To study the impact of different types of train traffic management technologies on the performance of railway operations

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Abstract. In this article information to investigate the impact of various train traffic management technologies on the operational efficiency of the railway section. A train movement graph is presented along with the calculation of key throughput indicators and the results of their comparative analysis. By rerouting freight trains following the existing route, the level of congestion on the section has been reduced, and the main indicators of the train movement graph have been improved.

INTRODUCTION

The strategy for the development of the transport system of the Republic of Uzbekistan until 2030 and the business plan for the railways of Uzbekistan for 2023 envisage the development of transport infrastructure, the development of measures to increase the transport capacity and throughput of the railway, the development of high-speed train traffic, the implementation of modern mechanisms in transport organization, as well as the creation of scientific foundations for increasing the throughput of railway lines.

Undoubtedly, in conditions of limited economic resources, the identification and implementation of ways to introduce resource-saving and alternative methods of organizing the movement of trains of various types on railway sections will contribute to the development and growth of our national economy.

The priority directions for the development of railways include increasing the reserve capacity of the existing line through the organization of passenger and freight train traffic at the maximum permissible speed and improving the performance indicators of the railway. This is achieved by increasing the length of existing freight trains compared to the norm, combined and standard composition, through the implementation of additional operations at the station receiving and sending routes.

EXPERIMENTAL RESEARCH

Research on the organization of train traffic of different types and the rational use of capacity, calculation of capacity and throughput of railway sections and stations, the influence of the duration of the technological "window" on the capacity of trains on the railway section, development of simulation models of transport processes, train movement under changing conditions, includes evaluation of random factors of organization, etc. [1-12, 23-25]. In the studies of modern foreign and domestic scientists, changes in infrastructure and parameters of railway lines and their influence on capacity and throughput are also taken into account [13-16].

In the scientific work of Kochnev, issues of comprehensive increase in the speed of freight and passenger trains on the railways of Russia and other countries were studied [17]. According to the author, solving the problem of increasing the speed of passenger trains by technical and organizational measures is not feasible. In his scientific work, the author emphasizes the need to bring the speed indicators of freight trains as close as possible to the indicators of passenger trains and to consider the efficiency obtained from their increase. However, the author has insufficiently studied the increase in train flows and at the same time the limit of their influence on the organization of train traffic of different categories, as well as its impact on the performance of the section.

In the scientific research of Bessonenko, issues of evaluating the capacity of railway sections were considered, including the calculation of the number of accelerated and high-speed trains on specialized sections [18]. In his calculations, the profile of the section was not taken into account, as well as the choice of a specific series of locomotives, weight norm, and standard length of the rolling stock used, and the different arrangement of trains in the schedule.

A.Y. Mironov [22] in his scientific work investigated the possibility of moving freight trains with a longer than standard train composition along the section according to a fixed schedule. However, the author did not pay enough attention to the issue of the movement of such trains along polygons with limited financial resources.

Landex A, Kaas A. H., Hansen S [21] in his scientific work focused on determining the throughput capacity of freight trains on one- and two-track sections in a non-parallel type of train movement schedule using the coefficient of "exclusion". However, not enough attention was paid to the calculation of the value of this coefficient. In addition, issues related to the ratio of passenger and freight train speeds in different types of traffic were also considered.

In the scientific research of A.A. Grachev [20] considered the possibility of non-stop freight trains on two-track sections with the construction of a three-track turnout structure. The authors did not consider the possibility of non-stop trains on existing sections (without the construction of artificial structures) in this research, and did not conduct a comparative analysis of their organization using different methods.

With a sufficient capacity of the railway section, stable passage of freight and passenger trains is achieved. Under conditions of increased train traffic volumes, there is a deficit in the section's throughput capacity. As a result, interruptions occur in the technological work processes of stations and sections, which leads to inefficient stops of rolling stock. Therefore, for the smooth and uninterrupted operation of stations and sections, they must have a certain reserve of throughput capacity.

By implementing reconstructive measures requiring large capital investments, it is possible to significantly increase the throughput capacity of the sections. When there is no need for this, it becomes possible to maintain the necessary reserve of sections' throughput capacity without unnecessary expenses through the application of organizational and technical measures. Taking into account these considerations and the analysis carried out above, as well as the fact that high-speed passenger trains of JSC "UTY" currently have a capacity reserve of 12-18%, we conclude that it is advisable to carry out organizational and technical measures on them [4,11,14].

As a result of the analysis, competitive technological options were identified, formed using the following organizational and technical measures for comparison with the current technology (C) for passing trains of various categories through a railway section:

- technology of joint passage of normally composed and combined freight trains through the railway section (B);
- technology of joint passage of freight trains of standard composition and over-standard composition through a railway section (D).

It is advisable to study and compare the performance indicators of the section in the technology of passing trains of various categories through the railway section.

RESEARCH RESULTS

Modern train traffic organization technology (S) is widely utilized in train rerouting on railway networks. In this technology, trains are constructed to specified lengths and weights, and with increasing volumes of transported goods, the number of freight trains operating on a segment increases, as well as the number of train stops at intermediate stations, leading to a decrease in segment speed. Consequently, there is a reduction in the platform's reserve carrying capacity.

Since the number of trains running on the U-X railway section is uneven, it is appropriate to distribute it based on the laws of distribution (fig.1)

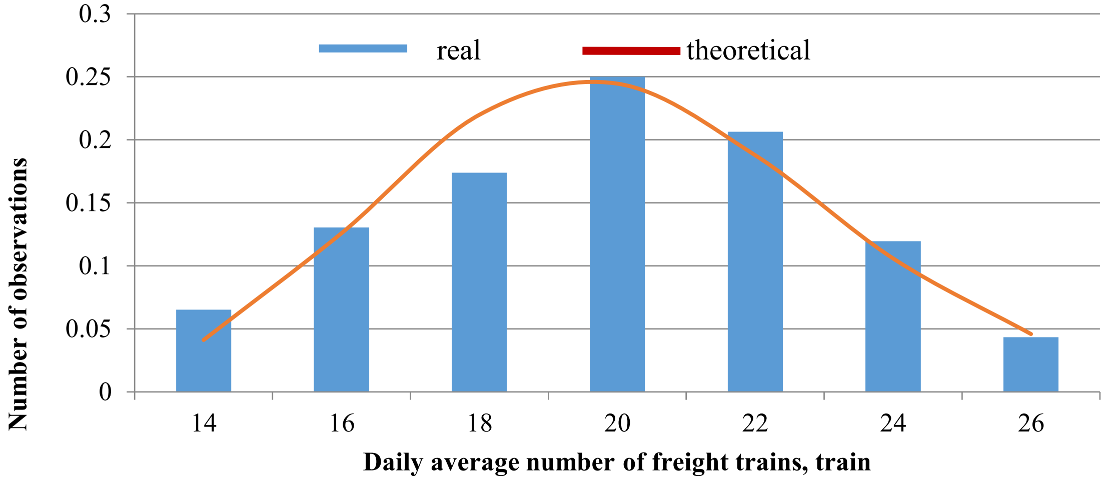


FIGURE 1. Statistical and theoretical distribution of the number of trains running on the U-X railway section per day.

Based on statistical data processing, it turned out that the number of trains running on the U-X railway section obeys the law of Normal distribution. The function of the law of Normal distribution has the following appearance [13,14]:

$$f(\mathrm{X}) = \frac{1}{\sqrt{2\cdot\pi}\sigma\mathrm{X}_i}\cdot e^{-\frac{(\mathrm{X}-\mathrm{X}_{aver})^2}{2\cdot\sigma^2}}, \quad (11)$$

there, $\mathrm{X}_{aver} -$ the average number of transit recyclable wagons (constituent wagons) is; $\sigma -$ mean quadratic deviation; $\mathrm{X}_i -$ i-day wagon current (number of cars included).

Based on combined and long-haul freight train transmission technologies (B), as well as long-haul and standard (D) train transmission technologies without altering their technical equipment, are widely applied in practice. Trains of combined and standard lengths, as well as standard and extended lengths, are constructed according to these technologies, and their dispatch along designated routes according to the movement schedule is carried out based on an approved schedule in coordination with the train dispatcher. In these technologies, the overall number of trains operating on a given segment decreases because the trains are longer than usual and are arranged in a combined composition. As a result, the required power decreases, allowing for additional trains to be operated according to the schedule and reducing non-operational losses of railways. The quantity of combined and longer-than-usual trains, created using these technologies, depends on their share in the overall flow (α_{bp},α_{mu}, respectively).

The investigation of the existing train rerouting technology, as well as the throughput capacity and performance of the railway segment, is illustrated in Figures 2-5. An increase in transport volumes (when the number of freight and passenger trains varies from minimum to maximum due to seasonal and annual irregularities in train movements) leads to an increase in the number of train stops at intermediate stations and simultaneously to a decrease in sectional train speed. The primary reason for this is the prioritized planning of train movements and the planning of high-speed train movements (Fig. 2).

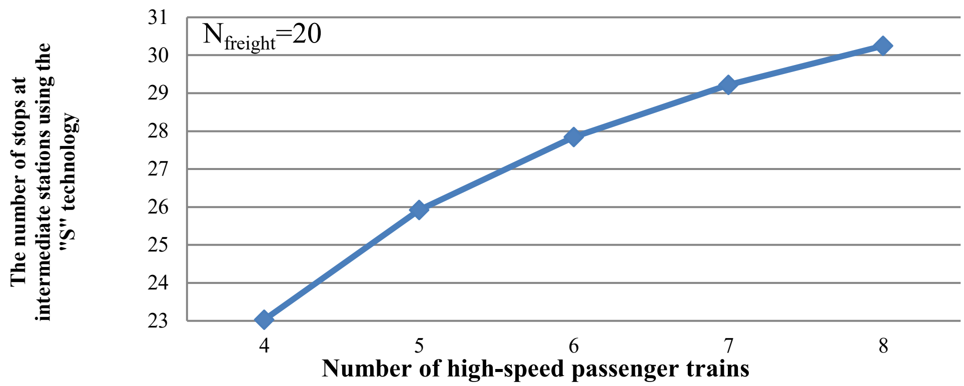
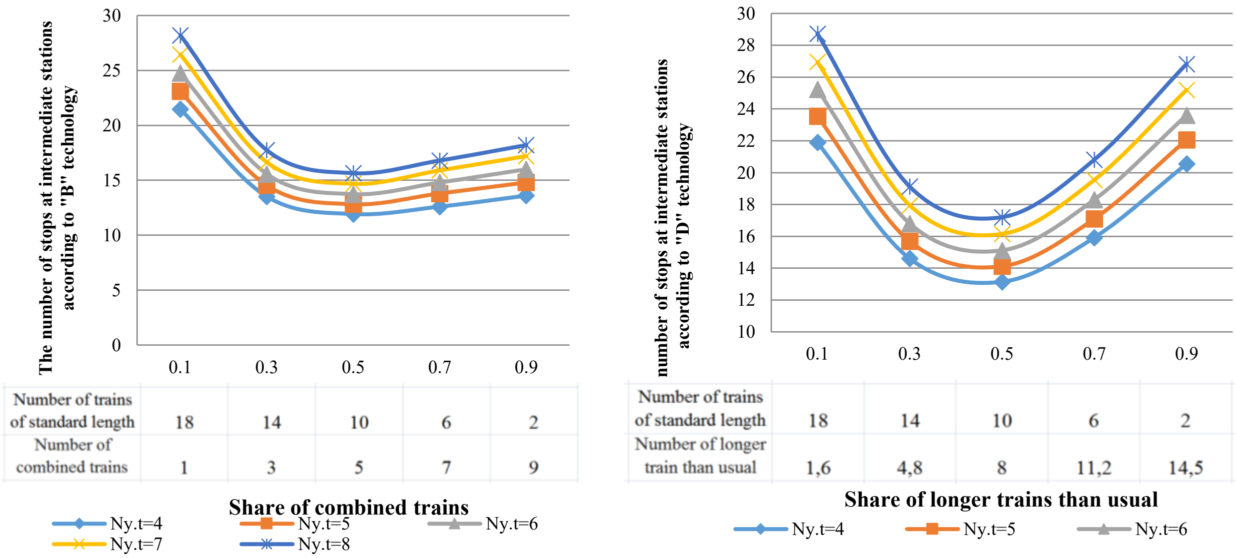


FIGURE 2. Dynamics of changes in the number of stops for train organization technology "S"



a) (organization technology "B") b) (organization technology "D")

FIGURE 3. Dynamics of changes in the number of stops for train organization technologies "B" and "D"

Trains of technologies "D" and "B" with a given volume of cargo should pass without stopping on the section between technical stations after the technical station. However, as a result of increasing the value of v from 0.1 to 0.5 for these technologies, the number of stops of freight trains at intermediate stations decreased, while it increased from 0.5 to 0.9. The reason is that with technologies "D" and "B" at values of α_{mu} and α_{bp} up to 0.5, the number of stops decreases due to the fact that the length of station tracks allows passenger trains to overtake freight trains (Fig. 2-3).

The rest lies in the fact that the length of station tracks does not allow trains to be overtaken, and additional maneuvering occurs because the train will block the station throat when receiving trains with longer-than-usual and combined compositions. Additionally, disconnecting and connecting wagons in a composite train occurs with technology "B" (see Figure 3).

Research shows that when the value α_{mu} changes from 0.1 to 0.9 for technology "D," the number of freight trains moving on the section decreases by 2-17.75%, while for technology "B," a decrease in the value α_{bp} is observed by 5-45%. With an increase in the number of circulating high-speed passenger trains on the section (from 4 pairs to 8 pairs), the number of stops for freight trains at intermediate stations using technology "S" increased by 7 (31.3%). Also, in technology "D," when the value α_{mu} changes from 0.1 to 0.5, it decreases by 5-9 (21.5-39.9%), and when the value α_{mu} changes from 0.5 to 0.9, it decreases by 4-10 (31-77%). In technology "B," when the value α_{bp} changes from 0.1 to 0.5, it decreased by 10 (44.5%), and when the value α_{bp} changes from 0.5 to 0.9, it increased by 2 (14.1%). Specifically, with an increase in the number of circulating high-speed passenger trains on the section, the number of stops for freight wagons at intermediate stations is 5-9 (21.4-37.9%) for technology "D" compared to technology "S," while a decrease to 8-10 in technology "B" (37.8-45.5%) was observed. The main reason for this is the uninterrupted passage of trains on the section in technologies "D" and "B" and the result of reducing the number of trains and increasing reserve capacity. Also, with technology "D" and "B," at values α_{mu} and α_{bp} up to 0.5, the length of station tracks allows a passenger train to overtake freight trains, while in the remaining part, the length of station tracks does not allow overtaking trains, and the longer-than-usual, the more additional maneuvering will occur when receiving composite trains at the intermediate station due to the train occupying the station throat. Technology "B" involves disconnecting and connecting wagons in the composition.

Using the graphical analysis provided above, the graph of the dependency of the number of stops for freight trains at intermediate stations on the number of trains based on the following expression for train organization technologies is presented: According to “S” technology

$$\boldsymbol{k_{frstop} = 1,382 \cdot N_{fr} + 1,8 \cdot N_{highpass} - 10,51;} \quad (1)$$

According to “D” technology

$$k_{fr.stop} = 1,375 \cdot N_{fr} + 0,764 \cdot N_{highpass} - 6,3 \cdot \alpha_{mu} - 4; \quad (2)$$

According to “B” technology

$$k_{frstop} = 1,67 \cdot N_{fr} + 0,62 \cdot N_{highpass} - 10,56 \cdot \alpha_{bp} - 11,5. \quad (3)$$

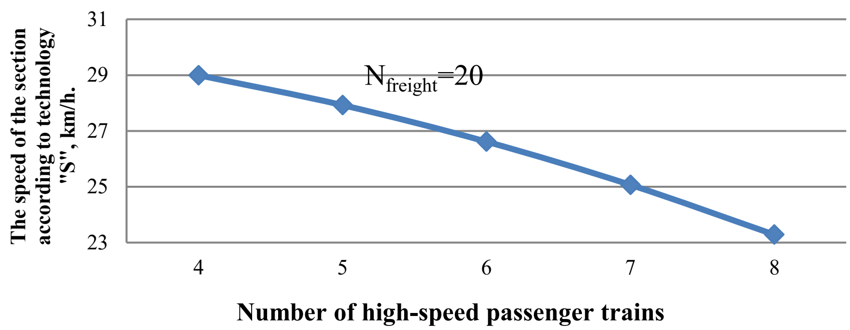
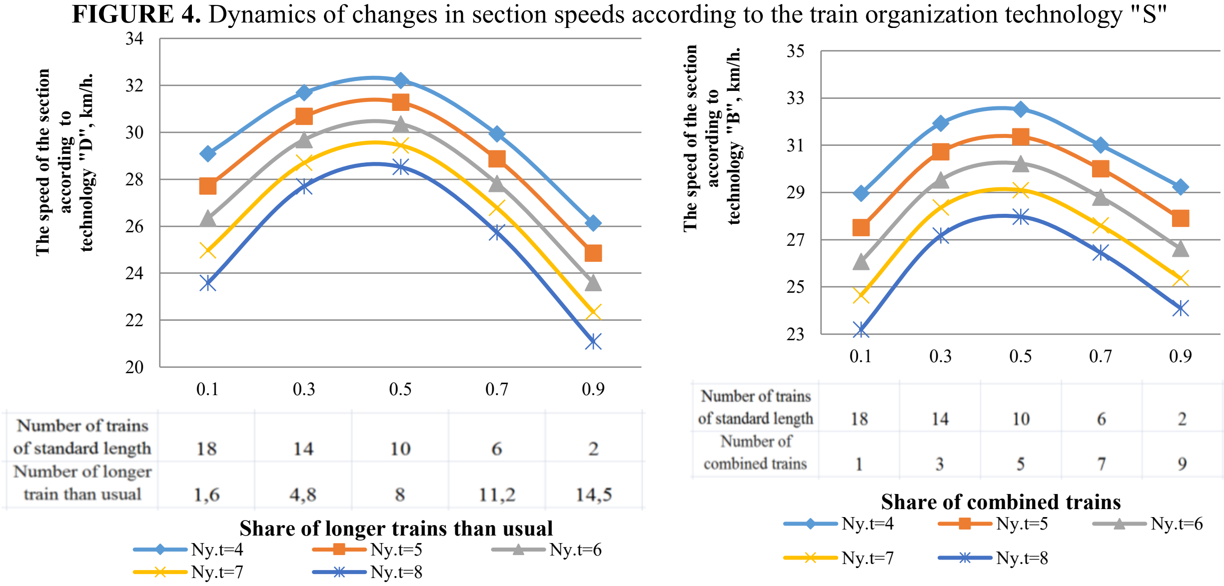


FIGURE 4. Dynamics of changes in section speeds according to the train organization technology "S"



a) (organization technology "D") b) (organization technology "B")

FIGURE 5. Dynamics of changes in section speeds according to the train organization technologies "D" and "B"

Expressions (1-3) are determined based on compiling a large number of experimental train movement graphs, which can be considered reliable due to the coefficient of determination of the determined quantity equaling R^2=0.9416. Utilizing the proposed empirical expression, one can determine the number of stops according to train organization technologies. This metric determines the sectional speed of freight trains. The dependence of the number of freight and high-speed passenger trains moving on the railway section according to train organization technologies on the speed of the section is illustrated in Figures 4-5.

Analysis has shown that with an increase in the number of high-speed passenger trains operating on the railway section, there has been a sharp decrease in the speed of freight trains (Figures 4-5).

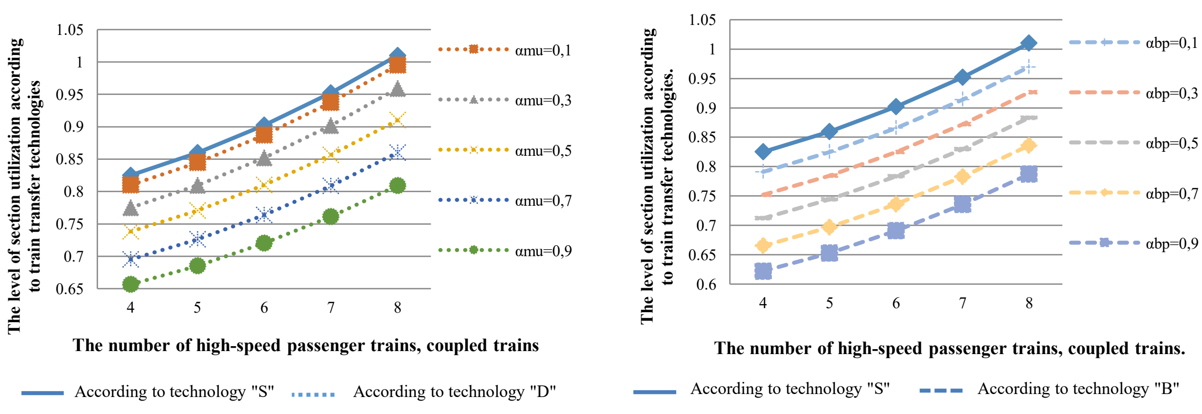
As seen from the figure, with an increase in the number of high-speed passenger trains from 4 pairs to 8 pairs, the section speed decreased by 5.7 km/h (20%), depending on the value of α_{long} $(0{,}1 \le \alpha_{long} \le 0{,}5)$ in technology "D" the section speed increased to 2.94 - 4.71 km/h (9.98-15.6%)and depending on the value of α_{comb} ($0{,}1 \le \alpha_{comb} \le 0{,}5$) in technology "B" the section speed increased to 3.6-4.8 km/h (12.3-20.6%). Also, in technology "D" the section transit time depending on the value of α_{long} $(0{,}1 \le \alpha_{long} \le 0{,}5)$ increased to 0.5-3.5 hours (1.8-12.4%) compared to technology "S", and depending on the value of α_{comb} in technology "B", increased to 0.03-3.52 hours (0.2-12.7%). The main reason for this is the increase in the reserve capacity of the section due to the reduction in the number of trains and the uninterrupted passage of these trains along the section. Changes in these parameters affect the capacity of the sections depending on the methods of train passing. For this reason, the coefficient "exclusion" of freight trains from the passenger train schedule was investigated based on the parameters of train flow transfer from the railway section and the scheduling scheme.

The existing expression for determining the value of this coefficient does not consider the placement scheme of freight and passenger trains in the train schedule and does not adequately reflect the overtaking process. Therefore, based on mathematical analysis of the experimental graph, a new expression was developed to determine the value of the coefficient "exclusion" of freight trains from the schedule, in order to accommodate passenger trains in the train schedule under any circumstances [4, 14]:

$$\varepsilon = \frac{1}{i \cdot N_{pass}} \cdot ((c_1 \cdot i + c_2) \cdot ((\frac{t_{bx}^{fr} - t_{bx}^{pass} + I_{dep}^{\min} + I_{arr} + t_{acc} + t_{dec}}{N_{fr} \cdot I_{fr}} - 1 - n_{\max}^{T_0})(x_1 + x_2 \cdot (t_x^{'fr} - t_x^{'pass}))) + \frac{c_2 \cdot (i-1) \cdot I_{pass}}{N_{fr} \cdot I_{fr}}) \qquad (4)$$

where i — number of passenger trains in a bundle; c_1, c_2 — number of passenger trains, arranged in dispersed and bundled forms; $t_{bx}^{fr}, t_{bx}^{pass}$ — transit time of freight and passenger trains along the section (excluding the first station), minutes; $t_x^{'fr}, t_x^{'pass}$ — transit time of freight and passenger trains through the first section, minutes;

I_{fr}, I_{pass} — interval between freight and passenger trains, minutes; $I_{arr}, I_{dep}^{\min}$ — interval between the arrival of a passenger train after a freight train and the departure time of a freight train after a passenger train, minutes; t_{acc}, t_{dec} — acceleration and deceleration time of freight trains, minutes; x_1, x_2 – number of freight trains on the railway section with stops and without stops.



a) (according technologies "S" and "D") b) (according technologies "S" and "B")

FIGURE 6. Graph illustrating the relationship between the section utilization level and the number of high-speed passenger trains according to train transfer technologies

The research results indicated that the deviation of the "exclusion" coefficient of freight trains from the schedule, calculated according to expression (4), from the standard schedule was between 0.3-6%. The proposed expression allows for an accurate assessment of the required throughput capacity and improves the method of determining the reserve throughput capacity.

During the study, the level of section utilization and its application area according to train organization technologies were determined, as depicted in Figure 6. The research results revealed that with an increase in the intensity of high-speed passenger train traffic on the section, the level of section utilization increases by 0.015-0.17 (1.8-20.5%) depending on the value of L α_{mu} in technology "D" compared to technology "S," and decreases by 0.034-0.203 (4.12-25%) depending on the value of $\alpha_{бр}$ in technology "B" compared to technology "S."

In particular, it was found that when the number of high-speed passenger trains operating on the section is 6 pairs for technology "S" and 8 pairs for technologies "B" and "D," it is possible to organize the movement of trains of different categories. Analyzing the provided data, we conclude that by consolidating freight trains and forming them into longer than usual trains, we can enhance the efficiency of rational utilization of train throughput capacity of the railway section and improve the railway operation. Additionally, by reducing the dwell time of trains at the technical station during the formation of these trains, we can. This creates the necessity to choose the most rational option through techno-economic comparison of railway transport utilization indicators related to train organization technologies for existing conditions.

CONCLUSION

By employing an alternative train traffic organization method, it is possible to enhance the utilization indicators by improving the efficiency of rational utilization of the railway section's carrying capacity. This necessitates selecting the most favorable option for existing conditions through techno-economic comparison of railway transport utilization indicators. As a result, it enables reducing delivery times for goods to customers, improving the train traffic organization method by conducting additional technological operations at the station.

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