Mathematical model of criteria for a comprehensive assessment of the state of railway transport infrastructure

A’zam Abdurakhmanov, Sakijan Khudayberganov, Utkir Khusenov, and Sherzod Jumayev

1 Tashkent State Transport University, 100000 Tashkent, Republic of Uzbekistan

Abstract. Today, in order to ensure the safety of cargo and passenger transportation on railways, there is no procedure for keeping records on the state of railway transport infrastructures, control of industrial enterprises and organizations over the quality of repairs, conducting examinations in ensuring traffic safety and eliminating identified shortcomings. This, in turn, is one of the main factors leading to the occurrence of accidents and accidents related to rail transport. In this article, the procedure for solving the problem of introducing inspections by inspection based on the collection of points determined based on the results of monitoring of violations carried out on the basis of criteria that assess the risk levels at which there is a probability of committing by business entities engaged in railway transport activities is considered. The mathematical model of mesons for a comprehensive assessment of the state of railway transport infrastructure, presented in the regulation on the procedure for organizing and conducting a commission monthly examination of railway transport infrastructures developed in order to ensure the safety of train traffic, is created on the basis of probability theory and the laws of normal distribution. The percentage, mathematical expectation, variance and mean quadratic limitations of the probability of occurrence of the signs of an offense in each of the points intervals are clarified.

1 Introduction

Of particular importance is the improvement of means of ensuring the required level of traffic safety based on in-depth statistical analysis, assessing the risks for solving the main production problems and improving the quality of transport services.

To date, a comprehensive study of the problems in the field of ensuring traffic safety on the Railways of the Republic of Uzbekistan has not been fully carried out, which affects the quality of the decisions made. From this, the need arose to solve theoretical, practical and methodological foundations that provide a systematic approach to solving the problems of movement safety.
In recent years, a wide range of measures have been implemented in our country aimed at developing the sphere of transport and transport communications, ensuring a high level of transport security, improving the management system in the field of transport [3].

Decree of the president of the Republic of Uzbekistan No. PF-6314 of September 15, 2021 “On measures to further reduce the administrative and tax burden for business entities, improve the system of protection of legal interests of business” and “On measures to improve the procedure for coordinating inspections in the activities of business entities” dated September 13, 2022 No. PP-374, also, in order to further improve the system of protection of the legitimate interests of business entities, in accordance with the resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 611 of October 19, 2022 “on additional measures for the organization of state control in the activities of business entities by the supervisory authorities state inspection for the control ensuring the safety of train traffic based on the implementation of assessment methodology and system, the regulation on the organization and conduct of the commission monthly examination of railway transport infrastructures was developed on the basis of the requirements of paragraph 152 of the rules for the technical use of industrial railway transport of the Republic of Uzbekistan. On the basis of this developed regulation, constant checks are carried out and require control.

The main objectives of the survey are:
- determination of the current state of railway rolling stock and infrastructure;
- identification of deficiencies in the maintenance of railway rolling stock and infrastructure;
- troubleshooting setting deadlines;
- monitoring the elimination of identified malfunctions.

The object of the study is the railway transport infrastructures of industrial enterprises and organizations that are not part of the railway transport system in general use. The subject of the study is the methods of identification, elimination of identified shortcomings and malfunctions that are not part of the railway transport system in general use, which bring the traffic safety of the railway transport infrastructure of industrial enterprises and organizations.

The purpose of the study is to ensure the safety of movement by conducting an examination of railway transport infrastructures, a comprehensive assessment of the current state of the structure and infrastructure of movement, and determining the procedure for conducting inspections by analyzing the risks of violations of the law on the safety of cargo and passenger traffic on railways.

The objectives of the study are to develop a mathematical model of mesons for assessing the state of traffic safety of trains with a systematic approach to assessing risks in the field of traffic safety of railway transport.

2 Materials and methods

On the basis of a comprehensive assessment of the state of the infrastructure of railway stations and their increasing unloading fronts, a number of scientific results have been achieved in the field of research carried out in the world to ensure the safety of train traffic. In particular, J. Shi and others developed a whole number of linear programming models to eliminate the problem of planning maniovr work in a warehouse with several electrical units [4]. Suyunbaev Sh.M. and others [5] have developed a method to reduce the duration of daily employment of their locomotives by changing the infrastructure of an electric decentralized railway station in their scientific work and performing maniovr work safely and in a short time. As a result, as a result of the development of the infrastructure of the industrial railway station and equipping it with an electrical centralization system, a reduction in the duration of the daily work plan schedule to be carried out at the station was achieved. Yusupov A.A. in his [6] scientific work, others have developed the algaritm of his system, which automatically works without human factor in time during a sudden movement of motion.
contents on Station roads, improving measures to prevent an accident in cases where the railway leaves the motion structures on its own. And to determine the safety of this system, a mathematical model of system security based on the semi-Markov chain showed the safe operation of the automatic stop system in case of spontaneous departure of the working contents. D.Y. Levin [8] in his scientific article analyzed the technological operations of train handling at intermediate stations and the station work bench when organizing local work on railway sections. At the intermediate station, the optimal options indicators were determined, ensuring the safety of movement in the cargo-loading operations of the wagons. As a result, it was made possible to process trains at intermediate stations and to determine the time by which trains stand at the station. A.M. In his dissertation, Zamishlyayev conducted a study on improving road safety based on a comprehensive assessment of the state of the railway station infrastructure. As a result, the stations developed a classifier of road, track conductors, SMB devices, communication equipment faults, which should be identified at the commission monthly examinations, and carried out systematization of criteria for a comprehensive assessment of the state of Traffic Safety at the station [9]. A.P. Plekhanov [10] in his scientific work described approaches to ensuring integrated security in railway transport in the conditions of strategic development. As a result, the main types of security that constitute comprehensive security in rail transport, which includes Traffic Safety, transport Safety, fire safety, sanitary and epidemiological Safety, Information Security, Cybersecurity, Occupational Safety, Environmental Safety, industrial safety, emergency safety.

In addition to the above, several scientific works have been carried out aimed at issues of ensuring the safety of train traffic on the basis of the implementation of a methodology and system for a comprehensive assessment of the state of railway transport by effectively organizing maniovr work carried out on the basis of the development of the railway station infrastructure and improving [7, 11, 13-15, 18-28]. Despite significant success, the Multi-Stage Complex is considered a scientific and technical task, which is not part of the general-use rail transport system, the scientific problems associated with the development of a model for a comprehensive assessment of the state of the railway transport infrastructure based on the scores concentrated on the indicators and the probabilities of occurrence of the criteria that make up them, which determine the level of security of industrial enterprises and organizations, are not sufficiently studied.

The procedure for assessing the risk is the systematic determination of the likelihood of the occurrence of danger in a violation of Traffic Safety and the consequences of the violation of legislative acts related to the field of railway transport in the event of its occurrence. The condition of the risk, which is determined in such a way as to the probability of occurrence of the risk and its possible consequences, is the degree of risk [5,9-10, 16-17].

Based on the fact that there is a risk of committing an offense by business entities engaged in the activities of railway transport, the status of the object should be described and comprehensively assessed as the first step towards the introduction of inspections by the inspection. This description requires that it be carried out on the basis of sermons, which include the characteristics of objects measured with a certain accuracy or evaluated by specialists.

Each indicator that reports the signs of an offense in the activities of a business entity's railway transport consists of a sum of points, which is summed up from the probabilities of the occurrence of these criteria, covering several criteria. The indicators that report the symptoms of an offense in which there is a probability of occurring by rail transport are divided into 5 types, which are presented below.

1. Violation of the requirements of laws, decisions of the Cabinet of ministers, departmental regulatory documents on ensuring the safety of transportation by rail transport;
2. Regulatory documents in the field of technical regulation on the security of transportation in rail transport, violations of the requirements of documents approved by the Council of railway transport of member countries of the “Commonwealth of Independent States;  

3. Accidents and accidents in rail transport;  

4. Events related to violations of the safety requirements of actions and transportation that occur in railway transport;  

5. Indicators that are associated with the safety of transportation, as well as the possibility of bringing the risk of committing an offense. 

Based on the sum of the points of risk levels determined as a result of the assessment carried out by the business entity of the risk of committing an offense, the assessment of risk levels is divided into the following three categories (Figure 1). 

- The risk level is high – those who make up the first 20% of all business entities evaluated with the highest risk level scores. 
- The level of risk is medium – those that make up the first 20% of all business entities with the highest risk level scores, the next 30% of the total; 
- The risk level is low – the last 50% of all business entities evaluated with low risk level scores are the ones that make up the last 50%. 

Based on the results of the assessment, a list of business entities with a high level of risk for committing an offense related to ensuring the safety of transportation by rail transport is formed. 

Fig. 1. The procedure for assessing risk levels  

Based on the procedure for assessing risk levels (Figure 1), an inspection check is introduced in business entities with a high degree of risk and an average degree of risk. At a low level of risk, examination is not provided. 

The procedure for conducting inspections by the inspection on the basis of a comprehensive assessment of the state of the railway transport infrastructure is shown in Figure 2. 

As a test, the following mathematical model was used to assess the degree of risk of committing an offense related to ensuring the safety of transportation by rail transport. 

Let \( m \) of the elementary factors create comfort for the occurrence of an event from \( k \) elementary factors that make up 5 indicators that report signs of an offense. In that case the probability of an offense occurring is determined in the following order \[12\]: 

\[
P(x) = \frac{m}{k} \]
The procedure for conducting an examination by an inspection based on a comprehensive assessment of the symptoms of an offense in the activities of rail transport

The risk level is high

The level of risk is medium

The risk level is low

Fig. 2. The procedure for a comprehensive assessment and examination of the symptoms of an offense in the activities of rail transport

\[ \overline{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \]

\[ M(X) = x_1 p_1 + x_2 p_2 + \ldots + x_n p_n = \sum_{k=1}^{n} x_k p_k \]

\[ p_1 + p_2 + \ldots + p_n = 1 \]

\[ D = \frac{1}{n} \sum_{i=1}^{n} (x_i - \overline{X})^2 \]
3 Results and discussion

Indicators reporting signs of a violation in the activities of freight and passenger transportation in railway transport of business entities, presented in the regulation developed by the inspection, and the frequency range of violations of the rule assessed in the system of points that make up them will look like in Figure 3 below.

On the basis of the polygon of frequencies presented in Figure 3, the size of the selection, consisting of violations of the rule evaluating indicators reporting signs of an offense, is clarified in the following order:

- The criteria by which violations are assessed according to a 5-point system, there are only 6;
- The criteria by which violations are assessed according to a 10-point system, a total of 17;
- The criteria by which violations are assessed according to a 20-point system, a total of 39;
- The criteria by which violations are assessed according to a 30-point system, a total of 16;
- The criteria by which violations are assessed according to a 40-point system, there are only 4;
- The criteria by which violations are assessed according to the 80-point system are 30 in total;
- There are only 5 criteria by which violations are assessed according to a 10-point system.

Hence the total size of the selection, which consists of criteria that assess rule violations 6 + 17 + 39 + 16 + 4 + 30 + 5 = 117 is equal to. The size of this selection indicates that the number of criteria that make up 5 indicators that report signs of an offense is 117. These 117 rule violations are evaluated in 7 different orders. In the corresponding order, the probability of occurrence of factors allocated to points was determined based on the formula (Table 1).
Table 1. Probability of occurrence of offenses belonging to each Score

<table>
<thead>
<tr>
<th>$X_i$</th>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$x_4$</th>
<th>$x_5$</th>
<th>$x_6$</th>
<th>$x_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(x_i)$</td>
<td>0.01</td>
<td>0.05</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.40</td>
<td>0.50</td>
</tr>
</tbody>
</table>

For the mathematical expectation of the random amount of the offense ($M(X)$), the following formula is used:

$$M(X) = x_1 \cdot p_1 + x_2 \cdot p_2 + x_3 \cdot p_3 + x_4 \cdot p_4 + x_5 \cdot p_5 + x_6 \cdot p_6 + x_7 \cdot p_7$$

$$M(X) = 0.01 \cdot 0.05 + 0.05 \cdot 0.05 + 0.10 \cdot 0.05 + 0.20 \cdot 0.05 + 0.30 \cdot 0.05 + 0.40 \cdot 0.05 + 0.50 \cdot 0.05 = \approx 0.082$$

$$\overline{X} = \mu = \frac{0.01 + 0.05 + 0.10 + 0.20 + 0.30 + 0.40 + 0.50}{7} \approx 0.25$$

Table 2. Deviation of each element of the selection consisting of signs of an offense from the average

<table>
<thead>
<tr>
<th>$x_i$</th>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$x_4$</th>
<th>$x_5$</th>
<th>$x_6$</th>
<th>$x_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$\overline{X}_i$</td>
<td>-0.24</td>
<td>-0.10</td>
<td>-0.05</td>
<td>0.05</td>
<td>0.15</td>
<td>0.25</td>
<td>0.35</td>
</tr>
</tbody>
</table>

The deviation of the selection from the average is equal to:

$$D = \overline{X} - \mu = 0.25 - 0.25 = 0$$

The mean quadratic deviation is:

$$\sigma = \sqrt{D} = \sqrt{0} = 0$$

The normal distribution function of the occurrence of events is in the following form [12]:

$$f(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-a)^2}{2\sigma^2}}$$
The average value is 40.71.

The normal distribution function of the occurrence of offenses based on the formula looks like this:

$$f(x) = \frac{1}{\sqrt{\pi}} e^{-x^2}$$

The graph of the normal distribution function of the probability of occurrence of violations in each point system in the developed formula 7 is shown in Figure 4.

The proportion of probabilities of occurrence of violations in each interval of points is determined by the formula following the division of the surface consisting of a curved area consisting of the selected interval of criteria on the total surface of the sphere:

$$\eta = \frac{\int_{x_1}^{x_2} f(x) \, dx}{\int f(x) \, dx}$$

Fig. 4.
The appearance in shares of the assessment of the symptoms of an offense in the activities of railway transport.

The function of the normal distribution of the services of a comprehensive assessment of the state of the railway transport infrastructure is as follows, within the offenses committed by the business entity for which the verification is intended to be introduced, mainly 68.26% indicate that there is a possibility of belonging to the types of Appraisers in the 30 and 40 score criteria. The remaining offense indicates that the probability of the occurrence of mesons is 31.74%.

4 Conclusion

In order to ensure the safety of cargo and passenger transportation on railways, which are not part of the general-use rail transport system, industrial enterprises and organizations draw conclusions from foreign experiments on methods of preventing accidents, accidents and incidents at work through a comprehensive assessment of the state of the railway infrastructure, the significance of the development of the regulation on the “organization and conduct of the commission monthly examination of railway transport infrastructures” in the conditions of the Railways of Uzbekistan was shown.

Proceeding from the above, based on the scientific justification of compliance with the law of the normal distribution of criteria for a comprehensive assessment of the state of railway transport infrastructure, set out in the regulation developed on the basis of the rules of technical operation of industrial railway transport of the Republic of Uzbekistan, business entities have clarified the shares, mathematical expectation and variance of probabilities of occurrence from criteria assessing signs of an offense.

References

1. A.J. Ramatov, Comprehensive program for the development and modernization of the railway industry for 2009-2013 (Prezentatsiya, Tashkent, 2009)
3. Law of the Republic of Uzbekistan on transport, from 09.08.2021. № LRU-706