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Application of zonal technology for organizing train traffic on railway sections

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Abstract. The main objective of this work is to select the most optimal mechanism for organizing train traffic on railway routes. To achieve this goal, methods of analytical analysis, zonal technology, mathematical modeling, and solving systems of linear algebraic equations were employed. Based on the analysis results, it was determined that zonal technology is optimal for effectively organizing train traffic of various categories. A mathematical model for calculating the time standards for freight train movements according to zonal technology was developed using the "Arithmetic Progression" method. The zonal technology for organizing train traffic, utilizing the created mathematical model, was tested on the "U-M" railway route under the jurisdiction of Uzbekistan Railways. As a result, it was possible to reduce train travel times on railway route sections and increase the sectional speed. The proposed mechanism creates an opportunity to effectively organize train traffic and improve the performance levels of key railway transport indicators.

INTRODUCTION

The primary objective of any state railway network is to meet the population's transportation needs efficiently and promptly by utilizing the most effective transport mechanisms [1], [2].

The selection of transport mechanisms is based on the railway network's specialization in freight or passenger transportation [3]-[8]. Notably, in countries with extensive freight traffic, such as the USA and Russia, it has been proposed to organize freight train operations on a strict schedule. Meanwhile, in countries with a significantly higher number of high-speed and express passenger trains and specialized infrastructure (Europe, Japan, China), these have proven to be effective.

Although countries like Germany and Russia, which have developed advanced management mechanisms in the global railway transport market, operate both high-speed passenger trains and freight trains in a mixed manner on their railways, their operational performance indicators (for instance, average train speeds: Germany – 44,3 km/h; USA – 45,6 km/h, Russia – 42,9 km/h, and China – 43,6 km/h) are higher than the efficiency indicators of Uzbekistan's railways (31,08 km/h), including train speeds [9], [10].

Therefore, to increase transportation efficiency on Uzbek railways, it is advisable to study the experiences of foreign countries that implement mixed train traffic organization, select an appropriate resource-saving mechanism, and apply it to the production process.

ANALYSIS LITERATURE AND METHODOLOGY

Over the years, numerous scientists have conducted research on increasing the speed of freight and passenger transportation, as well as improving the throughput capacity of railway sections and stations on railways with mixed train traffic of various categories [11]-[14], [16]-[18], [19]. Various methods have been employed to address these challenges. Notably, one of the effective mechanisms for organizing freight train traffic on routes occupied by passenger trains has been implemented in the German railway system [15].

In this case, considering the factors that lead to delays in freight train operations on railway routes due to the increased number of passenger trains, a method has been developed to model the functional relationships that restrict the movement of various train categories [15].

$$f(n) = \tau\left(\frac{n}{k}\right)^{\beta} \quad (1)$$

here n – number of trains on the railway line;
τ – travel time of trains of different categories;
β – value of the slope along the railway line;
k – coefficient of variation of the train traffic restriction function.

This model makes it possible to increase the carrying capacity of passenger trains during periods free from scheduled time, which affects the movement of freight trains throughout the day. However, the influence of section-limiting stations on daily performance indicators has not been studied.

[16] the authors have developed a method for replanning schedule times by making changes to the freight train formation plan, taking into account the factors influencing the current sequence of schedule times for freight train traffic on railway sections.

$$N_{freight}^{\max} = \min\left(\sum_{i=1}^{n}\frac{\Delta t_{zon}^{i}}{T_{\text{int}}} + 1\right), train \quad (2)$$

here $N_{freight}^{\max}$ – the maximum number of freight trains on the railway route during their stay outside the zone occupied by passenger trains;
Δt_{zon}^{i} – time of movement of freight trains in certain zones, minutes;
T_{int} – interval time of freight trains, minutes;
1 – additional train for quick train traffic schedule (TTS) conversion.

Researchers utilized the SIA (Schedule Inherited Adjustment) algorithm for rapid planning of freight train schedules to increase their travel speeds. Within the scope of this study, the time standards for movement in zones for various categories of trains have not been sufficiently examined.

[17] developed a method for minimizing the interval between trains on sections, taking into account the time when trains occupy station tracks, in order to prevent the occurrence of a shortage of available capacity of railway sections when their load level exceeds the limit

$$t_{busy} = t_{rec}^{'} + t_{sor} + t_{dep}^{'}, \text{ min} \quad (3)$$

here $t_{rec}^{'}$ – time of reception of trains on station tracks, minutes;
t_{sor} – time spent on technological operations performed by trains on station tracks, minutes;
$t_{dep}^{'}$ – time of departure of trains from station tracks, minutes.

In this regard, based on the infrastructure of railway sections, the implementation of the European system has made it possible to reduce the interval between trains to the minimum level, thereby increasing the capacity of railway lines. Furthermore, by reducing the time spent on technological operations

Researchers [18] developed a method for the effective use with trains at the station (tbusy), the station's load level was regulated, which led to the identification of reserve capacity.of daily schedule times, based on the existing technology for planning the departure of freight trains from technical stations connected to a double-track railway section.

$$t_{tech.p} = \frac{t_{norm} + t_c}{60} + \frac{\sum t_{del}}{N_{dep} \cdot Z \cdot 10^{-2}}, \text{ min} \quad (4)$$

here t_{norm} – the standard time spent on changing locomotive crews and technological operations performed with the train, minutes;
t_c – correction coefficient;

$\sum t_{delay}$ – total time that trains were delayed from the station beyond the scheduled time, minutes;

N_{dep} – the number of train departures from the station according to schedule times;

Z – the degree of filling the chart times, %.

This method allows for the distribution of freight trains into zones free of passenger trains according to the schedule period and the efficient use of trains based on the criterion of minimizing operating costs and maximizing their schedule time ($t_{tech.p}$).

The authors [19] developed a mathematical model for estimating train flow indicators, taking into account the number of receiving and sending tracks of technical stations bordering railway sections and their occupancy time

$$\vartheta_{\sec}^{aver} = \frac{60 \cdot L_{\sec}}{t_{\sec}^{move} + t_{del}^{aver}}, km/h \quad (5)$$

here $L_{\sec}$ – length of the railway section, km;

$t_{\sec}^{move}$ – time of movement of freight train flows on the section, minutes;

t_{del}^{aver} – average waiting times for trains to arrive at technical stations, minutes.

Currently, JSC "Uzbekistan Railways" organizes train traffic using the "Automated Operational Transportation Management System (ATMS)". JSC "UTY" is in the process of implementing stages to create an "Automated National Information System for Operational Management of Freight Transportation (ANISOMFT)" for the future. This system aims to increase the volume of cargo transportation by monitoring train movements and wagons in real-time using artificial intelligence.

In implementing these tasks, it is deemed appropriate for JSC "UTY" to introduce advanced technologies from countries with developed railway networks and management structures for organizing train traffic on railway sections.

Based on the analysis results, it is advisable to implement the most effective mechanism for organizing train traffic and making prompt changes to the train schedule, taking into account the number of railway sections and their level of utilization.

RESULT AND DISCUSSION

When implementing the technology of zonal organization of train traffic on railway sections and routes where the movement of various categories of trains is organized in a mixed manner, it is necessary to adhere to the following technological processes: adapting the plan for the formation of transit trains to periods when there are no passenger trains during the day, planning the locomotive turnaround distance according to the scheduled times of freight trains, and complying with the technological processes of station operation and traffic safety requirements.

The main goal of the scientific work is to increase the throughput capacity of railway sections and the main indicators of train traffic schedule based on the zonal organization of train movement on railway sections. Initially, this takes into account the occupancy time of the tracks at the technical station that separates two railway sections, and the travel time of freight trains on the railway sections. The average value of these time standards is determined as follows.

The mathematical model for calculating the movement time of freight trains on railway sections was improved using the "Arithmetic Progression" calculation method, taking into account the technological factors that influence them. The mathematical model for determining the time standards for freight train movement on railway sections is defined by the following expression.

$$t_{\sec}^{move} = \frac{L_{\sec}}{\vartheta_{\sec}^{aver}} - 0{,}5 \cdot (t_{busy} - m \cdot I) \cdot \left[\frac{n_{freight}}{m} - 1\right], \text{min} \quad 6)$$

here $L_{\sec}$ – length of the railway section, km;

$\vartheta_{\sec}^{aver}$ – average section speed of freight trains, km/h

t_{busy}– time of occupancy of station tracks by trains, minutes;

m – number of receiving and sending routes;

I – freight train interval, minutes;

n_{freig} – the flow of freight trains departing from the technical stations bordering the railway section.

A schematic representation of the regulation of freight train intervals on track sections within railway lines equipped with automatic blocking systems is shown in Figure 1.

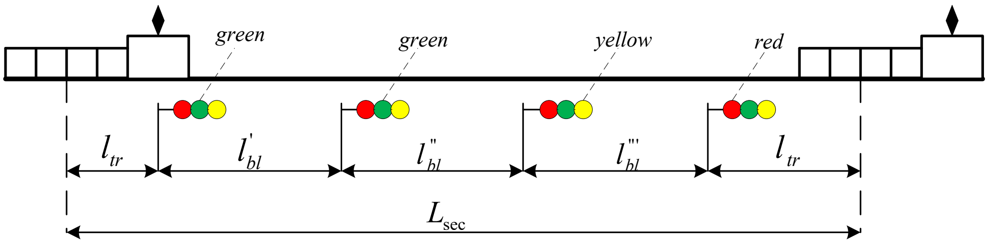

FIGURE 1. Schematic representation of regulating intermediate intervals during parallel train dispatch

When organizing train traffic according to the automatic locking system, it is possible to minimize the time norms for the interval of freight trains. The interval time of freight trains on railway sections equipped with three-way automatic blocking is determined by the following expression.

$$I = 0{,}06 \cdot \frac{3 \cdot l_{bl} + l_{tr}}{\vartheta_{sp}}, \text{ min} \tag{7}$$

here *0,06* – coefficient for converting kilometers to meters and hours to minutes;

l_{bl} – length of block sections in meters;

l_{tr} – train length, meters;

ϑ_{sp} – freight train speed on sections within a railway section, km/h.

Studying the experience of German railways, zonal technology for organizing train traffic (division of hours of the day into zones (X_1, X_2, X_3, X_4)) was introduced on sections of the "U-M" railway line under the control of "UTY" JSC (Figure 2).

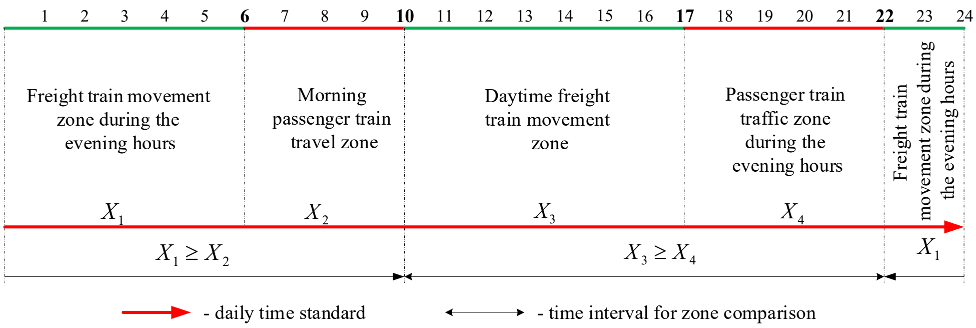

FIGURE. 2. Schematic representation of the zonal technology for organizing train traffic on railway routes

According to Figure 1, passenger train movement is carried out in the morning (X_2, from 06^{00} to 10^{00}) and evening (X_4, from 17^{00} to 22^{00}) zones. Freight train movement is carried out in the evening (X_1, from 22^{00} to 06^{00}) and daytime (X_3, from 10^{00} to 17^{00}) zones during periods when passenger train movement is low. Thus, organizing the movement of freight trains (passenger, route and section) in zones X_1 and X_3 makes it possible to minimize the factors affecting the speed of movement at intermediate stations.

Zonal technology for organizing train traffic on railway routes makes it possible to determine the (t^{move}_{sec}) timing of movement taking into account freight train flows in zones X_1 and X_3. It becomes possible to organize the movement of freight trains based on the conditions of time $(X_1 > X_2)$ intervals with high train flows. Organizing the movement of freight trains on the TTS based on the conditions of daytime (X_3) and evening (X_4) time interval zones $(X_3 > X_4)$ allows to increase the level of fulfillment of the main indicators of the TTS.

On the "U-M" railway line, according to established norms, the length of the three-track block section is 2600 meters, the travel speed is 60 km/h, and the length of the freight train is 1040 meters. In the X_1 and X_3 zones of the "U-M" railway line sections, a test was conducted on the standard train schedule, taking into account the time norms for the movement of freight trains.

Zonal technology for organizing train traffic on the "U-X" and "X-M" railway sections of the "U-M" railway line, taking into account such indicators as the number of stations where stopping of trains is provided in accordance with the train formation plan, freight train flows, was tested on dispatch sections according to the standard train schedule in the quartile section of manual train passage. A comparative analysis of the values of sectional speeds tested on the "U-X" and "X-M" railway sections was carried out over the years (Fig. 3 and 4).

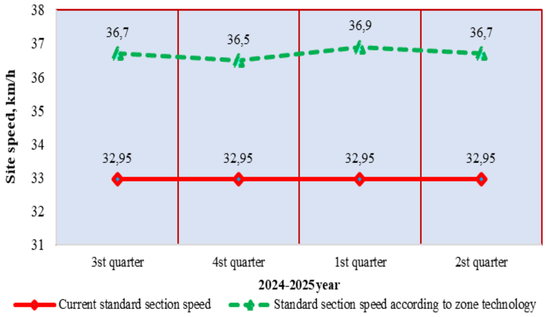

FIGURE. 3. Dynamics of changes in the section speed of freight trains on the "U-X" railway section

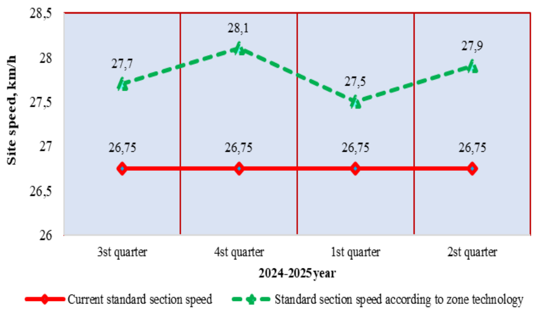

FIGURE. 4. Dynamics of changes in the section speed of freight trains on the "X-M" railway section

It can be seen that the section speed of trains in zonal technology has increased from the current one by an average of 3,5 to 3,9 km/h on the "U-X" section and by an average of 0,75 to 1,35 km/h on the "X-M" section (Figures 2 and 3). The main indicators of the standard TTS for the current and proposed zonal technology on the "U-M" railway route were compared and the results are presented in Table 1.

TABLE 1. Comparative analysis of the main indicators of the current and proposed regulatory TTS on the "U-M" railway route

TTS indicators	U-X				X-M			
	ϑ_{tech},	ϑ_{sec},	t_{sec}^{move},	$n_{freight}$,	ϑ_{tech}	ϑ_{sec},	t_{sec}^{move},	$n_{freight}$,
(In practice)	40,81	32,95	3,90	21	37,97	26,75	6,75	14
(Suggestion – zonal technology)	41,84	36,77	3,53	26	39,01	27,86	6,41	17
Difference (+/-)	1,03	3,82	-0,37	5	1,04	1,11	-0,34	3

It was found that it is effective to organize freight train traffic on railway sections in the evening (X_1, from 22^{00} to 06^{00}) and daytime (X_3, from 10^{00} to 17^{00}) zones throughout the day. In addition, the zonal organization of train traffic on the TTS is mainly based on the morning (X_2, from 06^{00} to 10^{00}) and evening (X_4, from 17^{00} to 22^{00}) zones, and freight train flows are not planned.

It was determined that the average time spent on the movement of freight trains along railway line sections according to the current standard TTS is 5,32 hours. As a result of implementing zonal technology for organizing train traffic on railway sections, this time was reduced to 4,97 hours, achieving a savings of 0,35 hours (21 minutes).

Within the framework of the study, it is advisable to conduct scientific research on a comprehensive study of the daily operational indicators of technical stations delimiting railway sections [20], influencing human factors, electricity consumption, and economic costs.

CONCLUSIONS

It has been determined that zone-based technology is the most optimal mechanism for effectively organizing train traffic on railway routes.

The zone-based technology for organizing train traffic was implemented in the operational process of the “U-X” and “X-M” railway sections. As a result, the throughput capacity of these sections increased by an average of 4 train pairs, and the main performance indicators improved. Specifically, the section and technical speeds increased by 3,82 and 1,11 km/h, respectively.

Applying zone-based technology for organizing train traffic on railway line sections creates the following opportunities:

- rapid change of TTS;
- regulation of intervals between trains;
- maximum use of traction forces of locomotives;
- planning the movement of freight trains on a strict schedule;
- standardization of train intervals by making changes to the freight train formation plan, taking into account factors affecting the movement of freight trains on railway sections;
- reduction of average freight train travel times;
- reducing the average travel time of freight trains on railway sections.

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