**Application of zonal technology for organizing train traffic on railway sections**

Dilmurod Butunov1, Sardor Abdukodirov1, a), Boranbek Baimurzayev2,   
Muslima Akhmedova1, Choriyor Jonuzokov1

1 Tashkent state transport university, Tashkent, Uzbekistan

2Akhmet Yassawi International Kazakh-Turkish University, Turkistan, Kazakhstan

a) Corresponding author: [sabduqodirov588@gmail.com](mailto:sabduqodirov588@gmail.com)

**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].

 (1)

|  |  |
| --- | --- |
| here | number of trains on the railway line; |
|  | travel time of trains of different categories; |
|  | value of the slope along the railway line; |
|  | 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.

 (2)

|  |  |
| --- | --- |
| here | the maximum number of freight trains on the railway route during their stay outside the zone occupied by passenger trains; |
|  | time of movement of freight trains in certain zones, minutes; |
|  | interval time of freight trains, minutes; |
|  | 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

, min (3)

|  |  |
| --- | --- |
| here | time of reception of trains on station tracks, minutes; |
|  | time spent on technological operations performed by trains on station tracks, minutes; |
|  | 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.

min (4)

|  |  |
| --- | --- |
| here | the standard time spent on changing locomotive crews and technological operations performed with the train, minutes; |
|  | correction coefficient; |
|  | total time that trains were delayed from the station beyond the scheduled time, minutes; |
|  | 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 (*ttech.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

(5)

|  |  |
| --- | --- |
| here | length of the railway section, km; |
|  | time of movement of freight train flows on the section, minutes; |
|  | 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.

, min 6)

|  |  |
| --- | --- |
| here | length of the railway section, km; |
|  | average section speed of freight trains, km/h |
| *tbusy*– | time of occupancy of station tracks by trains, minutes; |
| *m* – | number of receiving and sending routes; |
| *I* – | freight train interval, minutes; |
|  | 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.

, min (7)

|  |  |
| --- | --- |
| here *0,06* – | coefficient for converting kilometers to meters and hours to minutes; |
| *lbl*– | length of block sections in meters; |
| *ltr*– | train length, meters; |
|  | 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 (*X1, X2, X3, X4*)) 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 0600 to 1000) and evening (*X*4, from 1700 to 2200) zones. Freight train movement is carried out in the evening (*X*1, from 2200 to 0600) and daytime (*X*3, from 1000 to 1700) zones during periods when passenger train movement is low. Thus, organizing the movement of freight trains (passenger, route and section) in zones *X1* and *X3* 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  timing of movement taking into account freight train flows in zones *X*1 and *X3*. It becomes possible to organize the movement of freight trains based on the conditions of time  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  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 *X1* and *X3* 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 | | | |
|  |  |  |  |  |  |  |  |
| (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 2200 to 0600) and daytime (*X*3, from 1000 to 1700) zones throughout the day. In addition, the zonal organization of train traffic on the TTS is mainly based on the morning (*X*2, from 0600 to 1000) and evening (*X*4, from 1700 to 2200) 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.

**REFERENCES**

1. Ziyoda Mukhamedova, Diyor Boboyev, Shukhrat Saidivaliev, Rustam Abdullaev, Jamshid Kobulov, Sardorbek Akhmedov and Sherzod Fayzibayev. Mathematical modeling of fastening conditions in piggyback transport: ensuring safety and stability across different transport modes. Discover Applied Sciences (2025) 7: pp. 1-17, <https://doi.org/10.1007/s42452-025-07188-7>
2. [Jozef Marian](https://www.researchgate.net/scientific-contributions/Jozef-Marian-BENDKOWSKI-2186050249?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19), Jacek Bendkowski. Development of freight transport in the european union – selected issues. Scientific Papers of Silesian University of Technology Organization and Management Series (2020) 145: pp. 23-45, (2020). DOI: [10.29119/1641-3466.2020.145.2](https://doi.org/10.29119/1641-3466.2020.145.2)
3. Ibragimova, G., Mukhamedova, Z., Khudayberganov S., Buriyev S., Kayumov S., Bashirova A., & Tokhtakhodjaeva M. Assessment of options for the location of railway infrastructure facilities. Discover Applied Sciences (2025) 7(5), pp. 1-16. DOI: [10.1007/s42452-025-06869-7](https://doi.org/10.1007/s42452-025-06869-7)
4. W. Zhou, S. Li, J. Kang, and Y. Huang. “Capacity-oriented train scheduling of high-speed railway considering the operation and maintenance of rolling stock” Mathematics (2022) vol. (10) 10, 1639, pp. 1-30. <https://doi.org/10.3390/math10101639>
5. Dilmurod Butunov, Sardor Abdukodirov, Shuhrat Buriyev, and Muslima Akhmedova. Development factor model of train movement graph indicators, E3S Web of Conferences (2024) 531, 02008: pp. 1-10. <https://doi.org/10.1051/e3sconf/202453102008>
6. Baturin A.P., Osipov A.P. Modern Systems of Train Traffic Interval Control on World Railways. World of Transport and Transportation (2023) 21(2): pp. 18-26. <https://doi.org/10.30932/1992-3252-2023-21-2-2>
7. Khusenov U., Suyunbaev S., Umirzakov D., Tokhtakhodjayeva M., Adizov I. Assessment of the effect of train traction by locomotives of different types on the quality indicators of the train schedule. In E3S Web of Conferences (2024) Vol. 583, pp. 1-6. [DOI: https://doi.org/10.1051/e3sconf/202458303018](DOI:%20https://doi.org/10.1051/e3sconf/202458303018)
8. Barotov J., Kobulov J., Saidivaliyev S., Sattorov S., Fayzullayev G., & Kibishov A. Effectiveorganization of acceleration of local train movement at railway transportdepartments*. In* E3S Web of Conferences (2024) Vol. 515, pp 1-8.
9. Zyabirov X.SH. Sovremenniye texnologii v upravlenii perevozochnim protsessom na jeleznodorojnom transporte / X.SH. Zyabirov, I.N. Shapkin. - Moskva: Finansi i statistika (2016) - 480 pp. - ISBN 978-5-279-03576-2. [URL: https://www.ibooks.ru/bookshelf/355172/reading](URL:%20https://www.ibooks.ru/bookshelf/355172/reading)
10. Abdukodirov S.A. Organization of the technology of transport processes of railway directions based on the operational adjustment of the train schedule: Dissertation abstract of the doctor of philosophy on technical sciences (PhD) ... – Tashkent: (2023) TSTrU. pp 116. <http://library.ziyonet.uz/uz/book/127999>
11. Okhotnikov A.L. Virtual coupling as an element of interval regulation of train movement. Science and Technology of Railways (2024) №2(30) pp. 42-47. <https://www.elibrary.ru/item.asp?id=67883568>
12. Dilmurod Butunov, Zhansaya Kalimbetova, Sardor Abdukodirov Shuhrat Buriyev and Mafiratxon Tuxtaxodjayeva*.* E3S Web of Conferences (2023) 460, pp. 1-9. <https://doi.org/10.1051/e3sconf/202346006002>
13. Brigitte Jaumard. Freight train scheduling with minimum energy consumption. WIT Transactions on State of the Art in Science and Engineering (2017)Vol (94), pp.195-204. DOI:[10.2495/TDI-V1-N3-501-510/020](https://doi.org/10.2495/TDI-V1-N3-501-510/020)
14. Francesco Flammini, Stefano Marrone, Roberto Nardone and Valeria Vittorini. Compositional modeling of railway Virtual Coupling with Stochastic Activity Networks. Formal Aspects of Computing (2021)№33. pp. 989-1007. <https://doi.org/10.1007/s00165-021-00560-5>
15. Borndörfer, Ralf & Fügenschuh, Armin & Klug, Torsten & Schang, Thilo & Schlechte, Thomas & Schuelldorf. “The Freight Train Routing Problem” Angewandte Mathematik und Optimierung Schriftenreihe (2014)n. 8, pp.1-15.<http://opus4.kobv.de/opus4-zib/frontdoor/index/index/docId/1899>
16. Huaqing Mao, Zhu Li. Train Schedule Adjustment Strategies for Train Dispatch. *TELKOMNIKA* (2013) №5, pp. 2526-2534. DOI: [10.11591/telkomnika.v11i5.2483](https://doi.org/10.11591/telkomnika.v11i5.2483)
17. Olencevich V. A., Olentcevich A.A., Gozbenko V.E. Optimization of railway stations operation in the context of the introduction of modern systems of train traffic interval regulation at the eastern polygon. Modern technologies. System analysis. Modeling(2021) № 3 (71), pp. 149 – 157. [DOI: 10.26731/1813-9108.2021.3(71).149-157](DOI:%2010.26731/1813-9108.2021.3(71).149-157)
18. Badazhkov M. A. Improving Idle Hours of Trains at Technical Stations during the Regulation of Influencing Factors. Bulletin of the siberian state university of railway transport (2019) № 1 (48), pp. 44-49. <https://elibrary.ru/item.asp?id=39189716>
19. Muginshtein L.A., Mekhedov M.I. Issues of organization of stable passage of transit freight trains on the railway lines in accordance with technical and technological features of operation of technical stations and running sections. Russian railway science journal (2016) № (1): pp. 3-11. <https://doi.org/10.21780/2223-9731-2016-0-1-3-11>
20. Dautbay Nazhenov, Utkir Khusenov, Azizjon Yusupov, Shinpolat Suyunbaev; Substantiation of the influence of the number of shunting locomotives on the working fleet of freight cars and other qualitative indices of railway transportation operations. AIP Conf. Proc. 4 November (2025) 3331 (1): 040002. <https://doi.org/10.1063/5.0306962>