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Determining the scope of application of train traffic management technology

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Abstract. In the article information rational use of the railway section capacity in determining the efficiency area of technology for joint organization of movement of trains longer than the norm and with standard content. Based on the results of reviewed scientific studies, it is proposed to calculate parameters such as throughput and capacity of the section and the interval between trains to determine the scope of application of train transfer technology. Conditional length and the ratio of intervals between trains longer than the norm and the standardized composition, as well as the percentage of trains, are considered as variable elements. Optimization criteria include increasing the proportion of trains with longer than normal content, increasing the throughput capacity of the section, and increasing the interval between trains. A nomogram depicting the dependence of the section's throughput capacity on the ratio of intervals between longer than normal and standard trains and the proportion of trains longer than normal in the overall flow of freight trains is provided based on the calculation results. The nomogram allows determining the interval between trains longer than normal and trains with standard content.

INTRODUCTION

The development of the transportation infrastructure outlined in the Transport System Development Strategy of the Republic of Uzbekistan until 2030 and the Business Plan of Uzbekistan Railways for 2023, the development of measures to increase the transport capacity and throughput of railways, the advancement of high-speed and rapid train movement, and the implementation of modern mechanisms in transportation organization set important tasks. In pursuit of these goals, a crucial and relevant task is the development of alternative methods for stable train transmission and determining the scope of application, considering the need for reserve capacity of railway sections to accommodate increased movement of high-speed passenger trains.

LITERATURE REVIEW AND METHODOLOGY

Many scientists and specialists have conducted scientific research at different times on the analysis, evaluation, rational utilization, and determination of the scope of application of train movement organization methods [1-9].

The APK "Elbrus" system was developed by a group of scientists from the All-Russian Scientific Research Institute of Railway Transport (ARSRIT) and has been used on railway networks for many years [13]. Scientists from ARSRIT presented and implemented a methodology for choosing a relatively effective train movement method along specified graphical lines on railway sections. This methodology includes assessing key technical and economic indicators and determining the scope of feasibility of various measures under different working conditions, considering the efficient use of the technical equipment of existing sections.

The method presented by the authors involves solving the issue of choosing the optimal train movement organization method in two stages, considering the efficient use of section capacity from a technical and economic perspective. The first stage involves selecting possible measures to cover the specified volume of transportation and meeting relatively large conditions of economic and operational efficiency. At the second stage, key technical and

economic indicators are determined for a limited volume of a pre-selected option, and a train movement schedule is implemented based on another train transmission option.

In her scientific work, Kharina developed a comprehensive model for assessing various train movement organization options based on the criterion of minimizing transportation costs and investments [14]. The distinctive feature of this model includes:

- the ability to combine the movement of freight and passenger trains by organizing the movement of combined freight trains to create reserve capacity;
- comprehensive solution to the problem of increasing the speed of passenger trains and diverting freight trains from the schedule of parallel movement;
- justification of rational technical and technological parameters of the railway line when organizing the movement of freight and passenger trains of different categories;
- the share of combined freight trains and the speed of high-speed trains;
- the number of freight trains transferred to the third main track.

However, in her scientific work, the author focused only on train movement organization based on reconstruction measures.

In the scientific research of E. Castillo, M. Nogal and Z. Grande [22], the issues of reducing the costs of organizing the movement of trains of different classes on secondary routes by using double-Single track (ADST) (single-double track railway lines) were considered. This idea involves expensive infrastructure, and they proposed the construction of double-track sections on all railway sections. They considered the configuration of railway lines from the point of view of optimizing the schedule of train movements. The authors concluded that the use of single-double track sections when organizing the movement of trains of different classes can lead to a reduction in capital costs of up to 40%.

The scientific research of Günther Prokop and André Stoller investigated the issues of determining the optimal weight and speed of long-distance, local and suburban passenger trains [20]. The author recommends bringing the speeds of freight trains as close as possible to the speeds of passenger trains and increasing the speeds of both passenger and freight trains in the technical and economic calculations. However, the increase in freight and passenger flows and their impact on the organization of the movement of express and high-speed passenger trains was not considered.

A. Rodrigo Fernández in his scientific research considered the issues of determining the rational number of high-speed passenger trains and their maximum speed in conditions of joint movement of freight and passenger trains. [21]. However, at present, in order to improve the quality of service to the population, it is necessary to determine the speed and number of high-speed passenger trains in order to meet the demand for passenger transportation and ensure traffic safety.

Research conducted by the aforementioned scientists has shown that in modern conditions, it is important to use measures to increase the throughput capacity of railway sections. The first measure is the construction of an additional mainline, which is a capital-intensive and labor-intensive process and is unfeasible under conditions of limited financial resources. Therefore, it is necessary to improve train movement organization methods and use modern innovative technologies and resource-saving methods developed by scientists, apply organizational and technical measures aimed at investment savings. This can be achieved through the rational use of the throughput capacity of the railway section and the application of train movement organization technology longer than the norm and with normalized content. As a result, in conditions of increasing the number of high-speed passenger trains on railway sections and test sites, it is advisable to determine that the section loading level does not exceed the permissible value even with the existing technology in the train movement organization, as well as in the technology of joint transmission of trains of standard weight and length.

RESEARCH RESULTS

Establishes a series of requirements for the creation and passage of trains longer than the norm and standard content [12, 15]:

- Assembly and distribution stations must have tracks of sufficient length to organize the coupling and uncoupling of trains longer than usual and combined trains, without occupying station entrances and platforms. Otherwise, delays occur due to additional maneuvering actions when receiving or dispatching trains and are taken into account when determining the economic effect;

- Road infrastructure should allow for technical and commercial inspection of wagons as part of a composite train at locomotive crew change points;
- Timely technical and commercial inspection of long and combined trains at stations using train processing technology;
- Intermediate station tracks must be long enough for trains to overtake and intersect each other on the section. Otherwise, it is necessary to determine the number of stations whose tracks are extended for train overtaking and intersection, or the number of these trains that pass during idle periods of the timetable;
- The use of technology for forming and transferring freight trains of standard length and weight into longer-than-standard trains requires their uninterrupted passage through the section.
- Delays of other types of freight trains should be taken into account when dispatching these trains from the station.

As a result, the following positive outcomes can be achieved:

- Reduction in the number of operating locomotive fleets and locomotive crews;
- Decrease in the number of stops for freight trains at intermediate stations due to the reduction in the number of trains running on the section;
- Inclusion of additional trains in the schedule under conditions of limited capacity;
- The delivery time of cargo will increase as a result of forming and transferring freight trains of standard length and weight into longer-than-standard trains.

The section of the railway "U-Kh" equipped with a double-track automatic locking system, was taken as the object of the study, and it has the following main initial parameters: the interval between trains is 10 minutes, and the train weight is 4500 tons.

In the technology of jointly transferring long and standard weight-length trains, the train weight is assumed to be up to 5500 tons. The number of trains running on the section varies depending on the proportion of long and standard weight-length trains.

When calculating the technological efficiency of construction and transfer of long and standard weight-length trains, it was conducted for the following combinations:

- 1) Proportion of longer-than-usual trains: 0.1:0.3:0.5:0.7:0.9.
- 2) Ratio of intervals between trains of greater length and normal length is 1.1, 1.125:1.25:1.375:1.5.

A number of indicators were calculated to determine the technological efficiency of using the technology of construction and transfer of long and standard weight-length trains.

This technology is proposed to be used in organizing the movement of high-speed and express passenger trains, taking into account the proportion of long and standard weight-length trains in the overall freight flow.

According to references [10, 11, 12-19], the available throughput capacity on double-track sections is determined by the following formula, taking into account the organization of train movement of different categories:

$$N_{th.cap} = \frac{(1440 - t_{tex}) \cdot \alpha_n - \sum_{i=1}^k (t_{bx}^{ifreight} + t_{bx}^{ipass})}{k} - 1 + I_{high.speed}^{pass} \cdot (n_{high.speed} - 1) + t_{acc} + t_{spent} + \tau_{arr}^{pr} + \tau_{dep}^{pr} \quad (1)$$

where, t_{tex} — the duration of the technological break during the movement of trains along a railway section, in minutes;

$I_{high.speed}^{pass}$ — intervals between the movements of high-speed passenger trains when dispatching parcels;

k — the number of track sections on the segment;

$\tau_{arr}^{pr}, \tau_{dep}^{pr}$ — intervals between trains arriving at the station at different times, and their departures from the station, in minutes;

t_{acc}, t_{spent} — time spent accelerating and decelerating trains, in minutes;

α_n — reliability coefficient.

The interval between trains is determined by the following expression during the simultaneous passage of trains longer than standard length and standard mass from the railway section:

$$I_p = I_{freight} \cdot (1 - 2\alpha_0) + I_{freight}^t \cdot 2\alpha_t, \min \quad (2)$$

where, $I_{freight}^t$ — the interval between trains with longer than usual content.

The average weight of a train moving along the train schedule line is determined by the following expression [15]:

$$Q_{br} = Q_{freight} \cdot \alpha_0 + Q_{freight}^t \cdot \alpha_t, t. \quad (3)$$

The throughput capacity of the railway section using the technology of joint organization of train movements longer than standard length and standard loading is determined by the following expression [15]:

$$G = \frac{365 \cdot Q_{br} \cdot N_{freight}}{10^6} \cdot \varphi_{netto}, \text{ million tons per year.} \quad (4)$$

The total number of freight trains transported along the train route is as follows:

$$N_{freight} = N_{th.cap} - \sum_{i=1}^n \varepsilon_{pass.i} \cdot N_{pass.i}, \text{ train} \quad (5)$$

Based on the aforementioned technologies, it is necessary to refine the dependence of the throughput capacity and the carrying capacity of the railway section on the interval between trains, using the technology of joint transmission of trains longer than standard length and standard length. The calculation results are presented in Figure 1-2, where a graph of the dependency of the throughput capacity of the railway section and the interval between trains on the technology of joint transmission of trains longer than standard and standard length is plotted based on computational analyses.

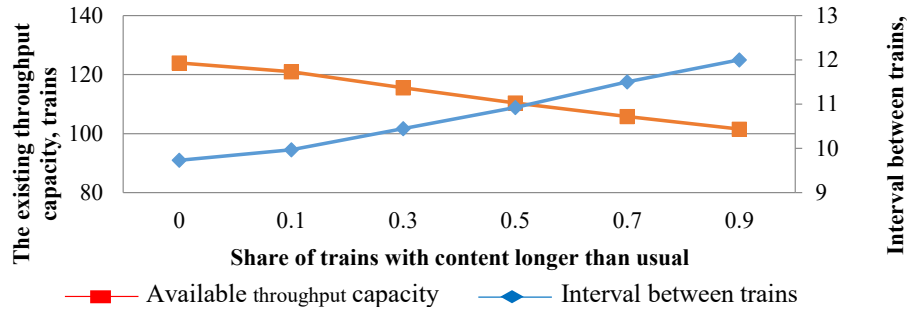


FIGURE 1. Graph showing the dependence of the proportion of freight trains with longer travel times on the section, on the available capacity and the interval between trains

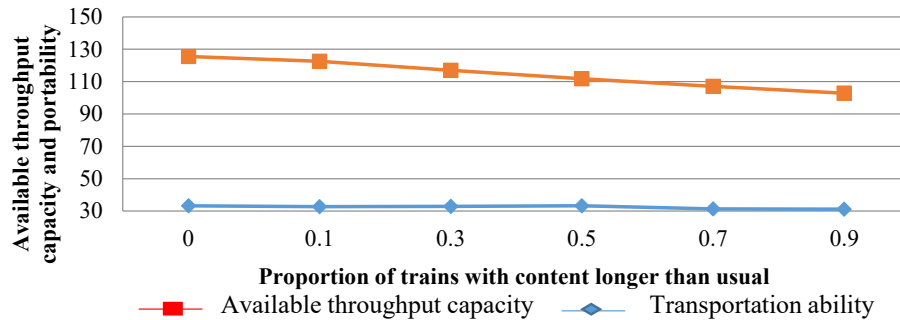


FIGURE 2. Graph illustrating the dependence of the proportion of freight trains longer than standard on the section with available carrying capacity and carrying capacity

As seen from Figures 1-2, the increase in the proportion of trains with content longer than standard led to a decrease in the available carrying capacity of the section and an increase in the interval between trains.

Based on the obtained results, a nomogram was developed, which can be used considering the proportion of trains, the technology of transmitting the interval between trains of long and standard weight and length, depending on portability and throughput capacity.

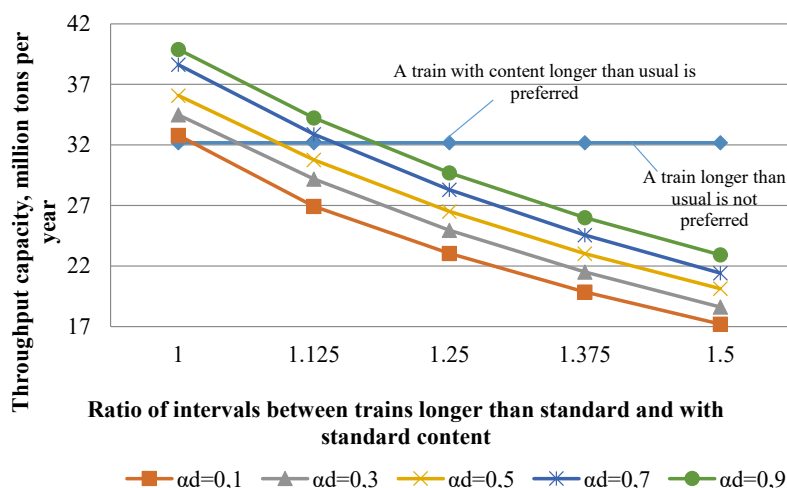


FIGURE 3. Nomogram illustrating the dependency of the carrying capacity of the railway section on the ratio of the weight of freight trains α_d - share of trains with content longer than usual in the overall freight traffic.

Based on the nomogram, the feasibility of using the technology for transmitting long and oversized trains is determined by the graph's dependence on the carrying capacity of freight trains and the ratio of intervals between trains, as well as the proportion of trains longer than standard. The area above the horizontal axis indicates the applicability of this technology, while the area below this region indicates the opposite.

The technical and economic significance of the minimum interval between trains is determined using a multifactor minimum method. This method allows for identifying and evaluating the feasibility area of the train passage technology for trains moving along the section.

According to the train movement organization technologies, the interval between trains (I_i) depends on the proportion of trains longer than the standard and of standard length passing through the section (m_{hi} , m_{di}) and their hypothetical length (α_i). The composition of relationships between such indicators (variables) is determined by constructing regression equations using the least squares method. A multifactor regression equation is created based on the variable indicators X_i depending on the value Y for each element involved in determining the value of these indicators I_i .

The following equation [16] is used as the adaptive multifactor regression equation:

$$y = a_0 + a_1 \cdot x_1 + \dots + a_n \cdot x_n. \quad (6)$$

The sum of the squares of the differences between actual values Y and smoothed values should be minimized, i.e.,

$$S = (Y - \bar{Y}) \rightarrow \min. \quad (7)$$

In general, the system of normal equations is expressed as follows:

$$\begin{cases} \sum y = na_0 + a_1 \cdot \sum x_1 + \dots + a_n \cdot \sum x_n \\ \sum x_1 y = a_0 \cdot \sum x_1 + a_1 \cdot \sum x_1^2 + a_2 \cdot \sum x_1 \cdot x_2 \dots + a_n \cdot \sum x_n \\ \vdots \\ \sum x_n y = a_0 \cdot \sum x_n + a_1 \cdot \sum x_1 \cdot x_n + a_1 \cdot \sum x_2 \cdot x_n \dots + a_n \cdot \sum x_n^2 \end{cases} \quad (8)$$

The correlation coefficient for each variable is determined by the following expression:

$$R_{yx_1} = \frac{\sum yx_1 - \sum y \sum x_1}{\sigma_y \cdot \sigma_{x_1}}, \quad (9)$$

$$R_{yx_2} = \frac{\sum yx_2 - \sum y \sum x_2}{\sigma_y \cdot \sigma_{x_2}}, \quad (10)$$

$$R_{x_1x_2} = \frac{\sum x_2x_1 - \sum x_2 \sum x_1}{\sigma_{x_2} \cdot \sigma_{x_1}}. \quad (11)$$

(6) The regression coefficients in the system of equations a_j are expressed in different units of measurement and qualitatively measure the influence of different factors. Therefore, to verify the result of the given values of this equation, inverse recursive equations are constructed.

The regression coefficient in this recursive equation is equal to α :

$$\beta = a_j \frac{\sigma_{x_j}}{\sigma_{x_i}}. \quad (12)$$

As a result, the equation of multidimensional regression is expressed in the following form:

$$\bar{y} = a_0 + b_1 \cdot z_1 + \dots + b_n \cdot z_n. \quad (13)$$

If we accept the obtained values of the sign and coefficient in the normal scale:

$$\bar{u}_{\text{lx}_j} = b_1 \cdot z_1 + \dots + b_n \cdot z_n = \sum_{i=1}^n \beta_j - z_j. \quad (14)$$

Equation (12) leads to solving the following system of normal equations to determine the coefficients for β_j in the equation::

$$\left\{ \begin{array}{l} \sum uz_1 = \beta_1 \cdot \sum z_1 + \beta_2 \cdot \sum z_1z_2 + \beta_3 \cdot \sum z_1z_3 \dots + \beta_n \cdot \sum z_1z_n \\ \sum uz_2 = \beta_2 \cdot \sum z_2z_1 + \beta_2 \cdot \sum z_2^2 + \beta_3 \cdot \sum z_2 \cdot x_3 \dots + \beta_n \cdot \sum z_2z_n \\ \\ \sum uz_n = \beta_n \cdot \sum z_nz_1 + \beta_2 \cdot \sum z_n \cdot z_2 + \beta_3 \cdot \sum z_3 \cdot z_n \dots + \beta_n \cdot \sum z_n^2 \end{array} \right. \quad (15)$$

To convert the coefficients of the multidimensional regression equation β_j – into natural values (a_j), their natural values (a_j) are calculated from the standardized regression coefficients in expression (11) based on the following expressions:

$$a_j = \beta_j \frac{\sigma_y}{\sigma_{x_j}}, \quad (16)$$

$$a_0 = \bar{y} - \sum_{j=1}^n a_j \bar{x}_j. \quad (17)$$

There exists a correlation between the regression coefficients and the elasticity coefficients.

It is known that the elasticity coefficient is equal to the following expression:

$$\mathfrak{D}_j = a_j \frac{x_j}{y} . \quad (18)$$

If we substitute a_j in expression (16-19) with (14), then the elasticity coefficient will have the following form:

$$\mathcal{D}_j = \beta_j \frac{\sigma_y}{\sigma_{x_j}} \cdot \frac{\overline{x_j}}{y}. \quad (19)$$

Using the results of this mathematical model, the relationship between the train length and the percentage of the interval between trains according to the train movement organization technologies is established by the following expression:

$$\overline{y}_x = 6,95 + 0,45 \cdot \alpha_m + 1,4 \cdot \frac{m_{sp}^m}{m_{sp}} + \varepsilon_0 \quad (20)$$

Using the proposed method, its dependence on the maximum interval between freight trains was obtained when determining the application area of the technology for transmitting trains of long and standard content. In this case, it is recommended to increase the carrying capacity of the section using train transmission technology.

CONCLUSIONS

To determine the application area of the efficiency of the technology for joint organization of movement of long and standard trains, a large number of scientific studies are required, aimed at the rational use of the carrying capacity of the railway section. This is achieved through the application of organizational and technical measures for the development of industries. Based on the obtained results, a nomogram was developed, and it was determined that the carrying capacity of the section correlates with the proportion of trains with content longer than normal and the ratio of intervals between trains with longer and normal content, while also allowing to determine the application area of train transmission technology.

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