cdot (1-\Delta)}{2 \cdot (I_{passinarrival.} \cdot (1+\gamma) + t_{sl.})} + 1.5$

In general, we write the estimated capabilities of freight trains and their maximum number based on methodological recommendations [1] and scientific research [2, 3, 14, 19] as follows:

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

Here, t_{tech} - the break time allotted for routine maintenance and construction work during the day, min; α_n - coefficient taking into account the reliability of technical devices; k - coefficient of uneven volume of traffic (1.1); β - reserve factor (15%); $\varepsilon^{hig-s}_{pass}$, ε_{pass}, $\varepsilon^{sub..}_{pass}$, ε^f_{fast}, ε^f_{prefab} - compression ratios for high-speed passenger, other passenger, mass, accelerated freight and thermal trains, respectively; $N^{hig-s}_{pass.}$, $N_{pass.}$, $N^{sub..}_{pass}$, N^f_{fast}, N^f_{prefab} - 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 procedure for placing high-speed passenger trains in the train schedule available at JSC "Uzbekistan Railways". In particular, taking into account the fact that the movement of high-speed passenger trains is partially carried out in a batch way, the coefficient of displacement of freight trains from the schedule is described in scientific studies [4, 16, 19-24] as follows:

$$\begin{cases} N_{available} = \dfrac{(1440 - t_{tech}) \cdot \alpha_n - \left(\dfrac{\sum_{i=1}^{k} (t^{if}_{pl.} + t^{ihig-s}_{pl.})}{k} - 1 + I_{hig-s} \cdot (N^{hig-s}_{pass} - 1) + t_{ov.} + t_{sl.} + \tau^{pr}_n + \tau_{sk} \right)}{I} \\ \varepsilon^{hig-s}_{pass} = \dfrac{1}{i \cdot N^{hig-s}_{pass}} \cdot \left((c_1 \cdot i + c_2) \cdot \left(\dfrac{t^f_{pl.} - t^{hig-s}_{pl.} + I_{passin arrival.} + I_{passin departure} + t_{sl.} + t_{ov.}}{I} - n^{T_0}_{\max} - 1 \right) + \dfrac{c_2 \cdot (i-1) \cdot I_{hig-s}}{I} \right) \end{cases} \quad (4)$$

In the aforementioned scientific studies, when determining the calculated train capacity and finding the maximum number of freight trains, the number of high-speed trains was halved, and when calculating the compression coefficient of freight trains, only compression in one direction was taken into account, while compression in the opposite direction was not considered. The issues of reducing the time interval between trains ($I_{high-speed}$) and the arrival time of consecutive high-speed passenger trains following freight trains ($I_{passin arrival.}$), as well as the total waiting time at the points of separation of freight trains on the double-track section of Tashkent-Yangi-Yangier equipped with an automatic blocking system, were partially resolved. To study the aforementioned issue, the order of placing high-speed passenger trains in the train schedule was examined (Figure 3).

$$\begin{cases} \tau_2 - \tau_1 = I_{passin departure} \\ \tau_4 - \tau_2 = t^f_{running} + t_{ov.} + t_{sl.} \\ \tau_5 - \tau_3 = t^{high-s}_{running} \\ \tau_5 - \tau_4 = I_{passin arrival} \end{cases} \Rightarrow \tau_3 - \tau_1 = I_{passin departure} + t^f_{running} + t_{ov.} + t_{sl.} + I_{passin arrival.} - t^{high-s}_{running} \quad (5)$$

$\tau_3 - \tau_1 = I_{high-s}$ is considered, then the following equality is formed:

$$I_{high-s} = I_{passin departure} + t^{f}_{running} + t_{ov.} + t_{sl.} + I_{passin arrival.} - t^{high-s}_{running} \tag{6}$$

From this equation, we can conclude that if the time interval between high-speed passenger trains is equal to or greater than a given value, then it is possible to send freight trains between packets. If the time interval between high-speed passenger trains is less than a given value, freight trains cannot be placed between packages, and in this column, high-speed trains are sent in a partially-packet way [4, 7, 10, 11, 20-22].

We analyze the arrival time of successive freight and high-speed passenger trains at the separation points and the downtime when trains cross. The following plot was used to determine the minimum residence time value (Figure 4).

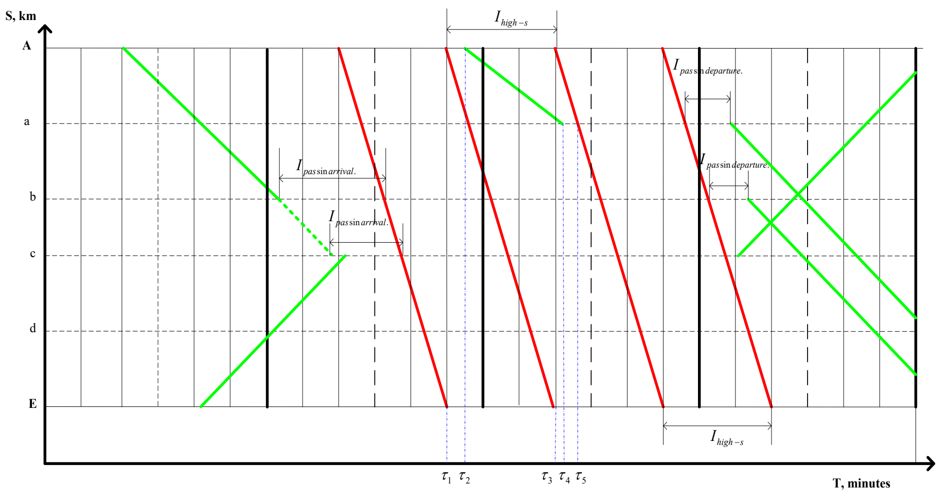

Fig. 3. The order of placement of high-speed passenger trains on the chart

Based on the graph above, when sending trains in a row, when overtaking a freight train at a separation point, the minimum waiting time for them is:

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

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

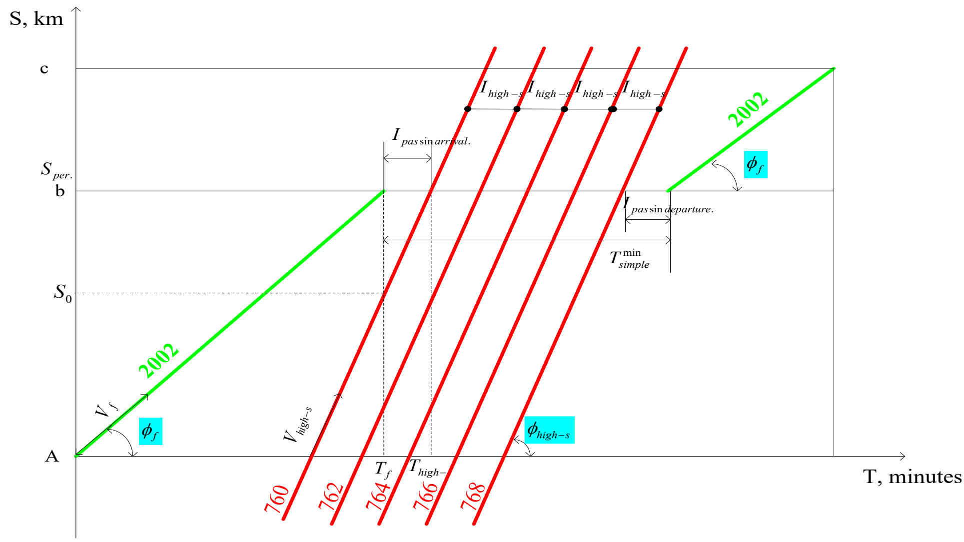

Fig. 4. Waiting time for a freight train when overtaking

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

Let us fix the time of successive arrival of freight and high-speed passenger trains at the separation points. In this case, when high-speed passenger trains move at speeds up to 250 km/h, the route must be prepared 10 minutes before arrival at the separation point, and the distance of the train approach to the station must be at least three block sections (Fig. 5, 6) [1, 8, 9, 15, 21].

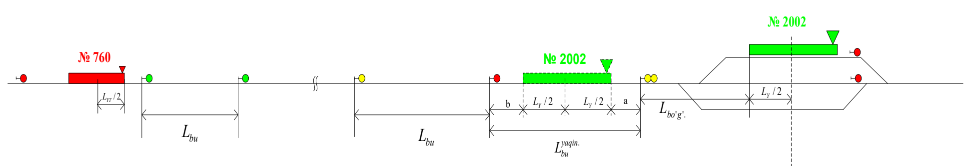

Fig. 5. Technological scheme of freight and high-speed passenger trains arriving sequentially along the way to the separation points

$$I_{passinarrival.} = t^{reserve}_{marsh.} + 0.06\cdot\frac{(L_{nec.}+L^{yaqin.}_{bu} - \mathrm{b})}{(\mathrm{V_f}/2)} + 0.06\cdot\frac{(L_{nec.}+n\cdot L_{bu}+(L_f/2+L_{high-s}/2))}{\mathrm{V_{high\text{-}s}}} \qquad (9)$$

Here, $t^{reserve}_{marsh.}$ - the sum of the route preparation time and the additional reserve of the arriving high-speed passenger train, min; $L_{nec.}$ - length of the neck of the separation point, m; $L^{yaqin.}_{bu}$ - length of the section of the first block in the area of the place of separation, m; , $\mathrm{V_f}, \mathrm{V_{high\text{-}s}}$ - speed of freight and high-speed passenger trains, respectively, km/h; n - number of block sections; b - distance between the interval of insulated rails and the traffic light, m; $L_f, L_{high\text{-}s}$ - length of freight and high-speed passenger trains, respectively, m; L_{bu} - length of block sections, m ($L_{bu} = 1000 \div 2200$ m).

Result and discussion

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

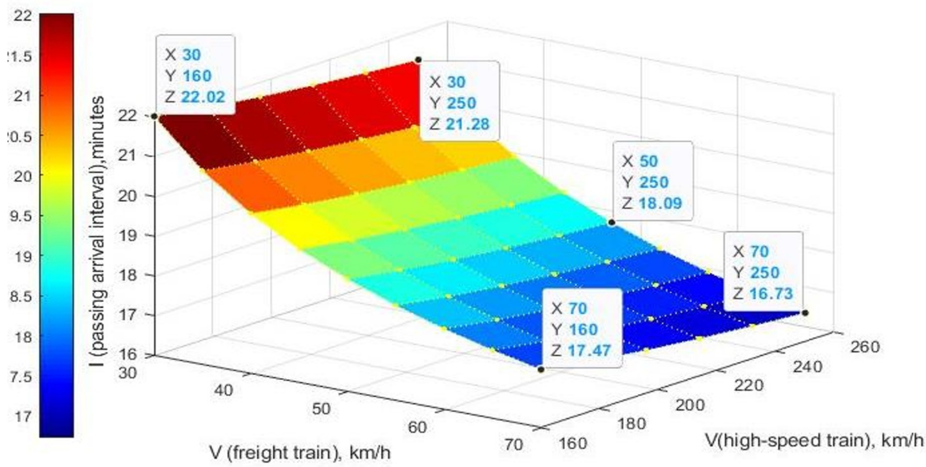

Fig. 6. Graph of the time interval of the arrival of successive high-speed passenger trains on the route of freight trains at the points of separation and the speed of trains

Similarly, as a result of freight train No. 2002 $N_{pass.}^{high-s}$ passing high-speed passenger trains at the separation point, the total waiting time depends on the time interval of successive arrivals on the track (Fig. 6).

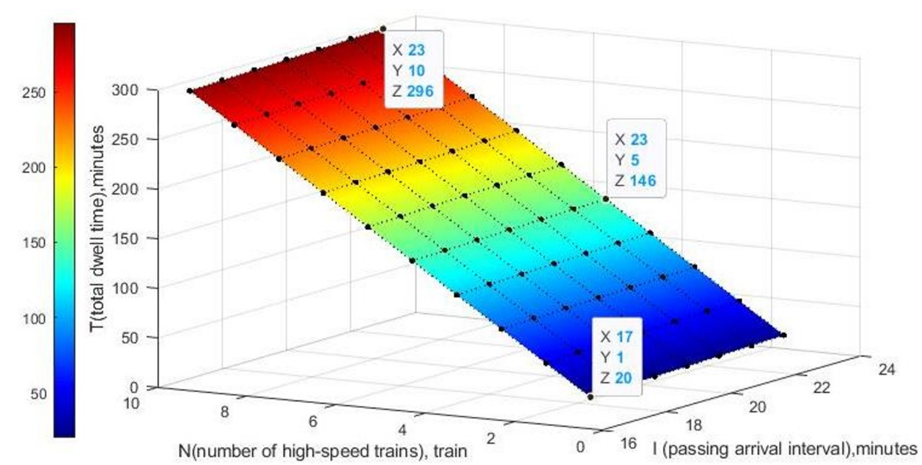

Fig. 7. Graph of the total idle time of freight trains as a result of the passage of high-speed passenger trains at the separation point, depending on the time interval of successive arrivals on the track.

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In general, based on 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 the column depends on the number of destination stations to which high-speed passenger trains run (Fig. 8) [1, 17, 18]:

$$T_{simple}^{\min}(N_{yo'l.}^{YT},\mathrm{V}_{\mathrm{YT}},\mathrm{V}_{\mathrm{Y}})=\begin{cases} N_{yo'l.}^{YT}=2\cdot n\ \Rightarrow I_{yo'lakay\ jo'n..}+I_{yo'lakay\ yet.kel.}+I_{YT}\cdot(\dfrac{N_{yo'l.}^{YT}}{2}-1) \\ N_{yo'l.}^{YT}=2\cdot n\pm 1\ \Rightarrow I_{yo'lakay\ jo'n..}+I_{yo'lakay\ yet.kel.}+I_{YT}\cdot\dfrac{(N_{yo'l.}^{YT}-1)}{2} \\ i\in\{1,2,3,...,k\};\quad n\in\forall\ N \end{cases} \qquad (10)$$

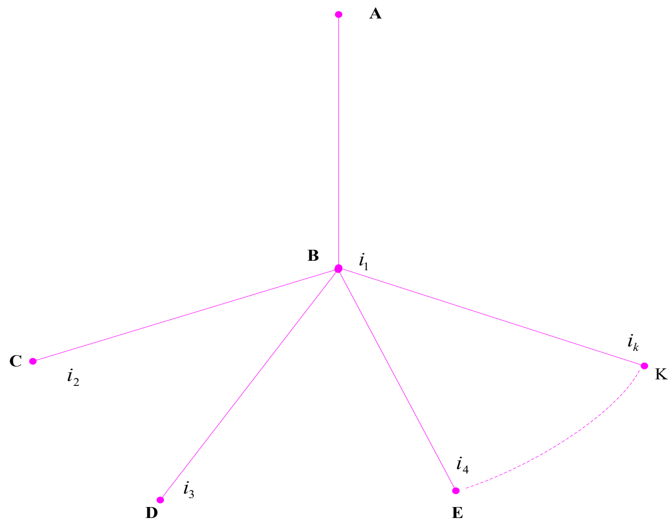

Fig. 8. Technology for connecting high-speed passenger trains by directions

Figure 9 shows the result for an even and odd number of trains.

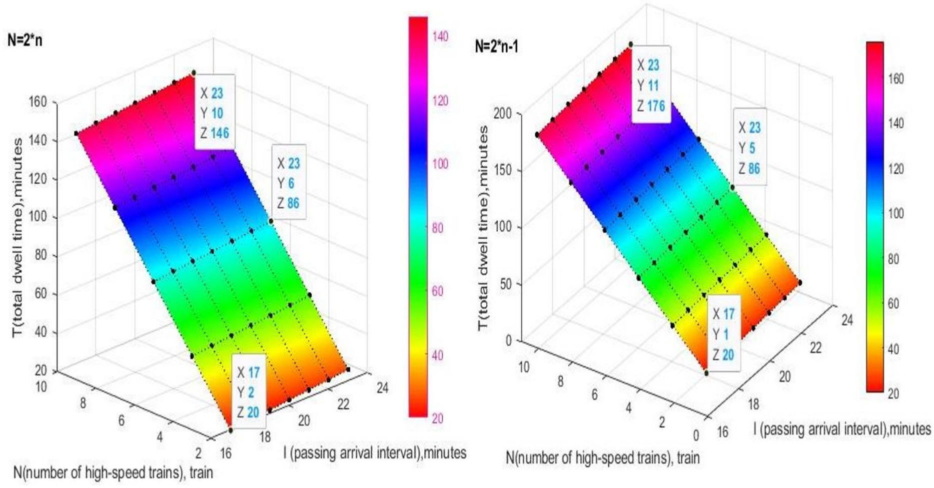

Fig. 9. Waiting time for freight trains at a separation point based on high-speed passenger train connection technology

By utilizing the technological methods outlined above and employing mathematical models, we analyzed changes in the coefficient of displacement for freight trains from their scheduled routes, as well as the maximum number of trains hat can be transported through individual sections.

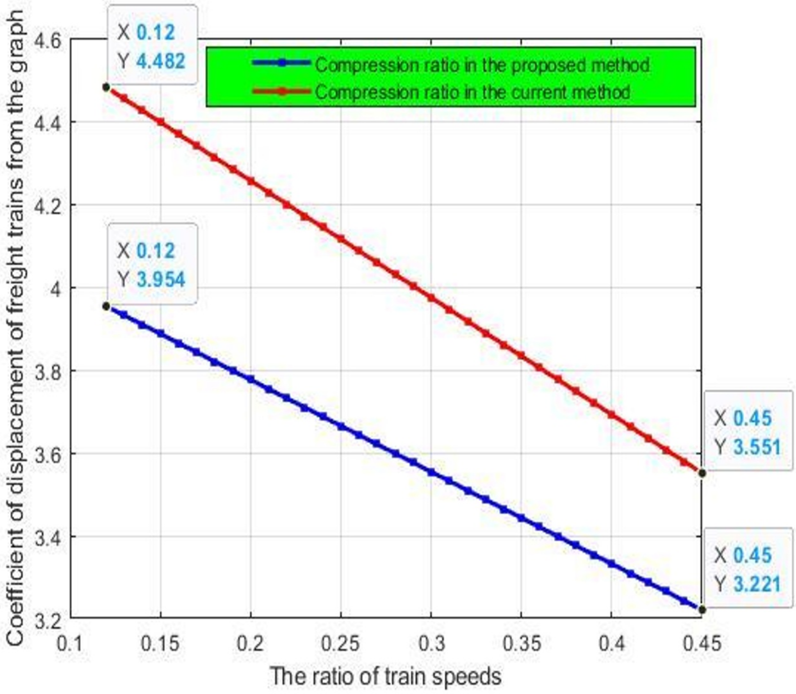

Fig. 10. Comparative analysis of the coefficient of displacement of freight trains from the graph

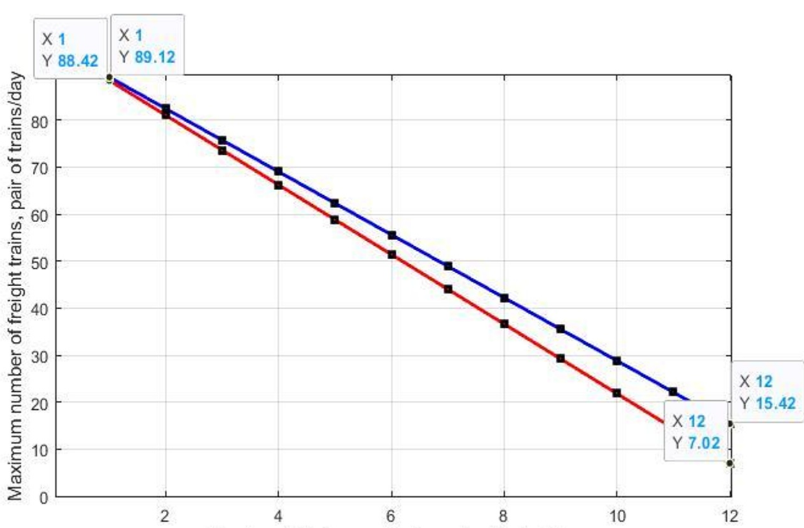

Fig. 11. Graph of the relationship between the maximum number of freight trains that can be passed through this section during the day, and the number of high-speed passenger trains

Conclusion

The analysis of the results shows that the arrival time of consecutive freight and high-speed passenger trains in the points of separation is reduced from 30 minutes to 17-23 minutes depending on the speed of the trains, achieving an average reduction of 33%. Using train coupling technology, the total waiting time for freight trains at separation points is reduced from 153 minutes to 86 minutes when sending partial packages (an average of 5 trains per package), resulting in an average reduction of 43.8%. The deviation coefficient of freight trains from the schedule, in turn, decreases by an average of 9.3% depending on the speed of the trains (70/160). The proposed methods allow for an increase in the maximum number of freight trains that can be transferred from the section during a day by up to 24.1% with 10 pairs of high-speed passenger trains per day.

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