Development of measures to reduce the downtime of transit processed wagons at the technical station based on the least squares method

Adylkhan Kibishov[1] , Zhasurbek Abdullayev[2, a)]

[1] *Khoja Akhmet Yassawi International Kazakh-Turkish University, Turkistan, Kazakhstan*
[2] *Tashkent state transport university, Tashkent, Uzbekistan*

[a)] *Corresponding author:zafarchik0901@mail.ru*

Abstract. In this article, measures are developed to reduce the dwell time of transit-repaired cars at a technical station based on the least squares method in conditions of limited economic resources. According to the results of the considered scientific research, it was found that the number of cars in a train arriving at the station obeys the law of normal distribution. The relationship between the variable elements of the dwell time of trains at the technical station with the share of combined, longer than standard and standard-length trains and the number of cars arriving for reconditioning is taken into account. According to the modeling results, time efficiency diagrams are presented when building combined and longer than standard trains.

INTRODUCTION

The sequence of technological processes at a technical station determines the quality and efficiency of the station's performance indicators. One of the important tasks is to find resource-saving methods for improving these indicators by effectively using the existing technical and technological capabilities of the station and organizing train traffic [1-4,7-8]. In implementing these tasks, great attention is paid to developing an improved system for organizing train traffic with rational use of the capacity of the railway section, taking into account the implementation of additional technological operations on the receiving and sending tracks of the station. Studies show that the waiting time of trains at the railway station under the jurisdiction of Uzbekistan Railways JSC increased by an average of 40% compared to the plan in 2024, and by 5-10% compared to the plan in May, July, and August 2023 (Figure 1).

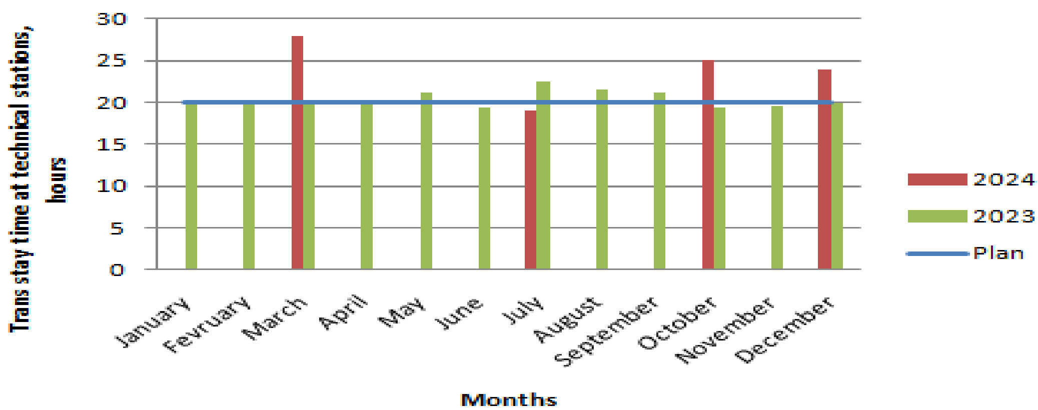


FIGURE 1. Train station dwell times in 2023-2024

One of the main reasons for this is the unevenness of the train arrival interval and the human influence on the technological factors involved. It is advisable to implement organizational and technical measures to reduce these factors. [4-6].

EXPERIMENTAL RESEARCH

Gerhard Troche [8] and M. Rasulov [9], who are considered one of the world's leading researchers in the field of organizing and managing wagon flows, including reducing the stowage time of transit processed wagons at a technical station by improving the methods of forming a freight train plan, in their research work, taking into account the arrival of wagons as separate groups, considered in detail the process of accumulating wagon flows and determined the options for accumulating trains. Analytical dependencies that determine wagon-hour costs during the assembly of wagons are substantiated. However, the author did not pay sufficient attention to other elements of the train's downtime at the technical station.

Ibragimova G.R. [10] in her research work developed methods for the technical and operational assessment of the organization and management of wagon flows of sorting stations, taking into account the impact of inefficient time losses during the processing of wagons, based on the application of railway infrastructure placement options. However, the author did not take into account that the application of these methods in conditions of limited resources requires a lot of investment.

Suyunbaev Sh.M. [11,15,16] in his scientific work practically applied information technologies to improve the technology of transportation processes in the organization and management of wagon flows at railway stations and sections. However, the author, taking into account the technical and technological capabilities of the station during the processing of wagon flows, did not develop methods for deploying trains with longer and combined trains by performing additional operations.

S.I. Muzykina [12], in her scientific work, developed methods for calculating the processing capacity of sorting stations in order to rationally organize wagon flows at Ukrainian stations. However, when developing the method, the authors did not take into account the factors of random inefficient time losses arising during the processing of wagon flows.

M. Masharipov's scientific research presents elements of methods for evaluating various technical solutions for covering freight flows [13]. This work is mainly devoted to assessing the structure and efficiency of freight trains. According to the author, reconstruction and technical and organizational measures have a positive effect on increasing the performance of the station on the routes. In their research, the authors noted that in the long-term, as well as in the process of forming and sending integral trains, financial resources are limited, there is no comprehensive approach to improving the technology of transporting trains along railway lines and its impact on the efficiency of using railway transport.

During technological operations involving transit wagons at technical stations, the time of stay depends on the methods of passing trains along the lines of motion graphics. In these ways, the execution sequence of these technological processes remains constant. The execution sequence of technological processes, on the other hand, determines the efficiency of the station and its quality.

One of the important indicators that determine the efficiency of station work and the quality of its work is the average stay time of wagons during technological operations at stations, and according to the technology options for conducting trains on graphic lines, standby operations differ from each other. Because these technologies differ in the number of trains and the number of wagons it contains, the intervals between arrival and departure to the station. These values, on the other hand, are made up of several elements. The station standing elements of the carriages can be studied in ($\boldsymbol{t_{tr}}$) three main groups:

1. the time spent on technological operations is the sum of the time spent on technical and commercial inspection of the contents before entering and sending to the station, distributing the contents, completing the composition, transferring the wagons from the sorting park to the shipment park, disconnecting, connecting the wagons in the composition, allocating;
2. waiting time to complete these technological operations;
3. time to stand in the process of assembly of wagons.

The time for transit recyclable wagons to stay at the technical station is determined by the following expression:

$$t_{tr}^{proc} = t_{tex} + t_{wait} + t_{ass} \tag{1}$$

In this way, the $\boldsymbol{t_{tr}^{proc}}$ value comes to be a function of three magnitudes, $\boldsymbol{t_{tr}^{cproc}}$

$$t_{tr}^{proc} = f(t_{tex}, t_{wait}, t_{ass}) \,, \tag{2}$$

There, $t_{tex}, t_{wait} -$ time spent on technological operations and its wait, minute;

$t_{ass} -$ time to stand in the process of assembly of wagons, minute;

The duration of the execution of individual elements of technological operations will depend on the technical equipment of the station, its operating technology, as well as the flow of cars to be processed. To carry out these technological operations, it is possible to determine the laws of the distribution of transit train flows and intervals between them at the station through the data of the daily work plan and the motion graph. In determining the performance of the technical station when sending trains to plots adjacent to the sorting station, the modeling of the interval between freight trains running along the line of the traffic graph on a given plot according to the train layout plan is carried out in accordance with [4, 7]. (t_{tr})

Analysis of the studies shows that the main reason for the change in the (t_{tr}) of technological operations and the time of its waiting is the uneven flow of trains and wagons moving on the railway track. In addition, in technological operations, the duration of the waiting time is determined by the fact that the station is loaded, the arrival of trains at the station depends on the time variation of the intervals. This causes transit trains to change the time they stay at the station. Based on the data of the station's daily operating plan and movement graph, the time of arrival and departure of trains to the station is indicated. This is followed by technological operations such as preparing a route for reception of the train to the station, fixing the contents, maintenance of the train contents at the reception park (TexService-2), distributing the train contents, composing the finished contents and transmitting it from the sorting park to the departure park, connecting, disconnecting and separating the contents, fixing the contents to the departure park with brake

"S" by technology is the time spent on these executable technological operations and its expectation is determined by the following expression [4]:

$$t_{tex} = t_{bloc}^{rec} + t_{proc}^{rec} + t_{diss} + t_{form} + t_{trans} + t_{bloc}^{dep} + t_{proc}^{dep} + t_{ass}^{lok} + t_{sent} \tag{3}$$

$$t_{wait} = t_{wait}^{rec} + t_{wait.proc}^{rec} + t_{wait}^{diss} + t_{wait}^{form} + t_{wait}^{trans} + t_{wait}^{mane} + + t_{wait.proc}^{sent} + t_{wait.ass}^{lok} + t_{wait}^{sent} \tag{4}$$

Due to the fact that freight trains with combined (B) and long content (D) from norm are shipped to the lines adjacent to the station on a strict graph, the technical and commercial inspection, distribution, provision of locomotives and waiting times when sending from it are not provided. However, when composing and dispatching unified freight trains, operations such as connecting-separating additional cars and waiting for it are performed. Also, due to the fact that these trains occupy station track junctions when sending from the station, the waiting time for trains of norm length must be taken into account.

The time spent on technology operation "B" and its expectation are determined by the following expression [4]:

$$\mathrm{t_{tex}=t_{bloc}^{rec}+t_{proc}^{rec}+t_{diss}+t_{form}+t_{trans}+t_{bloc}^{dep}+t_{proc}^{dep}+t_{ass}^{lok}+t_{sent}+t_{diss}^{ass}} \tag{5}$$

$$\mathrm{t_{wait}=\Delta t_b+t_{wait}^{form}+t_{wait}^{trans}+t_{wait}^{mane}+t_{wait.diss}^{ass}} \tag{6}$$

The time spent on technology operations "D" and its expectation are determined by the following expression [4]:

$$\mathrm{t_{tex}=t_{bloc}^{rec}+t_{proc}^{rec}+t_{diss}+t_{form}+t_{trans}+t_{blok}^{dep}+t_{proc}^{dep}+t_{ass}^{lok}+t_{dep}}, \tag{7}$$

$$\mathrm{t_{wait}=t_{wait}^{form}+t_{wait}^{trans}+t_{wait}^{mane}}. \tag{8}$$

The time for "S" and "D" technologically transit non-recyclable wagons to stand at a technical station is determined using the following formula:

$$\mathrm{t_{tr}^{unproc}=t_{proc}^{dep}+t_{wait}^{proc}+t_{wait}^{dep}}$$

The time for "B" - Technology transit non-recyclable wagons to stand at the technical station is determined using the following formula:

$$\mathrm{t_{tr}^{unproc}=t_{proc}^{dep}+t_{diss}^{ass}+t_{wait.diss}^{ass}+\Delta t_b} \tag{9}$$

there, $\mathrm{t_{bloc}^{rec}}$- the time spent fixing and blocking the structures with brake, hour; $\mathrm{t_{proc}^{rec}, t_{proc}^{dep}, t_{wait.proc}^{rec}, t_{wait.proc}^{dep}}$- the time spent on technical and commercial inspection of content in the station's reception and departure park and its wait, hour; $t_{dist}, t_{com}, t_{trans}, t_{ass}^{lok}, t_{sent}, t_{wait}^{diss}, t_{wait}^{form}, t_{wait}^{trans}, t_{wait\backslash ass}^{lok}, t_{wait}^{sent} -$ distribution, compilation, transfer from the sorting park to the shipment park, assembly of locomotives, time spent preparing a route on shipment and waiting for it, hour; $t_{wait}^{mane} -$ maneuver locomotive wait, hour.

These technological operations are determined by a formula in which a certain number of operations are performed for each element:

$$t_{wait} = \frac{\varphi^2 (1 + \nu_{ser.d}{}^2)}{2 \cdot r \cdot (1 - \varphi)}, \tag{11}$$

there, $\varphi -$ input channel load factor; $\nu_{ser.d} -$ variational coefficient of service duration; $r -$ the intensity of arrival of content at the station at intermediate intervals.

The technical station “Ch” was closed to the movement of wagons arriving at the depot around the clock (figure 1-2).

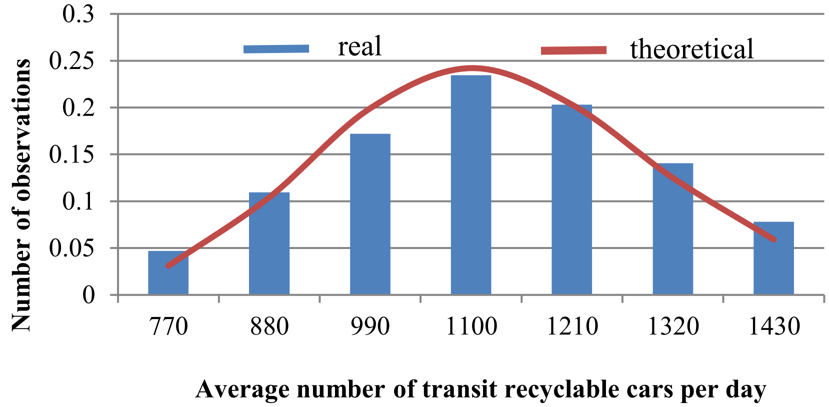


FIGURE 1. Statistical and theoretical distribution of the number wagons arriving in transit recyclable cars per day

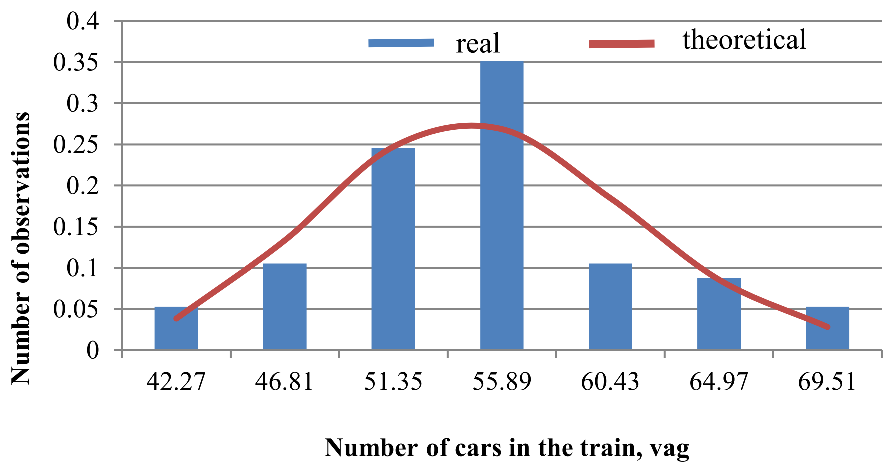


FIGURE 2. Statistical and theoretical distribution of the number of cars in the composition of the train coming to transit processing

Based on statistical data processing, it was found that the flow of transit recyclable cars to the station and the number of cars in the train structure are subject to the law of Logonormal distribution. The function of the law of Logonormal distribution has the following appearance [13,14]:

$$f(X) = \frac{1}{\sqrt{2 \cdot \pi} \sigma X_i} \cdot e^{-\frac{(\ln(X) - X_{aver})^2}{2 \cdot \sigma^2}}, \tag{11}$$

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

RESEARCH RESULTS

In train traffic organization technologies, the transit of recyclable trains at the station depends on the flow of cars coming to interoperability (U_i) as well as the share of trains longer, combined and of normative length (α_i) than the norm to be drawn up. The composition t_{tr} of the relations between such indicators (variables) is determined by constructing regression equations using the least squares method. A multi-factor regression equation is constructed on each element of the value of these indicators involved in the determination, that is, on the basis of the variable $X_i(U_i, \alpha_i)$ indicators that depend on the value of $Y(t_{tr}, t_{tex}, t_{dist}, t_{wait})$.

As an adaptive multi-factor equation of regression, the following equation is used:

$$y = a_0 + a_1 \cdot x_1 + ... + a_n \cdot x_n \tag{13}$$

The sum of the squares of the difference of the real quantities of Y from the flattened quantities must be the smallest, i.e

$$S = (Y - \overline{Y}) \longrightarrow \min \tag{14}$$

In general the system of normal equations is expressed as:

$$\begin{cases} \sum y = na_0 + a_1 \cdot \sum x_1 + ... + a_n \cdot \sum x_n \\ \sum x_1 y = a_0 \cdot \sum x_1 + a_1 \cdot \sum x_1^2 + a_2 \cdot \sum x_1 \cdot x_2 ... + a_n \cdot \sum x_n \\ .... \\ \sum x_n y = a_0 \cdot \sum x_n + a_1 \cdot \sum x_1 \cdot x_n + a_1 \cdot \sum x_2 \cdot x_n ... + a_n \cdot \sum x_n^2 \end{cases} \tag{15}$$

The correlation coefficient of the bond on each variable is determined by the following expression:

$$R_{yx_1} = \frac{\sum yx_1 - \sum y \sum x_1}{\sigma_y \cdot \sigma_{x_1}} \tag{16}$$

$$R_{yx_2} = \frac{\sum yx_2 - \sum y \sum x_2}{\sigma_y \cdot \sigma_{x_2}} \tag{17}$$

$$R_{x_1 x_2} = \frac{\sum x_2 x_1 - \sum x_2 \sum x_1}{\sigma_{x_2} \cdot \sigma_{x_1}} \tag{18}$$

(13) the regression coefficients a_j in the system of equations are expressed in different units of measurement and measure the influence of qualitatively different factors. Therefore, to test the result of the values given this equation, recurrent equations are constructed that are inverse to it.

The regression coefficient in this recurrence equation is calculated as follows:

$$\beta = a_j \frac{\sigma_{x_j}}{\sigma_y} \tag{19}$$

The resulting multidimensional regression equation is expressed in the following way:

$$\overline{y} = a_0 + b_1 \cdot z_1 + ... + b_n \cdot z_n \tag{20}$$

If we take the resulting character and factor values on a normal scale:

$$\overline{u}_{1x_j} = b_1 \cdot z_1 + ... + b_n \cdot z_n = \sum_{j=1}^{n} \beta_j - z_j \tag{21}$$

(19) arises the solution of the following system of normal equations to determine the coefficients of β_j in the equation:

$$\begin{cases} \sum uz_1 = \beta_1 \cdot \sum z_1 + \beta_2 \cdot \sum z_1 z_2 + \beta_3 \cdot \sum z_1 z_3 ... + \beta_n \cdot \sum z_1 z_n \\ \sum uz_2 = \beta_2 \cdot \sum z_2 z_1 + \beta_2 \cdot \sum z_2^2 + \beta_3 \cdot \sum z_2 \cdot x_3 ... + \beta_n \cdot \sum z_2 z_n \\ .... \\ \sum uz_n = \beta_n \cdot \sum z_n z_1 + \beta_2 \cdot \sum z_n \cdot z_2 + \beta_3 \cdot \sum z_3 \cdot z_n ... + \beta_n \cdot \sum z_n^2 \end{cases} \quad (3.22)$$

To bring the coefficients of the multi-dimensional regression equation β_j to natural values (a_j), from the standardized regression coefficients in the expression (19), their natural values (a_j) are calculated based on the following expressions:

$$a_j = \beta_j \frac{\sigma_y}{\sigma_{x_j}} , \quad (23)$$

$$a_0 = \bar{y} - \sum_{j=1}^{n} a_j \bar{x}_j . \quad (24)$$

There is a reciprocal ratio between the regression coefficients and the elasticity coefficients.

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

$$Э_j = a_j \frac{\bar{x}_j}{\bar{y}} . \quad (25)$$

(23) iodine (25) niobium, the coefficient of elasticity of which is:

$$Э_j = \beta_j \frac{\sigma_y}{\sigma_{x_j}} \cdot \frac{\bar{x}_j}{\bar{y}} . \quad (26)$$

It was modeled on the technologies of organizing train traffic using a mathematical model on the basis of the law of distribution of the number of cars coming to the processing of trains at the technical station for the time of their stay at the "Ch" station. Figure 3 presents the dynamics of the change in the time spent on technological operations on technologies for organizing train movement.

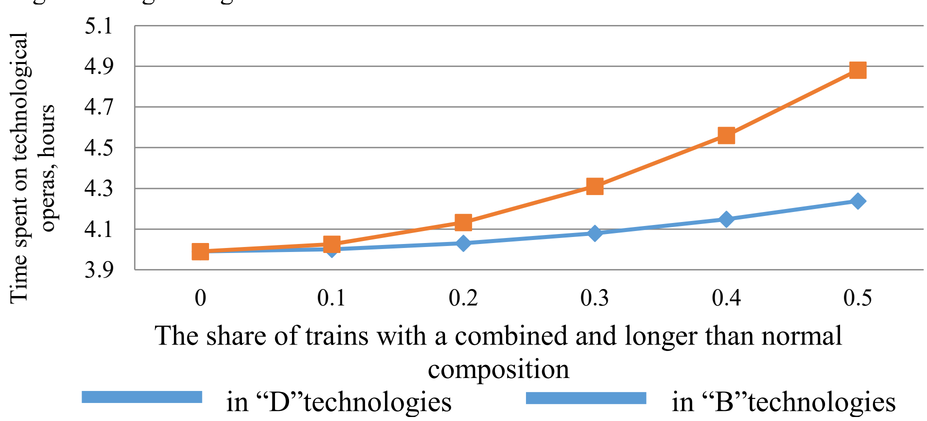


FIGURE 3. The dependence of the technologies for organizing the movement of trains on the time spent on the performance of technological operations

Studies have shown that the duration of the t_{tex} value does not change, regardless of the change in the number of transit recyclable wagons at the technical station to the minimum and maximum value (from 770 to 1430) in seasonal and annual irregularities. The time spent on technological operations was observed to increase by 0.1 - 0.25 hours (1.4 – 6.2%) depending on the value of α_{long} in” D “technology compared to” S “technology, and 0.1 – 1.9 hours (2.4 – 22.3%) depending on the value of $\alpha_{coupl.d}$ (coupled train) in “B” technology The main reason for this is that in “D”and “B”technologies, the number of wagons in trains is higher than in “S” technology.

An increase in the volume of work at the station (when the number of processed transit wagons changes from minimum to maximum value due to seasonal and annual irregularities) leads to an increase in the waiting time of the processed transit wagons to perform technological operations. This is due to the appearance of queues for performing technological operations (figure 4,5).

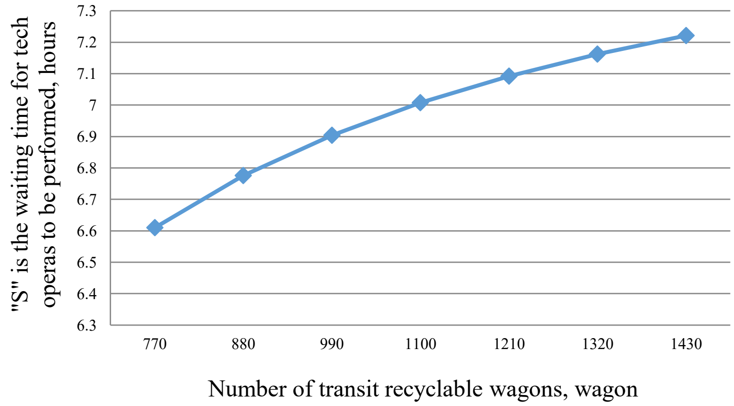
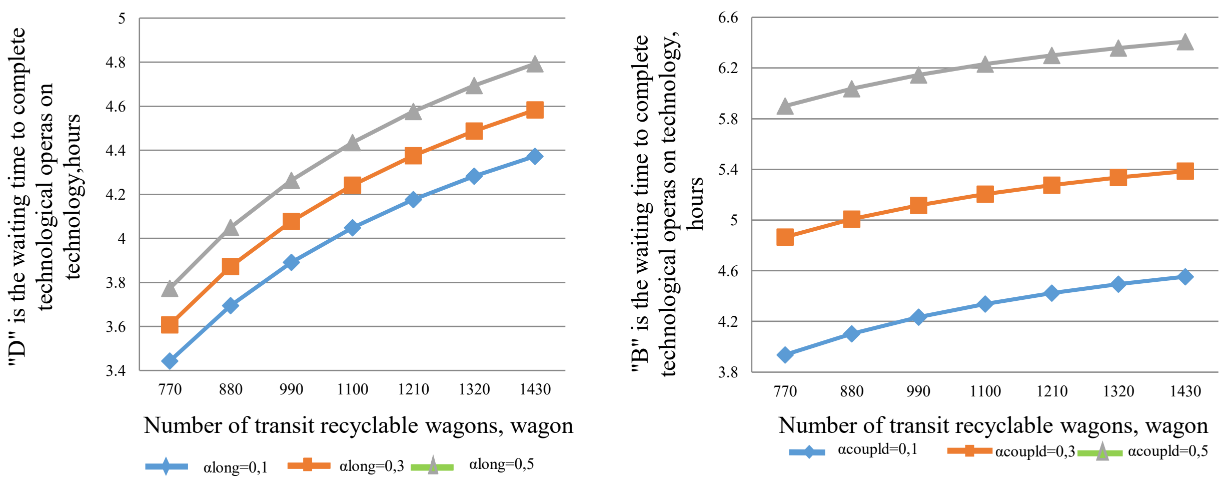


FIGURE 4. Dynamics of change in waiting times to perform technological operations on train movement organization technologies “S”



a) The share of trains with longer and than normal composition

b) The share of trains with a combined and than normal composition

FIGURE 5. Dynamics of change in waiting times to perform technological operations on train movement organization technologies

Figures 4,5 shows that t_{wait} value increased by 0.61 hours (9.3%) in “S” technology when the number of recyclable transit cars increased, 0.93-1.33 hours (27-39.2%) in “D” technology depending on the value of α_{long}, 0.62-2.47 hours (15.7-67.2%) in “B” technology depending on the value of $\alpha_{coupl.d}$. There was also a decrease in waiting time for technological operations to 2.24-3.2 hours (33.8-48%) in “D” technology compared to “S” technology, and 1.5-3.1 hours (32.6-67.4%) in “B” technology. The main reason for this is the arrival of trains at stations on “D”and “B” technologies on a strictly graphical basis. Alternatively, the “B” technology involves waiting for norm length trains as a result of the station’s track banding the strait in the process of connecting and disconnecting trains combined.

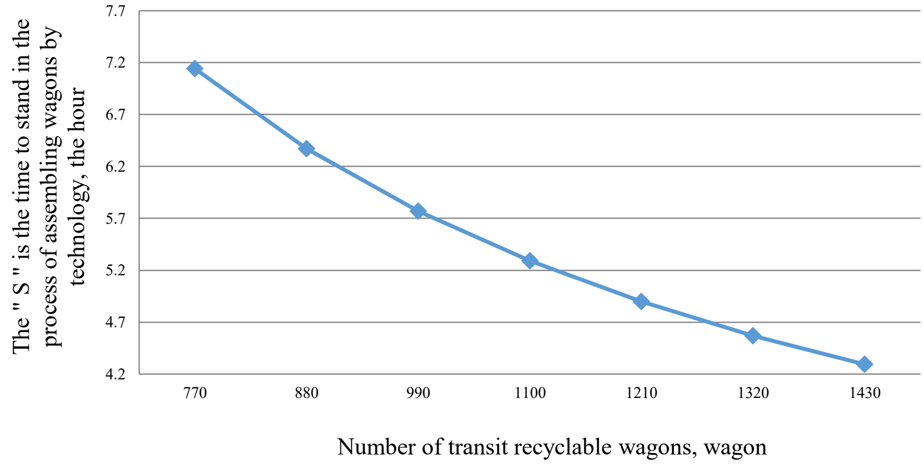
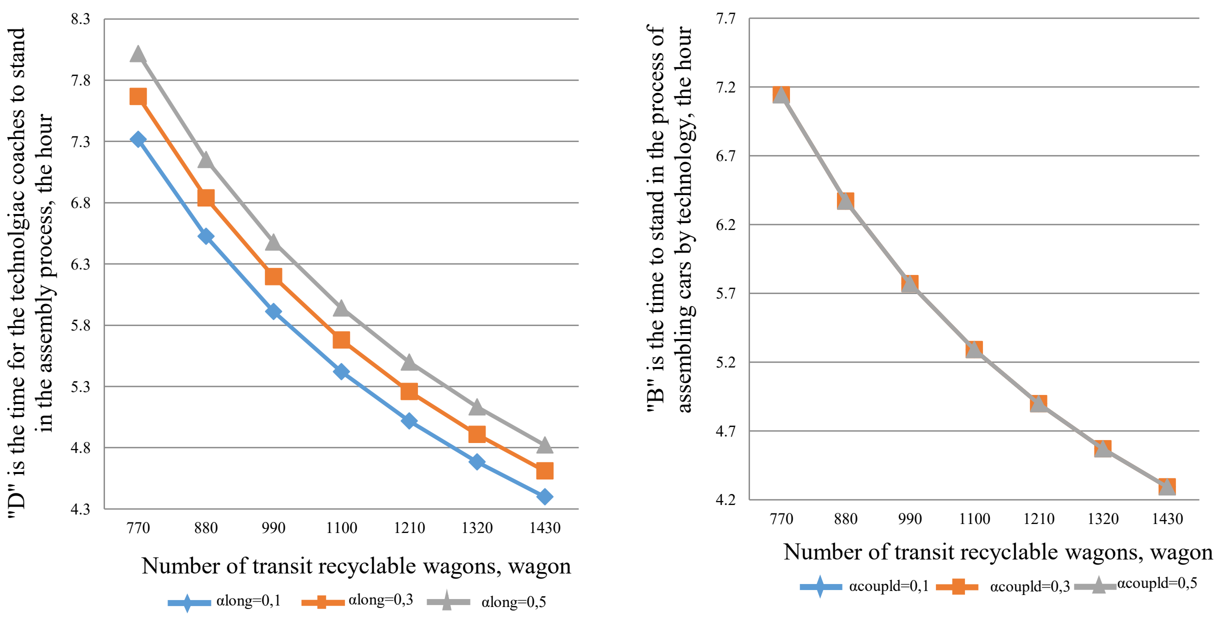


FIGURE 6. During the assembly process of structures on train traffic organization technologies “S”, the time for the wagons to remain standing



a) The share of trains with longer and than normal composition

b) The share of trains with a combined and than normal composition

FIGURE 7. During the assembly process of structures on train traffic organization technologies “B and D”, the time for the wagons to remain standing

When the number of recyclable transit wagons increased at the station there was a sharp decrease in the time of staying in the assembly process of the wagons in the sorting park (figures 6,7). The figure shows that t_{ass} value was observed to decrease by 2.85 hours (38.8%) in “S” technology, 2.9-3.6 hours (39-49%) in “D” technology depending on α_d value, 2.85 hours (38.8%) in “B” technology regardless of $\alpha_{coupl.d}$ value. The reason for this is the assembly of content of normative length in “S” and “B” technologies, and of content longer than norm in “D” technology. Also, during the assembly process in the sorting park of recyclable transit wagons, the stay time increased by 0.2-0.9 hours (2.5-12.3%), depending on the value of α_{long} in “D” technology compared to “S” and “B” technologies.

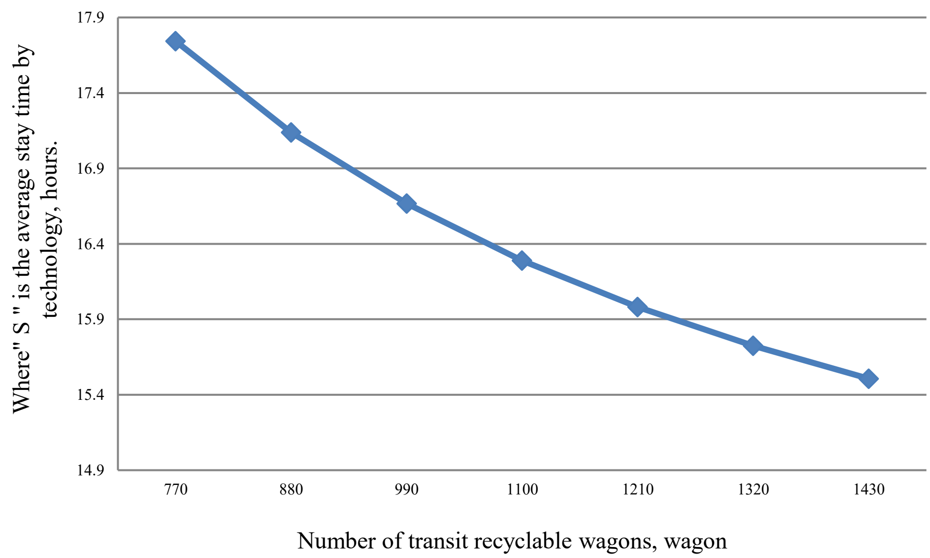
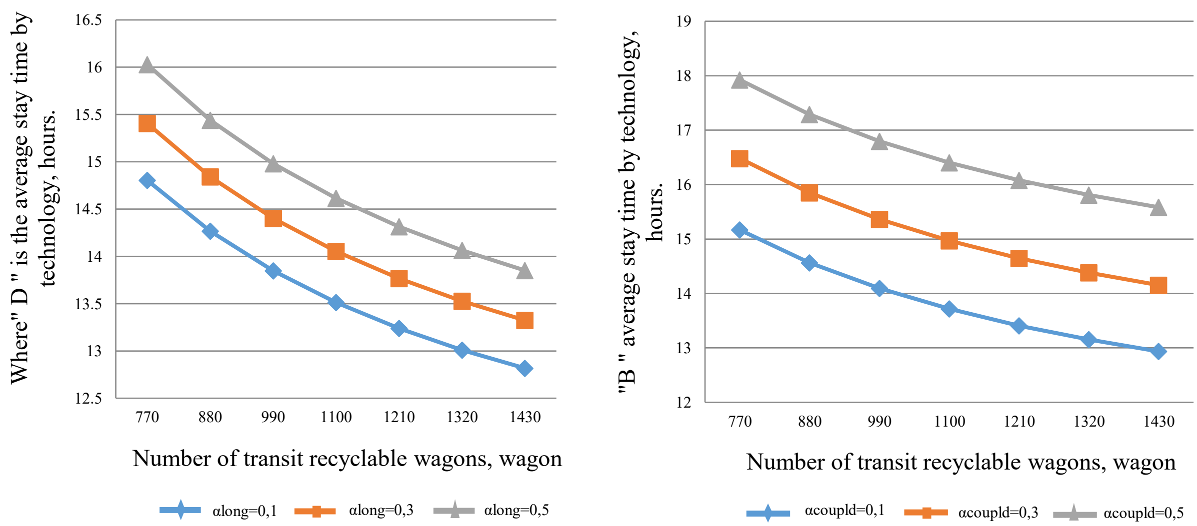


FIGURE 8. Dynamics of change in the time of stay of transit recyclable trains at the station in train traffic organization technologies "S"



a) The share of trains with longer and than normal composition

b) The share of trains with a combined and than normal composition

FIGURE 9. Dynamics of change in the time of stay of transit recyclable trains at the station in train traffic organization technologies "B and D"

The timing of transit recyclable trains at the station was determined, taking into account the times when the renewable transit wagons stood at the technical stations in different processes (figures 8,9). Analysis shows that t_{tr}^{proc} value was observed to decrease by 2.23 hours (12.6%) in "S" technology, 1.98-3.2 hours (13.4-21.7%) in "D" technology depending on the value of α_{long}, and 2.23-4.98 hours (14.7-32.9%) in "B" technology depending on the value of $\alpha_{coupl.d}$. In particular, there was a decrease in the time spent by renewable transit wagons staying at the technical station by 1.7-2.94 hours (9.6-16.6%) in "D" technology compared to "S" technology, and 0.1-2.6 hours (1% -14.5%) in "B" technology. The main reason for this is the arrival of trains at stations on "D" and "B" technologies on a strict graph.

When the number of non-recyclable transit wagons increases at the technical station, t_{tr}^{unproc} will cause an increase in value. The main reason for this is the occurrence of queues when performing technological operations. This leads to an increase in the time for non-recyclable transit wagons to stay at the station (figure 9). Figure 9 shows that when the number of non-recyclable transit wagons increased, the value of t_{tr}^{unproc} was observed to increase by 0.18 hours (14.5%) in "S" technology, 0.18-0.28 hours (14.2-22%) in "D" technology depending on the value of α_{long}, and 0.3-2.6 hours in "B" technology depending on the value of $\alpha_{coupl.d}$. In particular, non-recyclable transit wagons had a 2.8-3.7 hour (60.9-80.4%) increase in "D" technology compared to "S" technology, and a 1.5-3.1 hour (32.6-67.4%) increase in "D" technology. The main reason for this is the arrival of trains on the stations on a strict graphic basis in "D"and "B" technologies, and the formation of trains with a combined and longer than normal composition on these technologies. Also connecting trains under "B" technology is the result of these trains waiting for trains of norm length due to the fact that during the disconnection process these trains occupy the station straits.

In the selection of rational options for organizing the movement of trains of different categories, as well as in the coplex assessment of development prospects, the following objective function is used as a criterion for minimizing the cost of transportation:

$$Z = \begin{array}{l} \sum_{i=1}^{k}\Sigma \quad \sum_{j=1}^{n_i}\Sigma \quad (E(\alpha_{coupld}, \alpha_{long}, \vartheta_{speed}, m_{long}, m_{coupld}) \to min \\ \sum_{i=1}^{k}\Sigma \quad \sum_{j=1}^{n_i}\Sigma \quad T_{ij} \to min \end{array} \tag{29}$$

$$0 \le \alpha long \prec 1;$$
$$0 \le \alpha coupld \prec 1;$$
$$57 \prec m_{long} \le 71; 71 \le m_{coupld} \le 114; \vartheta_{don} \le \vartheta_{speed} \prec \vartheta_{constr.speed};$$
$$\rho_{ij} \le \alpha_{н}, i = \overline{1,k}; j = \overline{1,n_i} \tag{28}$$

there α_r − reliability coefficient;

α_{long} − share of trains with a composition longer than the norm in the total freight flow;

α_{coupld} − share of combined train transfers;

$m_{num.wag}$ − the number of wagons in a train longer than normal;

m_{coupld} − the number of wagons in a combined train;

ϑ_{speed} − the freight train has a running speed of.;

k − the number of elements of the time to ride trains of different categories on the road and stand at technical stations;

n − number of options offered.

The rational variant of the organization of train traffic using the purpose function presented above was determined on the basis of technical economic calculations. A comparative assessment of the existing and optimal options for organizing the transfer of trains of different categories showed that the total economic effect, which is due to the transfer of a share of 0.5 freight trains to a combined train, is 0.300 billion in one year. som.

Based on the data analysis obtained, it can be concluded that the introduction of this technology not only increases the reserve capacity of the railway site, but also allows a reduction in the number of trains running.

CONCLUSIONS

The method of organizing the movement of trains of different categories, taking into account the use of the existing technical and technological capabilities of the station, significantly reduces the cost of use. Increasing the bandwidth of the railway infrastructure due to the optimal use of station roads, reducing the time of delivery of goods to customers by introducing modern innovative technology into the methods of effective organization of train traffic of various categories, making it possible to improve the method of organizing train traffic due to the performance of additional technological operations at the station.

REFERENCES

1. Abdullaev, Z., Rasulov, M., & Masharipov, M. (2021). Features of determining capacity on double-way lines when passing high-speed passenger trains. In E3S Web of Conferences (Vol. 264, p. 05002). EDP Sciences. (https://doi.org/10.1051/e3sconf/202126405002)

2.Abdullaev Zh. Ya. Features of determining the capacity of double-track sections /Zh. Ya. Abdullaev. - News of the Petersburg University of Railway Engineering. - SPb.: PGUPS. - 2019. - Vol. 16, Issue 3. – 361 – 371 p. (https://cyberleninka.ru/article/n/osobennosti-opredeleniya-propusknoy-sposobnosti-dvuhputnyh-uchastkov)
3.Abramov A.A. Operational Management: Part II. Train Schedule and Throughput/Textbook/ Abramov A.A. - M.: RGOTUPS, 2002, −171 p. ISBN 5–7473–0116–0.
4. Grachev A.A. Selection of standards for the mass and length of trains on single-track railway sections / A.A. Grachev, G.M. Groshev, Zh.Ya. Abdullaev, A.V. Sugorovsky, A.S. Al-Shumari // Bulletin of scientific research results. - St. Petersburg: PGUPS, 2019. – Issue 3. – C. 25 – 37. (https://cyberleninka.ru/article/n/vybor-norm-massy-i-dliny-poezdov-na-odnoputnyh-zheleznodorozhnyh-liniyah/viewer).
5. Kravchenko M.V. Evaluation of the effectiveness and development prospects of high-speed passenger transportation on Russian railways /M.V. Kravchenko //– M.:MIIT, 2004. – 27 p.
6. Levin D. Yu. Calculation and use of railway capacity / D. Yu. Levin, V. L. Pavlov. - M.: Federal State Educational Institution "Educational and Methodological Center for Education in Railway Transport", 2011. –364 p.
7. Makhkamov N.Ya. Study of increasing the efficiency in the application of technology for passing trains of increased mass and length / N.Ya. Makhkamov, Zh.Ya. Abdullaev, G.Sh. Ikramov - "Fire and explosion safety"– 2021. – Issue 1(6). – C.260-268.
8. Boliang Lin; Yinan Zhao; Ruixi Lin; Chang Liu Shipment Path Planning for Rail Networks Considering Elastic Capacity IEEE Intelligent Transportation Systems Magazine Year: 2022 | Volume: 14, Issue: 3 | Magazine Article | Publisher: IEEE.
9. Masharipov, M., Rasulov, M., Suyunbayev, S., Adilova, N., Ablyalimov, O., & Lesov, A. (2023). Valuation of the influence of the basic specific resistance to the movement of freight cars on the energy costs of driving a train. In E3S Web of Conferences (Vol. 383, p. 04096). EDP Sciences.
10. G.R. Ibragimova, Z.G. Mukhamedova, S.K. Khudayberganov Assessment of options for location of railway infrastructure facilities. In AIP Conference Proceedings (Vol. 2432, No. 1, p. 030019). AIP Publishing LLC.
11. Aripov, Nazirjon & Arpabekov, Muratbek & Shinpolat, Suyunbaev & Masharipov, Masud & Khusenov, Utkir. (2024). Development of a Mathematical Model of Sequential Arrangement of a Group of Wagons Along Station Tracks. https://doi.org/10.1007/978-3-031-53488-1_2
12. Muzykina S.I. Study of working capacity of the marshalling yard / S.I. Muzykina, M.I. Muzykin, G.I. Nesterenko // Bulletin Dnipropetrovsk national University of railway transport, Ukraine, 2016, No. 2 (62) pages. 47-58.
13. Rasulov, M., Masharipov, M., & Ismatullaev, A. (2021). Optimization of the terminal operating mode during the formation of a container block train. In E3S Web of Conferences (Vol. 264, p. 05025). EDP Sciences.
14. Ventsel E. S. Theory of Probability / E. S. Ventsel. - M.: Nauka,2010. – 350 c.
15. 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
16. Khusenov, U., Suyunbaev, S., Umirzakov, D., Tokhtakhodjayeva, M., & Adizov, I. (2024). 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* (Vol. 583, p. 03018). EDP Sciences. https://doi.org/10.1051/e3sconf/202458303018