Reliability indicators of railway joints and crossings

Boris Gluzberg¹, Vadim Korolev², Irina Shishkina², Mikhail Berezovsky², Pavel Tregubchak³, Nadezhda Zverkova³

¹JSC Scientific Research Institute of Railway Transport (JSC VNIIZHT), 3rd Mytishchinskaya st., 10, Moscow, 129626, Russia
²Russian University of Transport (MIIT), Chasovaya St., 22/2, Moscow, 125190, Russia
³Moscow College of Railway Transport RUT (MIIT) - Kuchin per., 14, Moscow, 129626, Russia

E-mail: Glusberg@mail.ru

Abstract. The paper is devoted to the formation of a system of reliability indicators for joints and rail crossings. Reliability indices related to the groups: reliability, durability, maintainability, safety, are considered. Since the joints and crossings of rail tracks consist of a system of elements, a model of functioning, in particular turnout, is built for their analysis. As a comprehensive indicator of reliability, it is advisable to use the availability factor - the probability that the object will be in working condition at an arbitrary time moment, except for periods of scheduled maintenance, and will work without fail during the periods between scheduled maintenance works. The basis of the methodology for determining the readiness coefficient of the turnout economy of an infrastructure object can be the concept of a reference turnout. As a reference turnout, it is advisable to take the most widespread type of turnout products used on the railroads of a particular infrastructure owner. Reliability indices of specific types of turnout products operated at specific places of track development of stations can be determined using a system of coefficients that take into account the design features of this turnout and the conditions of its operation. The greater the availability factor, the more reliable the transportation process is.

1. Introduction

The system of requirements for turnouts and other types of railroad junctions and crossings used by the OSJD member countries should provide safety conditions for rolling stock handling along the way while optimizing and economical maintenance [1, 2]. The modern and most promising approach to developing a system of such requirements is the approach from the standpoint of ensuring specified reliability indicators.

This paper is devoted to the formation of a system of reliability indicators for joints and rail crossings. The commonality of the indicator system for the OSJD member countries should contribute to the integration processes within the organization, as well as the implementation of its immediate and future tasks.

The use of the resource and risk management system in the railways facilities allows the most efficient distribution of material resources and the planning of work to ensure the necessary parameters of the transportation process [3, 4]. In order to implement this system, normative documents and methodologies should be developed to determine reliability and risk indicators for each of the facilities, in particular the railway infrastructure.
Switchyard is part of the railway infrastructure. It has a significant impact on the capabilities and parameters of the transportation process [5, 6, 7].

2. Methodology and results of the research.

In the full formulation of the question of the reliability of the switchyard, it is necessary to consider the reliability of its components:
- technical means (turnouts and other structures of joints and rail tracks);
- the reliability of the facilities (groups of turnouts of the station or the neck of the station);
- the reliability of the work of aggregates of such objects (sections of the track, lines, directions, etc.);
- the reliability of the switchyard system of associations of objects (roads, road networks in general);
- the reliability of the management system of switch facilities as a subsystem of track facilities.

In this case, it is necessary to consider the reliability indicators related to the groups: reliability, durability, maintainability, safety [8, 9].

The performance of the technical means of switchyard is determined by its condition.

From the point of view of the implementation of the transportation process, the state of the technical means of the switch economy can provide the necessary parameters of the transportation process - this condition should be called operational;

From the point of view of the terminology and methods of the theory of reliability, the technical means of the switchyard can be in normal condition, in a damaged state, in a limiting state (partial failure) or in a faulty state (state of complete failure).

The features of these conditions for the technical means of switch economy are as follows.

Normal condition complies with the requirements set in the design documentation, in installation and operation instructions of the technical device, and deviations in its parameters are within permitted.

In a damaged state, the technical tool does not fully comply with the requirements of regulatory documentation. Certain elements are damaged that are not associated with a threat to the safety of train traffic (for example, spalling with a depth of up to 1 mm, etc.). However, the presence of these injuries does not require the introduction of speed limits.

The limit state (partial failure) should be understood as the state of a technical device (for example, a turnout element), in which its further operation is unacceptable, or is allowed with a limitation of train speeds. That is, the performance of the technical means is partially lost. Failures causing a limit state can be divided into repaired, that is, those that can be eliminated by repair along the way, and non-repaired, requiring replacement of a failed element [10, 11].

An inoperative state is a complete failure of a technical device, which requires its immediate replacement or stopping movement. (In some cases, trains may be allowed to pass at a speed of 5-15 km / h).

Damaged, limiting and inoperative conditions are caused by damage and failures that occur during operation, which can be classified as: failures due to wear, failures due to defects, failures due to malfunctioning of the rail track gauge, failures due to the state of the technical support systems (for example, the inability to switch a point rails due to the snow pressed between the point rail and the frame rail) [12, 13].

Reliability - the property of technical means of switchyard to continuously maintain a working condition for a certain operating time under the conditions of use established in the normative and (or) technical documentation.

Failure - an event consisting in the violation of the working condition of the technical means of switchyard.

The list of reliability indicators of technical means of switch facilities is presented in table 1.
Table 1. Reliability indicators of technical means of switchyard.

| Name of indicator | Definition |
|-------------------|------------|
| Uptime probability| The probability that within a given operating time hardware failures of technical means of switch facilities (elements) of a particular type (the project) will not arise |
| Probability of failure | The probability that within a given operating time of technical means of switch facilities (elements) of a particular type (the project) at least one hardware failure will arise |
| Mean time between failure (for recoverable objects) | The ratio of the total operating time of technical means of switch facilities (elements) of a particular type (the project) to the number of failures during this operating time |
| Mean time between failure (for non-recoverable objects) | The accumulation of technical means of switch facilities (elements) of a particular type (project), before the first failure |
| Failure stream (for recoverable objects) | The total number of failures of technical means of switch facilities (elements) of a particular type (project), referred to their total number and the period of time for which failures occurred |
| Failure rate (for non-recoverable objects) | The ratio of the number of failures of technical means of switch facilities (elements) of a specific type (project), to their time between the considered period of observation |

Durability is the property of technical means of switchyard to perform the functions provided for by technical requirements until the limit state is reached under the conditions of use and maintenance established in regulatory and (or) technical documentation [14, 15].

The list of indicators of durability of technical means of switchyard is presented in table 2.

Table 2. The durability indicators of technical means of switchyard.

| Name of indicator | Definition |
|-------------------|------------|
| Resource | The operating time of the technical means of the switchyard from its laying on the road till replacement, or overhaul |
| Life time | The time period of operation of the technical equipment of the switchyard from its laying on the road to replacement, or overhaul |
| Average resource | The mathematical expectation of the resource |
| Average life | The mathematical expectation of the life time of the object |

The maintainability and manufacturing quality of the technical facilities of the switchyard (their elements) should ensure the restoration of operational indicators of sections of the railway track in the areas where they are used, within the maintenance system (current maintenance) and repairs operating on the roads of the infrastructure owner [16, 17].

The list of maintainability indicators of technical means of switch facilities is presented in table 3.

Table 3. Indicators of maintainability of technical means of switch facilities.

| Name of indicator | Definition |
|-------------------|------------|
| Average time to replace an element (item by item) | The mathematical expectation of the duration of the inoperative state of the object for technical reasons |
| Average operating time between scheduled maintenance | The mathematical expectation of the time between the planned types of maintenance |
| Average operating time between scheduled repairs | The mathematical expectation of the operating time of the object between scheduled repairs |
Safety - the property of technical means of switchyard to maintain a safe state in relation to a specific hazardous event.

Dangerous failure - a failure of the technical facilities of the switchyard (their elements), threatening the safety of train traffic, and requiring immediate replacement of the element or the entire structure of the facility.

The list of safety indicators of technical means of switch facilities is presented in table 4.

**Table 4. Safety indicators of technical means of switchyard.**

| Name of indicator                              | Definition                                                                 |
|------------------------------------------------|---------------------------------------------------------------------------|
| Probability of safe operation                  | The probability that within a given operating time hardware dangerous failures of technical means of switchyard (elements) of a particular type (the project) will not arise |
| Probability of dangerous failure               | The probability that within a given operating time of technical means of switch facilities (elements) of a particular type (the project) at least one dangerous hardware failure will arise |
| Average operating time to dangerous failure    | The ratio of the total operating time of the technical facilities of the switchyard (elements) of a particular type (project) until dangerous failure, to the number of their dangerous failures for the considered periods of work |
| Average operating time to dangerous failure    | The ratio of the total operating time of the technical facilities of the switchyard (elements) of a particular type (project) to a dangerous failure, to the number of their dangerous failures |
| Dangerous Failure Stream                       | The total number of dangerous failures of technical equipment of switchyard (elements) of a particular type (project), related to their total number and time period for which dangerous failures occurred |
| Dangerous Failure Rate                         | The ratio of the number of dangerous failures of technical means of switchyard (elements) of a specific type (project) to their operating time for the observation period under consideration |

Since the joints and intersections of rail tracks consist of a system of elements, it is advisable to construct functioning models for their analysis. We consider building of such a model for the most common type of joints and rail track intersections – turnout switch.

Partial recoverable failures of the turnout elements are eliminated on the way as part of the current maintenance work, so they can be attributed to scheduled maintenance of turnouts. Most failures of turnout elements for defects and wear are unrecoverable.

For non-recoverable facilities, the main indicators of reliability are the probability of failure-free operation, the failure rate and average time of failure-free operation (mean time to failure) [18, 19].

If there is a distribution function of the operating time element until failure $F(t)$, and (or) its density $f(t)$, then these indicators are determined by known dependencies:

- probability of uptime $R(t) = 1 - F(t) = 1 - \int_{-\infty}^{t} f(\tau)d\tau$ ,
- average operating time to failure $E(t) = \int_{0}^{\infty} R(t)dt$ ,
- failure rate $\lambda(t) = \frac{f(t)}{R(t)}$ .

(1) (2) (3)

Failures of turnout elements, with accuracy sufficient for practical purposes, can be considered independent.

With this approach, turnout, from the point of view of analysis of its reliability, is a system with a series connection of elements.
The block diagram for studying the reliability of the turnout system will consist of several parts: a block diagram of the reliability of the turnout for wear and defects of its elements (Figure 1) and a block diagram of the reliability of the turnout in accordance with the geometry of the rail track (Figure 2). Each of these diagrams is a diagram with a series connection of elements.

The reliability block diagram of the turnout for wear and defects of its elements consists of 5 blocks connected in series. The “metal parts” block includes point rails, frame rails, crosses (sharp and blunt), rails of connecting tracks, rails of cross tracks, counter rails, fastening elements. The block “base” includes bars or another type of support for rail elements and gaskets located between the metal parts and the bars. The block ”switching mechanisms” consists of elements that transmit the force from the drive to the moving elements of the railroad switch (traction, levers, beds, etc.), devices for closing and control of the position of moving elements.

The block “turnout switch operation system in winter conditions” may include a different set of elements, depending on the type of system (pneumatic, thermal or mechanical) and its arrangement [20, 21].

The “drives” block consists of devices that create the effort necessary to move the moving elements — a manual drive, electric drives (one or more) or a hydraulic drive.

In order to a system with a series connection of elements to function, all its subsystems and elements must work without failures. The probability of failure-free operation of each block of such a system can be defined as the state in which all its elements work faultlessly:

$$R_{bl} = P \left[ A_1 \cap A_2 \cap \cdots \cap A_n \right],$$

(4)

where: $R_{bl}$ – probability of uptime of a block;

$A_i$ – lack of failure $i$-th element in a block;

$P$ – the probability of an event in which all elements of the block work without failure.

If the failures in the elements of the block are independent, then:

$$P \left[ A_1 \cap A_2 \cap \cdots \cap A_n \right] = P(A_1) \cdot P(A_2) \cdots P(A_n),$$

(5)

or,

$$R_{bl} = \prod_{i=1}^{n} R_i.$$

(6)

Figure 1. The block diagram of the reliability of the turnout switch for wear and defects of its elements.

Item blocks:
1 - metal parts of the turnout switch;
2 - the basis of the turnout switch;
3 - translation mechanisms and control systems;
4 - a system for ensuring the operation of the turnout switch in winter conditions;
5 - drives (manual, electric, hydraulic)

Figure 2. Block diagram of the reliability of the turnout switch for the geometry of the rail track.
Item blocks:
6 - safety dimensions;
7 - track gauge;
8 - dimensions of ordinates and gutters;
9 - the relative position of elements of the switch.

Since the number of blocks is five (Figure 1), and based on the fact that the failures of each block are independent in order to determine the uptime probability of the turnout switch for wear and defects, we have the formula:

$$R_{w.d.} = \prod_{i=1}^{N_1} R_{i} \cdot \prod_{j=1}^{N_2} R_{j} \cdot \prod_{k=1}^{N_3} R_{k} \cdot \prod_{l=1}^{N_4} R_{l} \cdot \prod_{m=1}^{N_5} R_{m},$$  

(7)

where: $N_{1...5}$ - number of elements respectively in blocks 1, ..., 5.

From the above materials one can see: $N_1 = 8$, $N_2 = 2$, $N_3 = 6$, $N_4 \geq 4$, $N_5 \geq 2$.

Thus, in order to obtain reliability (failure-free) indicators of the turnout placed in the track according to wear and defects, it is necessary to obtain the distribution of the operating time until failure of all its elements and then use the methodology above. The results obtained - for the most important elements and the turnout switch as a whole - characterize the quality of products manufactured by a particular manufacturer, and orient the consumer in the appropriateness of its application.

The reliability block diagram of the turnout in rail track geometry consists of 4 blocks connected in series (Figure 2).

The block "safety dimensions" includes the limited PTE distances between the elements of the spider joints, the size controlled by the KOR template, the sizes controlling the closure of the point rails and cores of the crosses with internal and external contactors.

The "track gauge" block includes the dimensions of the rail gauge in controlled sections. "Dimensions of ordinates and gutters" make up a separate block, which includes, in addition to the dimensions themselves, the pitch of the point rail and the difference between the gauge and the size of the gutter between the point rail and the frame rail at the end of its gouging.

The block "relative position of the elements" is the standards for the relative position and fit of the metal parts, as well as the gaps between the rail elements and the elements on which they are based.

When determining operational indicators of reliability of technical equipment of switchyard (as part of the infrastructure), all types of failures must be taken into account [22, 23]. The technical facilities of the switchyard are renewable objects, therefore the failure-free indicators - the probability of uptime operation and the failure rate used for non-recoverable elements may not make sense. So, one turnout can have several failures at the same time, for example, excessive wear of a cross and violation of maintenance standards along the gauge. In this case, the total number of failures $\sum_{i=1}^{N} n_i(t)$ for a group of turnouts can exceed the number of turnouts themselves $N$ in a group. Then the statistically determined probability of uptime $R = 1 - \frac{\sum_{i=1}^{N} n_i(t)}{N}$ will have a negative value, which contradicts the concept of this parameter.

Reliability indicators of technical means of switchyard in operation are the parameter of the flow of failures and the mean time between failures.

Since in the practice of operation a separate service of each turnout is not organized, it is advisable to consider the failure flows for infrastructure facilities, their aggregates and associations.

Statistically failure flow parameter $\omega(t)$ defined as total failure rate $\sum_{i=1}^{N} n_i(t)$, attributable to the total number of operated switches $N$, divided by the length of time $\Delta t$, for which these failures occurred:

$$\omega(t) = \frac{\sum_{i=1}^{N} n_i(t)}{N \cdot \Delta t}$$  

(8)

The necessary data to calculate values $\omega(t)$ and $t$ (av.$i$ can be obtained from the analysis of operational documentation kept during the way distances.
Reliability indicators of switchyard of infrastructure facilities - stations, lines, directions, road networks, switchyard as a whole - are determined by special methods developed and approved by the owner of the infrastructure.

As a comprehensive indicator of reliability, it is advisable to use the availability factor — the probability that the object (in our case, the switchyard of the station, the distance of the track, line, network of roads) will be in working condition at an arbitrary point in time, except for periods of scheduled maintenance, and will work during periods between scheduled maintenance work without failures.

The availability factor characterizes at the same time two properties that make up safety - reliability and maintainability. Methodologies for determining the availability factor should be based on specific goals for which it is planned to use data on the reliability of technical means. (In Russia, such a technique is being developed as part of the solution to the problem of managing resources and risks at the stages of the life cycle of infrastructure technical equipment).

The basis of the methodology for determining the readiness coefficient of the switchyard of an infrastructure object can be the concept - a reference turnout switch. As a reference turnout, it is advisable to take the most widespread type of turnout products used on the roads of a particular infrastructure owner.

Reliability indices of specific types of switch products operated at specific places of track development of stations are determined using a system of coefficients that take into account the design features of this switch and the conditions of its operation.

For example, the probability of uptime reduced to the reference j-th turnout of a particular station is determined by the formula

\[ R_j = R_r \cdot \prod_{i=1}^{A} k_i \]  \hspace{1cm} (9)

where: \( R_j \) – probability of uptime reduced to the reference j-th turnout of a particular station; \( R_r \) – probability of uptime of the reference turnout; \( k_1, ..., k_A \) - reduction coefficients of the considered j-th translation to the reference turnout switch, (A is the number of reduction factors).

The methodology should include accounting for at least the following features of the turnout switch operation:

1. Constructive: mark of turnout switch; rail type; type of rail fasteners; type of ballast;
2. Passed tonnage;
3. Operating conditions: class, category, group of tracks; set speed; cargo intensity; axial loads; track plan; track profile;
4. Type of turnout support system (including in the presence of snow and low temperatures);
5. Work of switching devices (number of switchings);
6. Control system (centralized, decentralized).

All these features of the switch work are tabulated in the form of tables for determining the coefficients \( k_i \) and are an integral part of the methodology for determining the reliability parameters of switch facilities of infrastructure facilities.

The availability factor is determined by the ratio

\[ K = \frac{T_{av}}{T_{av} + T_{re.av}} \]  \hspace{1cm} (10)

where \( T_{av} \) - mean time between failures of turnouts of an infrastructure object (average operation time); \( T_{re.av} \) - average time of an inoperative state (recovery) of the turnout switch of an infrastructure object.

In this case, if an object of infrastructure (for example, a station) \( N \) various turnout switches, on the tracks of different classes in different conditions, are operated then the number brought to the reference turnout will be
\[ N_{br.} = \sum_{j=1}^{N} [\prod_{i=1}^{A} k_i] \]  

where \( N_{br.} \) - the brought number of turnouts at the facility.

The total time of an inoperative state is determined from the operational documentation as the total recovery time of turnouts of this infrastructure for the period under consideration. Then

\[ T_{re.av.} = \frac{\sum_{j=1}^{N} T_j}{N_{br.}}, \]

where \( T_j \) - downtime status of j-th turnout.

Finally, the availability factor for one reference turnout at a given infrastructure object (station, track distance, line, etc.) is determined by the formula

\[ F_a = 1 - \frac{T_{re.av.}}{T}, \]

where \( T \) - calculation period, for example, a month. (Values \( T \) and \( T_{re.av.} \) must be substituted in the formula in one units (minutes, hours, etc.).

3. Conclusions

The greater the availability factor, the more reliable the transportation process is.

The owner of infrastructure can introduce the concept of the minimum acceptable availability factor, or a system for ranking the value of availability factors. For example: normative; permissible; unwanted; minimum; limit level.

Based on what is the ranking range limits the actual value of the readiness coefficient of the infrastructure facility gets in, you can plan the consumption of resources and adjust the timing of maintenance work on the switchyard at the facility.

References

[1] Gluzberg B, Korolev V, Loktev A, Shishkina I, Berezovsky M 2019 E3S Web of Conferences 138 01017 https://doi.org/10.1051/e3sconf/201913801017
[2] Korolev V 2020 TransSiberia 2019: VIII International Scientific Siberian Transport Forum TransSiberia 2019 1116 175
[3] Savin A V, Korolev V V and Shishkina I V 2019 IOP Conf. Series: Materials Science and Engineering 687 022035 https://doi:10.1088/1757-899X/687/2/022035
[4] Savin A, Kogan A, Loktev A, Korolev V 2019 International Journal of Innovative Technology and Exploring Engineering 8(7) 2325
[5] Glusberg B, Savin A, Loktev A, Korolev V, Shishkina I, Alexandrova D, Loktev D 2020 Advances in Intelligent Systems and Computing 982 556 https://doi.org/10.1007/978-3-030-19756-8_53
[6] Glusberg B, Savin A, Loktev A, Korolev V, Shishkina I, Chernova L, Loktev D 2020 Advances in Intelligent Systems and Computing 982 571 https://doi.org/10.1007/978-3-030-19756-8_54
[7] Korolev V 2020 TransSiberia 2019: VIII International Scientific Siberian Transport Forum 621-638 https://doi.org/10.1007/978-3-030-37916-2_60
[8] Glusberg B, Korolev V, Shishkina I, Loktev A, Shukurov J, Geluh P and Loktev D 2018 MATEC Web of Conferences 239 01054 https://doi.org/10.1051/matecconf/201823901054
[9] Loktev A A, Korolev V V and Gridasova E A 2019 IOP Conf. Series: Materials Science and Engineering 687 022036 doi:10.1088/1757-899X/687/2/022036
[10] Loktev A, Korolev V, Shishkina I, Basovsky D 2017 Transportation Geotechnics and Geocology, Russia Procedia Engineering 189 133 doi:10.1016/j.proeng.2017.05.022 https://doi.org/10.1016/j.proeng.2017.05.022
[11] Loktev A, Korolev V, Poddaeva O, Chernikov I 2018 *IOP Conf. Series: Materials Science and Engineering* **463** 032018 doi:10.1088/1757-899X/463/3/032018

[12] Shishkina I 2020 TransSiberia 2019: VIII International Scientific Siberian Transport Forum 834-844 https://doi.org/10.1007/978-3-030-37916-2_82

[13] Loktev A, Korolev V, Shishkina I 2018 *IOP Conf. Series: Materials Science and Engineering* **463** 032019 doi:10.1088/1757-899X/463/3/032019

[14] Korolev V, Loktev A, Shishkina I, Zapolnova E, Kuskov V, Basovsky D and Aktisova O 2020 *IOP Conference Series: Earth and Environmental Science* **403**(1) https://10.1088/1755-1315/403/1/012194

[15] Gridasova E, Nikiforov P, Loktev A, Korolev V, Shishkina I 2020 TransSiberia 2019: VIII International Scientific Siberian Transport Forum 559-569 https://doi.org/10.1007/978-3-030-37916-2_54

[16] Loktev A, Korolev V, Shishkina I, Chernova L, Geluh P, Savin A, Loktev D 2020 *Advances in Intelligent Systems and Computing* **982** 325 https://doi.org/10.1007/978-3-030-19756-8_30

[17] Savin A, Suslov O, Korolev V, Loktev A, Shishkina I 2020 TransSiberia 2019: VIII International Scientific Siberian Transport Forum 648-654 https://doi.org/10.1007/978-3-030-37916-2_62

[18] Loktev A A, Korolev V V, Poddaeva O I, Stepanov K D, Chernikov I Y 2018 *Vestnik of the Railway Research Institute* **77**(2) 77 https://doi.org/10.21780/2223-9731-2018-77-2-77-83

[19] Loktev A A, Korolev V V, Loktev D A, Shukyurov D R, Gelyukh P A, Shishkina I V 2018 *Vestnik of the Railway Research Institute* **77**(6) 331 https://doi.org/10.21780/2223-9731-2018-77-6-331-336

[20] Glusberg B, Loktev A, Korolev V, Shishkina I, Alexandrova D, Koloskov D 2020 *Advances in Intelligent Systems and Computing* **337**-345 https://doi.org/10.1007/978-3-030-19756-8_31

[21] Lyudagovsky A, Loktev A, Korolev V, Shishkina I, Alexandrova D, Geluh P and Loktev D 2019 *E3S Web of Conferences* **110** 01017 https://doi.org/10.1051/e3sconf/201911001017

[22] Savin A, Korolev V, Loktev A, Shishkina I 2020 TransSiberia 2019: VIII International Scientific Siberian Transport Forum 797-808 https://doi.org/10.1007/978-3-030-37916-2_78

[23] Loktev A, Korolev V, Shishkina I, Illarionova L, Loktev D and Gridasova E 2020 *Advances in Intelligent Systems and Computing, VIII International Scientific Siberian Transport Forum TransSiberia 2019* **1116** 209 https://doi.org/10.1007/978-3-030-37919-3_20