

# Evaluation of the effect of JSC RZD transportation infrastructure availability on the risks of losses in the process of transportation

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**Abstract. Aim.** The availability of transportation infrastructure facilities affects the quality of the transportation services provided by JSC RZD. At the same time, this effect may significantly differ depending on the operating conditions of the transportation infrastructure or a specific railway line and can cause various degrees of risk of damage to the transportation process. Such risks are defined as risks of train-hour losses due to transportation infrastructure failures. Planning dependability management activities under conditions of scarce resources requires targeted identification of the transportation infrastructure facilities whose availability most significantly affects the magnitude of the risks of damage to the transportation process. The aim of the paper is to develop a method for evaluating daily availability and identifying its correlation with the risk of train-hour losses. **Methods.** The authors used the methods of risk management, probability theory and mathematical statistics, correlation and regression analysis. **Results.** The paper suggests representing the daily availability indicator of JSC RZD's transportation infrastructure facilities as a two-parameter gamma distribution and describing its effect on the risks of the transportation process with a regression model. **Conclusions.** The paper's findings can be used as part of transportation infrastructure dependability planning and targeted allocation of resources, as well as for substantiating the dependability indicator when evaluating the practical capacity of railway lines and utilization ratio and in a number of other operational tasks.

**Key words:** risk of train-hour losses, capacity, dependability of transportation infrastructure facilities, daily equipment availability, interval estimate.

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## Introduction

The transportation process performed by Russia's railways involves technical operation of a territorially distributed transportation infrastructure that represents a set of facilities assigned to various services [1].

The operational dependability of transportation infrastructure facilities (TIF) significantly affects the quality of transportation operations. Inoperable TIF cause a risk of damage in the form of delayed train departures, passing or arrivals.

The concept of risk allows taking into account both the probabilistic nature of TIF failures, and the magnitude of the resulting damage to the transportation process. In this context, as regards technical operation of infrastructure, JSC RZD has adopted the concept of risk management [1, 2]. Risk is regarded as a combination of the probability (rate) of risk events, i.e., failures, and the magnitude of damage caused by an event, i.e., loss of train-hours. Loss of train-hours is understood as train delays caused by an individual TIF failure. In this case, the failures themselves, depending on the magnitude of the associated damage to the transportation process, are conventionally classified into three categories. Category 1 and 2 failures include those that cause significant train-hours losses, while category 3 includes those that cause insignificant or no loss.

Based on the information regarding category 1 and 2 failures, TIF functional dependability indicators are calculated that characterise the process of implementation, by means of TIF, of various functions that ensure the transportation process (service delivery).

Functional dependability is used for estimating certain indicators of the transportation process, e.g., practical capacity of railway lines, as well as for assessing the risks of train-hour losses due to TIF failures. The functional dependability calculations are often based on averaged values for long time intervals, e.g., annual. It is worth noting that practical capacity is calculated for daily time intervals. Given that category 1 and 2 failures are fairly rare, the associated time budget losses in the context of practical capacity calculation, as well as train-hour losses, fall within specific days, whereas within the remaining time no losses are observed. Accordingly, the functional dependability indicators should be regarded as random values on the same time intervals, i.e., daily.

As input information for estimation, statistical data on the moments of identification of category 1 and 2 failures, their duration and associated train-hour losses for each TIF can be used. As the result of the industry's digital transformation, they are now available in the company's information systems, including KASANT, AS-ANSh, ASU Sh-2, EK ASUI, etc.

As a functional dependability indicator, let us consider the TIF availability coefficient in terms of category 1 and 2 failures that, for a number of years, has been used in JSC RZD's infrastructure units. This coefficient is understood as

the probability of TIF being in a state that does not cause a significant delay (more than 6 minutes) in the train traffic at a random moment in time.

## Estimation of the availability coefficient of transportation infrastructure facilities in terms of category 1 and 2 failures

Individual realisations of  $K_{a12}$ , the TIF availability coefficient in terms category 1 and 2 failures over daily intervals, can be identified using formula:

$$K_{a12} = \frac{T_{\text{day}} - T_{t12}}{T_{\text{day}}},$$

where  $T_{\text{day}}$  is the daily time budget (taking into account maintenance possessions);

$T_{t12}$  is the total down time of TIF caused by a category 1 or 2 failure within the daily time budget.

Statistical estimation of  $K_{a12}$  should be done parametrically [3, 4] using the moment method and subsequent approximation with a two-parameter gamma distribution [5].

In order to do that, all realisations of TIF's  $K_{a12}$  within the daily intervals where category 1 and 2 failures were recorded over the monitoring period are submitted to statistical processing.

The first statistical moment  $m_t$  is found using the formula:

$$m_t = \frac{\sum_{j=1}^r (1 - K_{a12j})}{r},$$

where  $r$  is the number of realizations of  $K_{a12}$  within the observation period.

The second statistical moment  $\sigma_t$  is determined from formula:

$$\sigma_t = \sqrt{\frac{\sum_{j=1}^r [(1 - K_{a12j}) - m_t]^2}{r - 1}}.$$

The probability density for a random value is described using formula:

$$f(\beta) = \begin{cases} \frac{\beta^{k-1} \cdot e^{-\frac{\beta}{\theta}}}{\theta^k \cdot \Gamma(k)}, & \beta \geq 0; \\ 0, & \beta < 0, \end{cases}$$

where

$$\Gamma(k) = \frac{1}{k} \cdot \prod_{n=1}^g \frac{\left(1 + \frac{1}{n}\right)^k}{1 + \frac{k}{n}},$$

while  $k$  and  $\theta$  are the shape and scale parameters.

In turn, the shape and scale parameters are found using formulas:

– shape parameter  $k$ :

$$k = \frac{m_t^2}{D_t};$$

– scale parameter  $\theta$ :

$$\theta = \frac{D_t}{m_t},$$

where  $D_t$  is the sampling variance defined as:  $D_t = \sigma_t^2$ .

Next, an interval estimation of random value  $K_{a12}$  can be performed for daily intervals.

The confidence interval is defined in the form of a single-ended estimate using expression:

$$P(K_{a12\theta} \leq K_{a12} \leq 1) = 1 - \int_0^{1-K_{a12\theta}} f(K_{a12}) dK_{a12}, \quad (1)$$

where  $P(K_{a12\theta} \leq K_{a12} \leq 1)$  is the confidence probability of  $K_{a12}$  being not lower than the predetermined value  $K_{a12\theta}$ .

Using formula (1), confidence probability  $P(K_{a12\theta} \leq K_{a12} \leq 1)$  can be found that the true value of  $K_{a12}$  is within  $[1; K_{a12\theta}]$ . The inverse problem can also be solved that consists in determining the boundary value  $K_{a12\theta}$  that specifies the range  $[1; K_{a12\theta}]$ , within which its true value is found with the specified confidence probability.

## Transportation-related risk of loss estimate and estimation

While TIF remains inoperable, a risk of damage to the transportation process may arise in the form of train delays of varied duration. Moreover, the duration of train delays has a complex dependence not only on the duration of TIF inoperability, but on many other factors as well, i.e., the class and specialization of the line, granted track possessions, train schedule, type of facility, etc.

Risk matrices have proved to be useful in assessing the risk of train-hour losses due to TIF failures in JSC RZD's infrastructure units [6].

An example of a risk matrix is shown in Fig. 1.

In order to evaluate the effect of TIF availability on the risks of train-hour loss, it is required finding, for the calculated value  $K_{a12\theta}$ , a point in the risk matrix cell at the

intersection of the corresponding row on the frequency axis and column on the loss axis [7].

For the purpose of assessing the effect of the  $K_{a12}$  TIF availability coefficient in terms of category 1 and 2 failures on the magnitude of losses for the transportation process, the authors extracted from information systems and examined statistical data on  $K_{a12}$  realizations and the corresponding train-hour losses  $T_{12}$  per failure.

Correlation analysis revealed a persistent statistical relationship between the  $K_{a12}$  of the TIF that operate within railway lines of a certain class and specialization and the magnitude of train-hour losses  $T_{12}$  per failure. The evaluation was performed using the linear correlation coefficient, while the closeness of the correlation was analysed using the Chaddock scale. A weak to strong negative correlation was identified with the correlation closeness for the TIF of railway lines of various classes and specializations.

In this context, the following linear approximation can be used for estimating the effect of  $K_{a12}$  on the damage in the form of train-hour losses:

$$\tilde{T}_{12} = \Theta \cdot K_{a12\theta}$$

where  $\Theta$  is the proportionality coefficient between  $K_{a12}$  and  $T_{12}$  that is single for all TIFs within railway lines of individual classes and specializations, but different for different railway lines. For each combination of line class and specialization, it is found using a single formula:

$$\Theta = \frac{\sum_{j=1}^u T_{12j}}{\sum_{j=1}^u K_{a12j}},$$

where  $u$  is the number of  $K_{a12}$  realizations on a set of TIFs within a railway line of a single class and specialization over the observation period.

The rate of category 1 and 2 TIF failure rate is estimated using formula:

$$\tilde{f}_{12} = \frac{\sum_{k=1}^G f_{12k}}{G}, \quad (2)$$

where  $G$  is the number of years in the TIF observation period;  $f_{12k}$  is the number of category 1 and category 2 TIF failures in the  $k$ -th year of observation.

		Damage in the form of failure-specific train-hour losses, $T_{12}$			
		Insignificant	Significant	Major	Critical
Category 1 and 2 failure rates, $f_{12}$	Frequent	Tolerable	Undesirable	Intolerable	Intolerable
	Probable	Tolerable	Undesirable	Undesirable	Intolerable
	Occasional	Tolerable	Tolerable	Undesirable	Intolerable
	Remote	Negligible	Tolerable	Undesirable	Undesirable
	Improbable	Negligible	Tolerable	Tolerable	Undesirable
	Incredible	Negligible	Negligible	Tolerable	Undesirable

Fig. 1. Risk matrix of train-hour losses

Thus, for the calculated value of  $K_{al2}$  of TIF, using formula (1), the target value of damage in the form of train-hour losses is found, while using formula (2), the target category 1 and 2 failure rate is calculated and according to the matrix (see Fig. 1), the cell with the target risk level is found.

## Conclusion

The above findings can be used for transportation infrastructure dependability planning and targeted allocation of resources, as well as for substantiating the dependability indicator when evaluating the practical capacity of railway lines, utilization ratio and in a number of other operational tasks.

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## The authors' contribution

**Gorelick A.V.** analysed the current situation, defined the lines of research.

**Orlov A.V.** collected empirical data and implemented a method of statistical evaluation of the effect of failures on the risk of train-hour losses.

**Malykh A.N.** processed the empirical data and developed a method for statistical evaluation of the availability coefficient of transportation infrastructure facilities.

## Conflict of interests

The authors declare the absence of a conflict of interests.