Regression Model of the Factors Influencing the Section Speed of Freight Trains on Railway Routes

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**Abstract.** As you know, the section speed is one among the most significant operational, technical and economic indicators of the quality of the transportation process. The sectional speed reflects the average speed of train movement between the stations of technical inspection and the change of locomotive crews. When assessing the impact of the average daily number of trains and “seasonality” factors on the capacity of a railway line, the sectional speed plays an important role. It is assumed that the factors influencing the average section speed during the planned transportation period remain unchanged. As a result, there is a significant discrepancy between the planned section speed. This article reveals that, under the influence of a number of factors, the precinct speed decreases annually. Regression models of the factors influencing the decrease in section speed have been built based on statistical data on the “Tukimachi–Angren” railway line for 2014-2024. As a result, the correlation values between the average daily number of trains traveling in the direction of “Tukimachi–Angren” and the section speed were established. It is proved that the influence of the average daily number of trains on the speed on the railway line differs in the “summer” and “winter” periods. The influence of the “seasonality” factor on the area velocity was approximated with a high degree of confidence based on the developed regression model. As a result, it was found that the seasonality factor has a significant effect on the speed in the odd direction of the “Tukimachi–Angren” railway line, whereas in the even direction this effect is not statistically significant.

**Keywords:** seasonality factor, section speed, average daily number of trains, railway route, freight turnover, throughput capacity

# INTRODUCTION

The section speed of freight trains is a principal indicator characterizing the operational work of the railway and the quality of freight transportation. Operational performance indicators such as the time required to deliver goods, the operation of locomotives, and many others directly depend on the performance of the section speed of freight trains. In addition, this indicator has a direct impact on the organization of work and recreation of locomotive crews.

One of the most important tasks in the organization of train traffic on railway transport is to increase the speed of the section in the directions. The section speed affects the carrying and carrying capacity of destinations and stations, the delivery time of goods, the cost of transportation, and many other qualitative indicators. Therefore, high-quality planning of the precinct speed and analysis of losses in case of non-fulfillment are of great importance.

The movement of trains on railway routes is influenced by many destabilizing factors. Such factors lead to delays of trains on the stages and loss of time, which, in turn, causes a decrease in the section speed. The destabilizing factors leading to a decrease in the section speed can be identified by analyzing the executed train schedule. In general, the executed train schedule reflects the degree of accuracy and quality of the implementation of transport technology, the quality of operational work, the composition of traffic and the efficiency of using railway capacity. The fulfillment of sectional speeds is analyzed by the employees of the “Statistics and Accounting Department” (NCh) [1]. This analysis is carried out based on daily actual movement charts, which are compiled by train dispatchers of railway sections on a shift-by-shift basis.

Analytical engineers of the railway’s “Statistics and Accounting Department” determine the average daily section speed based on the following formula [2]:

 *km/h* (1)

|  |  |
| --- | --- |
| here | the number of freight trains moving along the railway section, train; |
|  | distance traveled by the *j*-th train, km; |
|  | travel time of the *j*-th train on the section, h; |
|  | parking time of the *j*-th train at the station, h, ч. |

Currently, various methods are used to assess the loss of the section speed of freight trains. These methods, as a rule, are reduced to taking into account the time of train delays for certain reasons. Forecasting the expected performance of the average section speed during the planned period of transportation work is based on an assessment of the factors influencing it. It is assumed that these factors will remain unchanged in the planned period. As a result, there is a significant failure to meet the planned speed limit.

For example, in JSC “Russian Railways” the assessment of sectional speed losses is carried out using an automated system for recording and analyzing the actual train movement schedule, developed by the All-Russian Scientific Research Institute of Railway Transport (VNIIZhT), or based on a regression model that takes into account factors influencing sectional speed [3]. Since such a system is not available at JSC “Uzbekistan Railways” it is advisable to develop a regression model that takes into account various factors influencing sectional speed, considering the specific operational characteristics of the corresponding railway section.

On sections and routes where there is a periodic increase in freight turnover (gross ton-kilometers), a slowdown in the growth of transportation volumes is observed after a certain point, resulting in a decline in both the quantitative and qualitative indicators of the transportation process.

The growing demand for freight transportation due to the development of our country's economy reveals discrepancies between the carrying capacity of the railways and the required transportation volumes. The main reason for this is the limited throughput capacity of railway sections and the technical capabilities of stations.

# LITERATURE SURVEY

The efficient organization of freight train operations on the railway network, particularly ensuring their movement according to schedule, is one of the pressing areas of current scientific research. Existing studies in this field focus on schedule adherence, risk factors affecting sectional speed and their economic consequences, as well as speed indicators used to assess the efficiency of the railway network. In particular, within the railway system of Uzbekistan, a number of scientific studies have been conducted aimed at improving the efficiency of freight transportation, ensuring the stability of train operations, and optimizing sectional speed [4, 5, 6, 7, 8, 9, 10]. At the international level, in the railway transport system, factors affecting the speed of freight trains are analyzed using artificial intelligence, neural networks, and machine learning models in the context of energy efficiency, environmental performance, and traffic safety. In addition, models integrated with GIS (Geographic Information Systems) are used to analyze the speed of freight trains in real time   
[11, 12, 13]. However, in the existing scientific studies dedicated to analyzing the factors influencing the sectional speed of freight trains on railways using regression models, the seasonal factor is insufficiently considered or treated as secondary, and the extent to which the number of trains affects sectional speed is not thoroughly examined.

**RESEARCH METHODOLOGY**

**The Impact of Freight Train Volume on Sectional Speed**

The single-track railway section “Tukimachi–Angren” with a length of 113 km, equipped with a microprocessor-based semi-automatic block system and part of the Tashkent regional railway hub branch of JSC “Uzbekistan Railways” was selected as the object of study (Figure 1).

**FIGURE 1.** Layout of the “Tukimachi–Angren” railway line on the map of the Tashkent Regional Railway Hub branch

The length of this railway line accounts for 2.44% of the total length of railway sections operated by JSC “Uzbekistan Railways” (4625.2 km) and 15.62% of the length of the Tashkent Regional Railway Hub (723.4 km).

The electrified railway section “Angren–Pop” was put into operation in 2016 as part of JSC “Uzbekistan Railways” enabling freight and passenger transportation by rail between the valley and oasis regions of the Republic of Uzbekistan. This began to yield positive results in a short period, including in the freight turnover of the “Tukimachi–Angren” railway line. Since 2017, the volume of freight transported on this section has been steadily increasing (Figure 2). The freight turnover and volume of transported goods on the studied line for the period 2014–2024 are shown in Figure 2.

According to the analysis shown in Figure 2 for the period 2014–2024, this railway line accounts for an average of 6.61% of the freight turnover (amounting to 2891.89 million gross ton-kilometers) and 3.46% of the total freight transported by JSC “Uzbekistan Railways”. Within the Tashkent Regional Railway Hub branch, this line accounts for an average of 7.49% of the transported freight and 20.76% of the freight turnover. This, in turn, indicates that the “Tukimachi–Angren” railway line is among the high freight traffic routes within the system of JSC “Uzbekistan Railways”.

**FIGURE 2.** Freight transportation indicators on the “Tukimachi–Angren” railway section for the period 2014–2024

The analysis of freight transportation indicators presented in Figure 2 shows that the lowest values of freight turnover and freight volume were observed in 2016, while the highest were recorded in 2023. As of today, the volume of freight transported on the studied section has almost doubled compared to the 2014 level, and freight turnover has increased by 87%. The year-by-year increase in freight transportation volumes leads to a mismatch between the existing throughput capacity of the section and the required transportation volume.

The growth in freight transportation volume, in turn, leads to an increase in the daily number of trains on the section, which under certain conditions negatively affects sectional speed and throughput capacity.

Between 2016 and 2023, the sectional speed in the even direction decreased by a maximum of 3.3 km/h, while in the odd direction, between 2014 and 2018, it decreased by up to 3.0 km/h. In 2024, due to a 13% decrease in freight transportation volume compared to 2023, as well as a 14.9% reduction in the average daily number of trains, the sectional speed increased by 3.3 km/h (Figure 3). Figure 3 presents the average daily number of freight trains and the sectional speed on the “Tukimachi–Angren” railway line for the period 2014–2024, indicating that the number of freight trains during these years changed proportionally to the volume of transported goods.

**FIGURE 3.** The number of freight trains and sectional speed on the “Tukimachi–Angren” railway line for the period 2014–2024

As can be seen from Figure 3, an increase in the number of freight trains has a negative impact on capacity and section speed. The factors influencing the decrease in sectional speed include a shortage of traction resources, low management efficiency, forced train stops at intermediate and technical stations, an increase in the number of trains on railway routes, as well as “technological windows” for the repair and maintenance of infrastructure facilities. Consequently, these factors contribute to the growth of the operational wagon fleet. The expansion of the active wagon fleet results in a rise in the number of trains, which subsequently contributes to a reduction in local train speeds.

Based on the data presented in Figure 3, we will analyze the fulfillment of sectional speed on railway lines and the factors influencing it in the following sequence. The impact of the number of passing trains on sectional speed will be examined using the example of the “Tukimachi–Angren” railway line.

Given the uneven daily distribution of train movements on railway lines, the data presented in Figure 3 were analyzed on a monthly basis by year. The main objective of this approach is to increase the number of observations in order to determine the optimal functional relationship between sectional speed and the number of trains.

Based on the conducted analysis, the data on the average daily number of operating trains  and the corresponding average sectional speed  on the “Tukimachi–Angren” railway line for the period 2014–2024 can be represented as a set of correlation points:

Figures 4 and 5 present the correlation points reflecting the average daily number of operating trains and the corresponding sectional speeds in the even and odd directions of the “Tukimachi–Angren” railway section for the analyzed period. Each correlation point represents the average sectional speed for a given month, corresponding to the average daily number of trains operating on the railway line during that month within the analyzed period presented in Figure 3.

**FIGURE 4.** Scatter plot of the average daily number of operating trains and the average sectional speed in the even direction

**FIGURE 5.** Scatter plot of the average daily number of operating trains and the average sectional speed in the odd direction

The analytical data on the average daily number of trains  and the corresponding average sectional speed  of train movement on the studied railway section, presented in Figures 4 and 5, will be refined using the least squares method to determine the optimal functional relationship. The least squares method is a statistical regression technique used to determine the optimal function based on a given set of points. To mathematically assess the impact of the number of freight trains on sectional speed, the following quadratic regression model will be used.

 *km/h* (2)

|  |  |
| --- | --- |
| here | unknown coefficients, respectively in *km/h/train2* and *km/h/train;* |
|  | sectional speed determined by traction calculations, km/h; |
|  | average daily number of trains operating on the section, train; |
|  | error between the regression model and the actual data. |

The main goal of the least squares method is to minimize the squared errors between the regression model and the actual data. From this perspective, we formulate the objective function for the research problem under consideration as follows:

 (3)

Then the least squares method for formula (2) has the following form:

 (4)

The coefficients of the quadratic model of the least squares method are determined based on the following equation obtained from formula (4):

 (5)

**RESULTS AND DISCUSSIONS**

The coefficients of the quadratic regression model for the even and odd directions of the “Tukimachi–Angren” railway section were determined based on formulas (4–5). As a result, the regression models representing the relationship between the average daily number of trains  and the corresponding average sectional speed  as shown in Figures 4 and 5, were obtained as follows:

- for the even direction:

 *km/h*

- for the odd direction:

 *km/h*

To determine the degree of correlation between the average daily number of freight trains operating on the railway line and its sectional speed, a correlation analysis was conducted. As part of the correlation analysis, a relationship was identified between the results obtained from the developed regression model and the actual values of sectional speed. This correlation was determined based on the square root of the ratio of the variances of the model and the actual values, using the following formula [14]:

 (6)

|  |  |
| --- | --- |
| here | mean squared deviation of sectional speed results obtained from the regression model, *(km/h)2;* |
|  | mean squared deviation of the actual sectional speed values, *(km/h)2*; |
|  | sectional speed determined by the regression model, *km/h*; |
|  | actual value of sectional speed used in the analysis, *km/h*; |
|  | arithmetic mean of the actual sectional speed values used in the analysis, *km/h*. |

The correlation between the actual sectional speed values and the results obtained from the developed regression model, according to formula (6), is  and  for the even and odd directions, respectively.

The correlation values between the average daily train traffic and sectional speed on the “Tukimachi–Angren” railway section in the even and odd directions fall within the interval . This indicates that the developed regression model for the even and odd directions of this section has a very high degree of accuracy in approximating the functional relationship between sectional speed and the average daily train traffic.

During periods when “technological windows” are implemented for the maintenance and repair of railway infrastructure facilities, the dwell time of freight trains at intermediate stations increases. This is because during a “technological window”, train movement is temporarily suspended while maintenance, routine or major repairs, or reconstruction work is carried out on the railway lines.

“Technological windows” are usually classified as either planned or unplanned. Those assigned on short notice in response to emergencies, malfunctions, or hazardous situations are considered unplanned. All “technological windows” related to the maintenance and repair of infrastructure facilities are planned in advance and coordinated with the train schedule. Planned “technological windows” that take weather conditions into account are mostly scheduled for the summer period. The “summer” period, is considered the main period for carrying out a large volume of repair work. In the “winter” period – the number and scope of “technological windows” are significantly lower compared to the summer season. As a result, seasonal factors also negatively affect the capacity of railway lines and lead to a decrease in the sectional speed of train movement.

**Assessment of the Impact of the “Seasonality” Factor on the Sectional Speed of Train Movement**

On the “Tukimachi–Angren” railway line, the distribution points of the average sectional speed corresponding to the average daily number of trains are presented for each month during the period from 2014 to 2024. Based on the data presented in Figures 4 and 5, an analysis of the seasonal factor's influence on sectional speed is carried out. That is, in the subsequent calculations, the distribution points of sectional speed shown in Figures 4 and 5 will be divided by seasons–into the “winter” period (from November to April, inclusive) and the “summer” period (from May to October). For each of these periods, the impact of seasonality on sectional speed will be determined separately.

In this study, “seasonality” refers to a certain period of the year when the number of passenger trains reaches a maximum, as well as repair and reconstruction work on the railway infrastructure, that is, the time with the largest number of “technological windows”.

Figures 6 and 7 present the data points corresponding to the average daily number of trains and the average sectional speed for each month of the analyzed years on the “Tukimachi–Angren” railway direction for the winter and summer periods, respectively.

**FIGURE 6.** Scatter diagram of the average monthly sectional speed and the average daily number of moving trains in the even direction (black dots – “summer” period, red dots – “winter” period)

**FIGURE 7.** Scatter diagram of the average monthly sectional speed and the average daily number of moving trains in the odd direction (black dots – “summer” period, red dots – “winter” period)

Taking into account that the maximum speed determined on the basis of traction calculations remains constant (*vt=const*) for both the summer and winter periods, the mathematical assessment of the impact of the number of freight trains on the sectional speed is represented as a quadratic regression model (2) in the following form [15]:

 *km/h* (7)

The maximum sectional speed is determined based on the established standard train schedule — by the travel time between block sections, assuming the train runs without stops at intermediate stations. In this case, the maximum sectional speed of the train will be equal to its technical speed. On the “Tukimachi–Angren” railway section, the maximum sectional speed of a single train is 35.31 km/h in the even direction and 37.05 km/h in the odd direction. If in formula (2) the unknown coefficient (*b=0*) is assumed to be zero, and the existence of a maximum sectional speed is taken into account, then the coefficient (*a*) a in the quadratic model is determined based on the following equation, derived from formula (5):

 (8)

The regression model describing the relationship between the average daily number of trains  and the corresponding average sectional speed  in the even and odd directions of the “Tukimachi–Angren” railway section was determined for both the summer and winter periods using the least squares method. The quadratic regression models corresponding to the data points presented in Figures 6 and 7 are as follows:

- for the even direction:

 *km/h*

 *km/h*

 *km/h*

- for the odd direction:

 *km/h*

 *km/h*

 *km/h*

The values of the unknown coefficient *(a)* in the quadratic regression model for the mathematical assessment of the influence of the number of freight trains on the speed on the “Tukimachi–Angren” railway section are: for the even direction –  in “winter” period and  in “summer” period; for the odd direction –  and , respectively. Based on the given data, Figure 8 presents the difference between the graphs of the function reflecting the impact of the number of freight trains on the sectional speed during the summer and winter periods for the “Tukimachi–Angren” railway direction.

|  |  |
| --- | --- |
|  |  |

**FIGURE 8.** Influence of the number of freight trains on the sectional speed for the “summer” and “winter” periods

The graphs of the function shown in Figure 8 show that the sectional speed of the Tukimachi–Angren railway line is influenced differently by the summer and winter periods of the year. That is, in both graphs of the function reflecting seasonality, the precinct speed in the “winter” period is slightly higher than in the “summer” period. This means that due to a certain abundance of planned “technological windows” in the “summer” period, there is a decrease in the section speed. Based on the graphs of the function shown in Figure 8, the regression model of the dependence of the section speed on the number of freight trains, taking into account the influence of different seasons of the year, given in formula (7), can be presented as follows:

 *km/h* (9)

here  unknown empirical coefficient, for the “summer” and “winter” periods, respectively, *km/h/train²;*

 empirical coefficient characterizing the “summer” and “winter” periods, *km/h/train².*

 *km/h* (10)

|  |  |
| --- | --- |
| here | unknown empirical coefficient, for the “summer” and “winter” periods, respectively, *km/h/train²;* |
|  | empirical coefficient characterizing the “summer” and “winter” periods, *km/h/train².* |

If the sum of the empirical coefficients reflecting seasonality satisfies the inequality , this indicates that the “summer” and “winter” periods have a significant impact on the sectional speed of the railway direction. Otherwise, the influence of seasonality is considered insufficiently significant to be taken into account and may be disregarded [14, 15]. The empirical coefficients reflecting the dependence of sectional speed on the number of freight trains were refined for different seasons of the year based on formula (9). Table 1 presents the values of the empirical coefficients characterizing the dependence of sectional speed on the number of freight trains on the “Tuqimachi–Angren” railway section during the “summer” and “winter” periods, as well as the dynamics of their changes.

**TABLE 1.** The values of empirical coefficients and the dynamics of their changes

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Direction | During the year | “Summer” period | | “Winter” period | | The overall impact of the “summer” and “winter” periods |
|  |  |  |  |  |  |
| Even | -0,09153 | -0,09383 | -0,0023 | -0,09070 | 0,00083 | 0,00313 |
| Odd | -0,09253 | -0,09724 | -0,00471 | -0,08868 | 0,00385 | 0,00856 |

It can be seen from Table 1 that the influence of seasonality is insignificant in the studied direction “Tukimachi–Angren”. The lower the overall impact of the “summer” and “winter” periods , the lower the impact of seasonality on the area speed. Conversely, the greater this sum, the more significant the seasonal impact on the sectional speed will be. “Technological windows” for train traffic organization, when the seasonal influence is at its peak, indicate that the influence of the traffic period and the summer passenger train schedule is the strongest.

**CONCLUSION**

As the main criterion for assessing the impact of the average daily number of trains and such factors as “seasonality” on the throughput capacity of the railway section, the sectional speed was chosen. It was established that the sectional speed  is approximated by the regression model with a high degree of accuracy.

Using this functional expression, regression models of the factors influencing the annual decrease in sectional speed were constructed based on statistical data from the “Tukimachi–Angren” railway direction for the years 2014–2024. As a result, it was found that the values of the correlation between the average daily train traffic and the section speed on the Tukimachi–Angren railway line are at least 0.8, that is,  which indicates a very high accuracy of the constructed regression model.

The average number of trains per day running along the railway line affects the speed of the section in the “summer” and “winter” periods to varying degrees. The degree of influence of the “seasonality” factor on the area speed is determined by the difference in empirical coefficients . The influence of the “seasonality” factor on the area velocity  is approximated with a high degree of accuracy based on a regression model. As a result, it was found that the influence of the “seasonality” factor on the speed of the Tukimachi–Angren railway in the odd direction is significant, while in the even direction the influence of “seasonality” is not significant.

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