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Method of evaluation of the railway track's availability for traffic operations

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Abstract. Aim. *The maintenance of Russia's railway network requires significant expenditures in order to support the dependability of infrastructure facilities operation. When resources are limited, a wrong decision can cause errors in maintenance planning. The activities of track enterprises define normal operation of the railway infrastructure as a system. Rational management of infrastructure facilities requires the availability of objective real-time information on their dependability and functional safety. One of the key indicators that characterizes the dependability of track is the availability coefficient. When evaluating partially available facilities, it must be considered how partial non-fulfilment or reduced quality of its functions impacts the availability. The conventional formula for the technical availability coefficient allows for only two possible facility states: operable and non-operable. Such evaluation of the technical availability coefficient does not, for instance, allow for reduced availability as a result of a speed restriction on a line section, as well as the impact of a failure of a line section on the overall availability of the line. Therefore, this article deals with the method of evaluation of the technical availability coefficient of a line section subject to its partial operability, as well as considers the approach to the standardization of the technical availability coefficient of a line section.* **Methods.** *The evaluation of the technical availability coefficient of a line section subject to its partial operability involved a system analysis of factors that reduce track capacity. Among such factors are speed restrictions and interruption of traffic due to scheduled and non-scheduled maintenance operations. A three-dimensional graphic model of dependency of movement speed from linear coordinates and time is suggested. It was used to deduce the formulas for evaluation of the technical availability coefficient of single and n-track lines. An approach to the standardization of individual components of the technical availability coefficient was considered. Correlations were deduced for calculation of standard value of the technical availability coefficient of single and n-track lines.* **Conclusions.** *Upon an examination of the factors that cause partial operability and non-operability of railway track, the authors offer a method for evaluation of the technical availability coefficient of a railway line subject to the effects of speed restrictions on the capacity and thereby the availability of track. Aspects of standardization of the technical availability coefficient were examined. Formulas were obtained that allow calculating the actual availability coefficient of a railway line subject to partial operability, as well as the standard value of this indicator. The approaches and methods that are considered in this paper aim to improve the objectivity of evaluation of track availability to enable well-founded decision-making in operation.*

Keywords: *railway track, technical availability coefficient, traffic speed restriction, standardization of availability coefficient, partial operability.*

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Introduction

The maintenance of Russia's railway network requires significant expenditures in order to support the dependability of infrastructure facilities operation and safety of traffic.

When resources are limited, a wrong decision can cause errors in maintenance planning. On the one hand, those line sections that require maintenance according to existing standards may have a sufficiently high level of dependability, which mean that the cost of maintenance would not be justified. On the other hand, sections affected by dependability problems can be still operated without modernization, overhauls or scheduled maintenance, which in turn causes increased risks of transportation incidents.

Currently, in the railway infrastructure, the cost of fixed assets of the track facilities accounts for over 60 percent of the total cost of JSC RZD fixed assets, while the operating costs of track infrastructure amount to around 35 percent of the total costs [1]. Thus, the activities of the track facilities define normal operation of the railway infrastructure as a system.

Rational management of infrastructure facilities requires the availability of objective real-time information on their dependability and functional safety.

One of the key indicators that characterizes the dependability of track is the availability coefficient, a composite indicator. According to [2], the operational availability coefficient and technical availability coefficient are distinguished.

The problem of evaluation of potentially partially available facilities is that it must be considered how partial nonfulfilment or reduced quality of their functions impacts the availability indicator itself. The conventional formula for the technical availability coefficient allows for only two possible facility states: operable and non-operable. Thus, as per [2] the railway track technical availability coefficient is defined according to the formula:

$$C_{t.a.} = \frac{T_{op}}{T_{op} + T_{schM} + T_r}, \tag{1}$$

where T_{op} is the total time of railway track being operational over the considered operation period;

T_{schM} is the total time of railway track being in scheduled maintenance and repair over the same period of time;

T_r is the total time to railway track recovery over the same period of time.

As it follows from formula (1), railway track can be either operable, or under scheduled maintenance and repair, or recovering after failure (the last two states are non-operable). Such evaluation of the technical availability coefficient does not, for instance, allow for reduced availability as a result of a speed restriction at a line section, as well as the impact of a failure of a line section on the overall availability of the line. Given the above, this article deals with the method of evaluation of the technical availability coefficient of a line section subject to its partial operability. Also, it considers the approach to the standardization of the technical availability coefficient of a line section.

Factors affecting a line section availability

Let us examine a single-track section. The maximum capacity of such section is defined by the design traffic speed and the proportion of time when the track is not under scheduled maintenance and repair.

On the one hand, if a speed restriction is imposed on a track section, the track will only use a part of its capacity, which can be considered a state of partial operability (the reduction of actual speed v_{act} compared to the design speed v_{des} along the whole length l of the section, Figure 1, a). On the other hand, as track is an extended facility, when a part of a section length is non-operable, it can be said that the section as a whole is in the state of partial operability (reduction of speed v_{act} to 0 on a part of section length l, Figure 1, b). In practice, the two cases shown in Figure 1 can combine. In addition, within the given time period speed restrictions may occur several times within a track section, each lasting its individual period of time.

Thus, if a speed restriction is in place or a part of the section has failed, as well as in combined scenarios, it can be deemed that the track section is in the state of partial operability and therefore has the availability coefficient

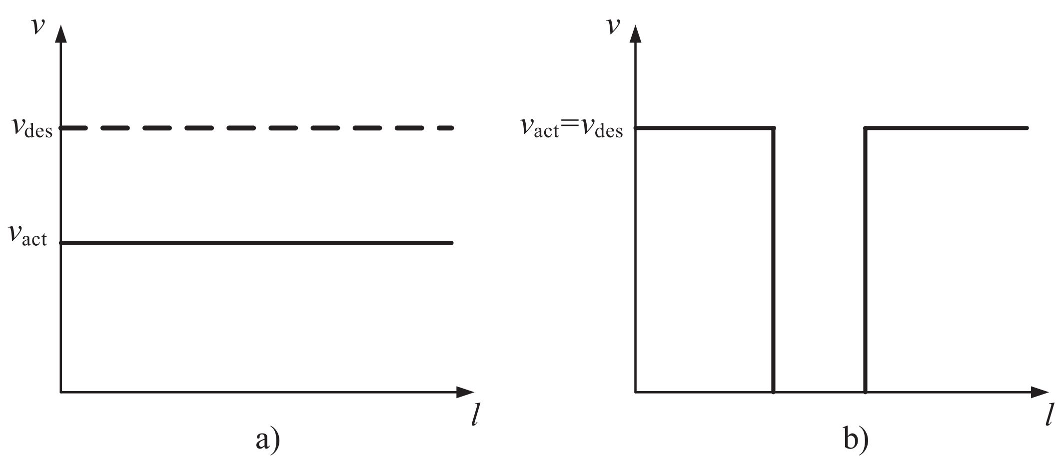

Figure 1. Traffic speed restriction within a track section (a) and failure of a part of track section (b)

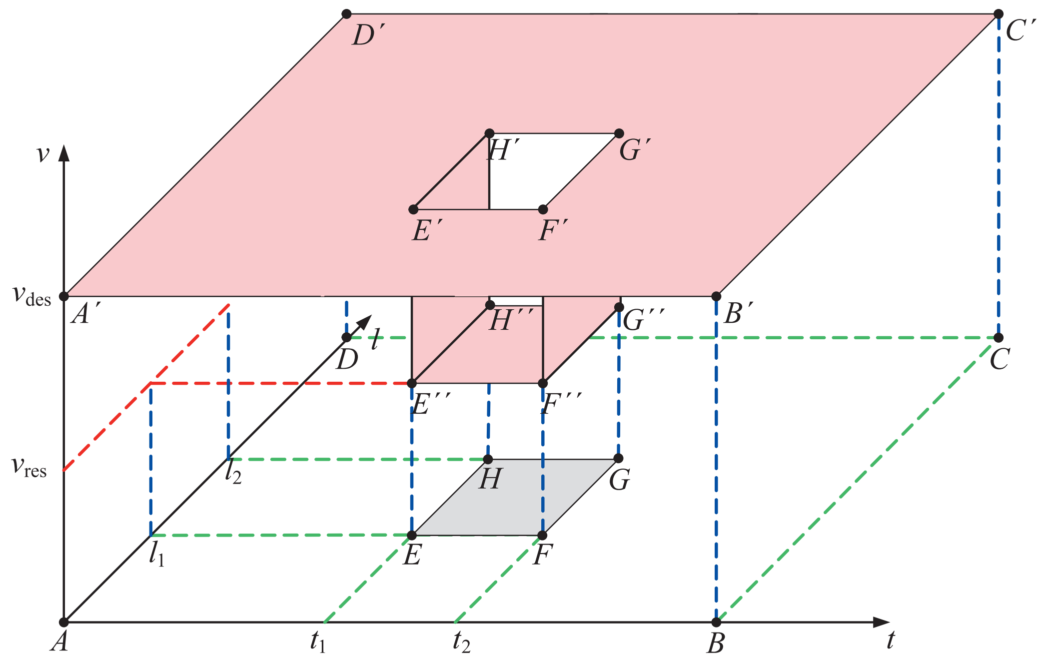

Figure 2. An example of the dependency of traffic speed v within the section from the length l and the time t

of 1. In terms of the technical availability coefficient it should also be noted that a track section is non-operable during scheduled maintenance and repair (planned possessions).

Given the above, it is advisable, when evaluating a track section's availability, to consider the function of speed v of the length (linear coordinate) l and of the time t. An example of such function is shown in Figure 2 in the form of a three-dimensional graph.

In the graph (Figure 2), the traffic speed is per the design value v_{des} except the part of the section from l_1 to l_2, where within the time period from t_1 to t_2 the speed restriction v_{rest} is in place. Therefore, within the time period from t_1 to t_2 the part of section from l_1 to l_2 is in the state of partial operability (train traffic is ensured, yet at a speed below the nominal value). Consequently, the track section as a whole is in the state of partial operability. As we can see in Figure 2, the case of full availability of the track section corresponds to the parallelepiped $ABCDA'B'C'D'$, while the case of partial availability corresponds to the same parallelepiped minus the volume of the parallelepiped $E''F''G''H''E'F'G'H'$.

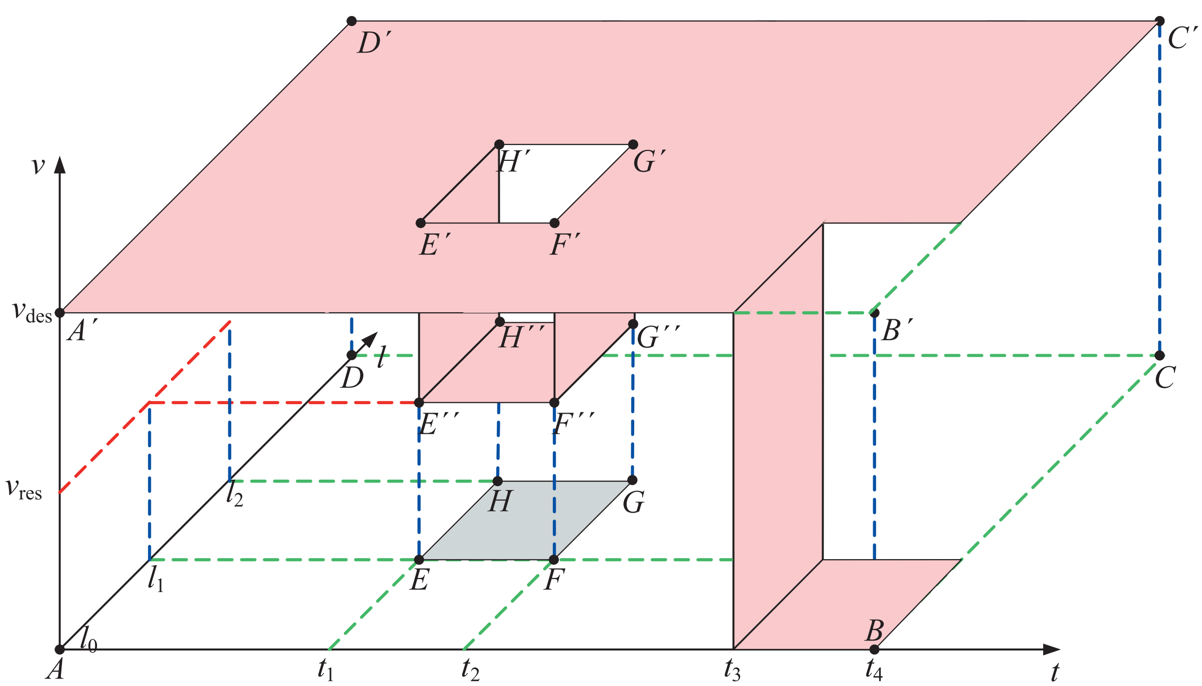

Figure 3. An example of the dependency of traffic speed v within the section from the length l and the time t subject to the maintenance possession

Evaluation of the technical availability coefficient of a line section

As per Figure 2, let $L = AD$ denote the length of the section, $T_o = AB$ denote the observation period, h, $\Delta l = l_2 - l_1$ denote the part of the track section with a speed restriction in place, km, and $\Delta t = t_2 - t_1$ denote the active period of the traffic speed restriction, h. Then, for the example shown in Figure 2 the track section availability coefficient can be defined by the formula:

$$C_a = \frac{T_o \cdot L \cdot v_{des} - \Delta t \cdot \Delta l \cdot (v_{des} - v_{res})}{T_o \cdot L \cdot v_{des}}. \quad (2)$$

It should be noted that Figure 2 and (2) do not take into consideration planned maintenance and repair.

In order to consider the evaluation of technical availability let us add to Figure 2 the time interval of scheduled maintenance and repair from t_3 to t_4 on the part of the section from l_0 to l_1. As the result we obtain Figure 3.

By denoting the duration of the planned possession as $\Delta t' = t_4 - t_3$, h, denoting the length of the part of the section for which the possession is issued as $\Delta l' = l_1 - l_0$, km, and assuming $v_{res} = 0$, we deduce out of (2) the formula for evaluation of the technical availability coefficient:

$$C_{t.a.} = \frac{T_o \cdot L \cdot v_{des} - \Delta t \cdot \Delta l \cdot (v_{des} - v_{res}) - \Delta t' \cdot \Delta l' \cdot v_{des}}{T_o \cdot L \cdot v_{des}}. \quad (3)$$

Formulas (2) and (3) describe special cases that explain the approach to the evaluation of the technical availability coefficient of a line section. In general, we can take for the observation interval a random number of speed restrictions and planned possessions. Also, the line section can have one or more tracks.

Let us transform formula (3) in order to take account of a random number of speed restrictions and planned possessions:

$$C_{t.a.} = \frac{T_o \cdot L \cdot v_{des} - \sum_{j=1}^{m} \Delta t_j \cdot \Delta l_j \cdot (v_{des} - v_{desj}) - v_{des} \cdot \sum_{k=1}^{p} \Delta t'_k \cdot \Delta l'_k}{T_o \cdot L \cdot v_{des}}, \quad (4)$$

where m is the number of speed restrictions issued for the section over the observation period T_o;

Δt_j is the effective time period of the j^{th} ($j = 1 \ldots m$) speed restriction, h;

Δl_j is the length of the part of track section for which the j^{th} ($j = 1 \ldots m$) speed restriction, km, has been issued;

Δv_{resj} is the value of traffic speed according to the j^{th} ($j = 1 \ldots m$) restriction, km/h;

p is the number of planned possessions provided for the section over the observation period T_o;

$\Delta t'_k$ is the effective time of the k^{th} ($k = 1 \ldots p$) planned possession, h;

$\Delta l'_k$ is the length of the part of track section for which the k^{th} ($k = 1 \ldots p$) planned possession, km, has been issued.

Assuming that on the n-track section ($n = 1, 2, \ldots$) the lengths of all tracks are equal, as are the design speeds, we deduce out of (4) the formula of the technical availability coefficient for the n-track section:

$$C_{t.a.} = \frac{n \cdot T_o \cdot L \cdot v_{des} - \sum_{i=1}^{n} \left[\begin{array}{l} \sum_{j=1}^{m_i} \Delta t_{ij} \cdot \Delta l_{ij} \cdot (v_{des} - v_{resij}) - \\ - v_{des} \cdot \sum_{k=1}^{p_i} \Delta t'_{ik} \cdot \Delta l'_{ik} \end{array} \right]}{n \cdot T_o \cdot L \cdot v_{des}}, \quad (5)$$

where m_i is the number of speed restrictions issued for the i^{th} ($i = 1 \ldots n$) track of the section over the observation time T_o;

Δt_{ij} is the effective time period of the j^{th} ($j = 1 \ldots m_i$) speed restriction for the i^{th} track, h;

Δl_{ij} is the length of the part of track section of the i^{th} ($i = 1 \ldots n$) track, for which the j^{th} ($j = 1 \ldots m_i$) speed restriction has been issued, km;

Δv_{resij} is the value of traffic speed according to the j^{th} ($j = 1 \ldots m_i$) restriction for the i^{th} track, km/h;

p_i is the number of planned possessions granted for the i^{th} ($i = 1 \ldots n$) track of the section over the observation period T_o;

$\Delta t'_k$ is the effective period of the k^{th} ($k = 1 \ldots p_i$) planned possession for the i^{th} track, h;

$\Delta l'_{ik}$ is the length of the part of the section of the i^{th} track, for which the k^{th} ($k = 1 \ldots p_i$) planned possession, km, has been granted.

In order to coordinate the dimension quantities in the numerator and denominator of the formula (5) with the dimensions used in the conventional formula for the availability coefficient [2], i.e. dimensions of time, the numerator and denominator of (5) by the formula $n \cdot L \cdot v_{des}$:

$$C_{t.a.} = \frac{T_o - \frac{1}{n} \sum_{i=1}^{n} \left[\sum_{j=1}^{m_i} \Delta t_{ij} \cdot \frac{\Delta l_{ij}}{L} \cdot \left(1 - \frac{v_{resij}}{v_{des}}\right) - \sum_{k=1}^{p_i} \Delta t'_{ik} \cdot \frac{\Delta l'_{ik}}{L} \right]}{T_н} =$$

$$= 1 - \frac{\sum_{i=1}^{n} \left[\sum_{j=1}^{m_i} \Delta t_{ij} \cdot \frac{\Delta l_{ij}}{L} \cdot \left(1 - \frac{v_{resij}}{v_{des}}\right) - \sum_{k=1}^{p_i} \Delta t'_{ik} \cdot \frac{\Delta l'_{ik}}{L} \right]}{n \cdot T_o}. \quad (6)$$

As a result, we obtain the formula (6) that enables the evaluation of the technical availability coefficient of the n-track section subject to planned possessions and states of partial operability (traffic speed restrictions).

Further, let us consider the approach to the standardization of the technical availability coefficient of a line section.

Standardization of the technical availability coefficient of a line section

The main purpose of dependability indicators standardization is in the selection of substantiated criteria that serve as the foundation for the definition of thresholds for actual values of indicators. The result of comparison of the actual values with the standard ones enables decision-making regarding the further operation of the evaluated facility.

In order to define the standardization criteria, let us consider the components of the availability coefficient of a track section, by replacing in formula (1) $T_o = T_{op} + T_{schM} + T_r + T_{res}$ (T_{res} is the total loss of time due to speed restrictions over the observation period, h; this component was added to the components of formula (1) based on the considerations given above):

$$C_{t.a.} = \frac{T_o - T_{schM} - T_r - T_{res}}{T_o} \quad (7)$$

Thus (see (7), the technical availability coefficient includes the following components:

1) T_{schM}, the total time of scheduled maintenance (repair); this component can be standardized based on the known graph of planned possession assignment:

$$T_{schM} = \frac{1}{L}\sum_{k=1}^{p} \Delta l'_{plk} \cdot \Delta t'_{plk}, \quad (8)$$

where p is the number of planned possessions for a track section within the observation period T_o;

$\Delta l'_{plk}$ is the length of the part of track section for which the k^{th} ($k = 1 \ldots p$) possession is planned, km;

$\Delta t'_{plk}$ is the duration of the planned k^{th} ($k = 1 \ldots p$) possession, h;

L is the length of the track section, km;

2) T_r is the total duration of unscheduled repairs at the section over the observation period, h; this component can be standardized based on the statistical evaluation of the mean time to recovery and the track's dependability function of operation time:

$$T_r = t_r \cdot R(X) \cdot L, \quad (9)$$

where t_r is the mean time to recovery of the section after failure, h;

$R(X)$ is the track's dependability function of operation time, 1/km;

X is the operation time of the track section, mil t gross;

L is the length of the track section, km;

3) T_{res} is the total loss of time due to speed restrictions of the observation time, h; this component can be standardized based on the definition of some allowed values of mean traffic speed restriction and mean duration of restriction, as well as the track's reliability function of the operation time (because as the operation time grows, the number of speed restrictions objectively increases):

$$T_{res} = \left(1 - \frac{v_0}{v_{des}}\right) \cdot t_0 \cdot R(X) \cdot L, \quad (10)$$

where v_0 is the mean speed restriction value, km/h;

v_{des} is the design traffic speed for the section, km/h;

t_0 is the standard (allowed) duration of the restriction (per 1 km), h;

$R(X)$ is the track's dependability function of operation time, 1/km;

X is the operation time of the track section, mil t gross.

L is the length of the track section, km.

Let us consider the track's reliability function of the operation time. The rail is the most vital component of the track superstructure. Therefore, when constructing the most simple model of the track's reliability function it is advisable to use the function of single rail failure depending on the operation time. Such functions per rail types are considered in [3, 4, 5]. In the calculation example, let us use the single rail failure graph [5] that we will describe with a regression equation of the 4th order (Figure 4):

$$R(X) = \min\left\{\begin{pmatrix} 4,809 \cdot 10^{-12} \cdot X^4 + 7,058 \cdot 10^{-9} \cdot \\ \cdot X^3 - 2,738 \cdot 10^{-6} \cdot X^2 + \\ +0,0013 \cdot X + 0,0409 \end{pmatrix}; q\right\}, \quad (11)$$

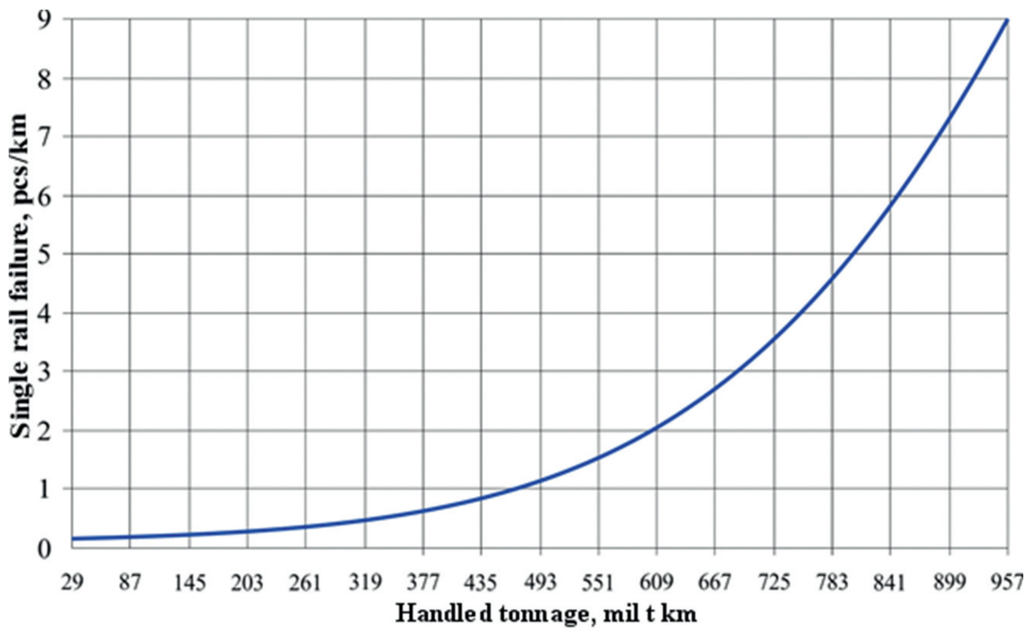

Figure 4. Graph of single rail failure depending on operation time

Table 1. Results of test calculations of availability of 3rd-class single-track open lines of the Bologoe Track Maintenance Division (PCh-47) of the Oktyabrskaya Infrastructure Directorate based on 2016 data.

Open line	Observation period, h	Length, km	Tonnage handled, mil t gross	Length of repaired track and total duration of maintenance possessions		Number of track circuit failures		Number of defective rail failures		Number of track geometry failures		Number of other failures		Warnings (ASU VOP-2): 25 km/h speed limit		Function of single rail failure depending on handled tonnage, 1/km	Technical availability coefficient	Standard technical availability coefficient
				km	h	pcs	h	pcs	h	pcs	h	pcs	h	pcs	h			
Sankovo - Podobino	8760	13,3	423,84	13	44,2	0	0	1	3	0	0	0	0	3	8,1	0,7926	0,9939	0,9839
Podobino - Bezhetsk		11,1	388,29	10,1	104,8	1	2,4	1	0,25	0	0	0	0	2	3,2	0,6554	0,9875	0,9804
Bezhetsk - Shishkovo		11,9	268,45	7,9	89,5	0	0	0	0	0	0	0	0	4	2,25	0,3541	0,9896	0,9853
Shishkovo - Viktorovo		9,5	21,48	9,5	60,8	0	0	0	0	0	0	0	0	32	1026	0,0676	0,9085	0,9924
Viktorovo - Sidorkovo		15	287,76	6	24,5	1	1,6	0	0	0	0	0	0	8	19,45	0,3894	0,9954	0,9911
Sidorkovo - Maksatikha		9,3	882,48	9,3	220,7	0	0	4	4,3	0	0	0	0	20	289,1	6	0,9505	0,9161
Total		**70,1**	**378,72**	-	-	-	-	-	-	-	-	-	-	-	-	**0,6228**	**0,9752**	**0,9446**

where X is the operation time of the track section, mil t gross;

q is the standard value of single rail failure for overhaul assignment [6], pcs/km.

Based on the formulas (7) – (11) we obtain the formula for the standard technical availability coefficient of a line section (for a single-track section):

$$C_{t.a.s.}=\frac{T_o-\frac{1}{L}\sum_{k=1}^{p}\left(\Delta l'_{plk}\cdot\Delta t'_{plk}\right)-R(X)\cdot L\left[t_o+\left(1-\frac{v_0}{v_{des}}\right)\cdot t_0\right]}{T_o}, \quad (12)$$

For an n-track section under the above assumptions, formula (12) transforms as follows:

$$C_{\text{t.a.s.}}=\frac{\left(\begin{array}{c}T_{\text{o}}-\frac{1}{n\cdot L}\sum_{i=1}^{n}\sum_{k=1}^{p_i}\left(\Delta l'_{\text{pl}ik}\cdot\Delta t'_{\text{pl}ik}\right)-\\-\left[\sum_{i=1}^{n}R_i(X)\right]\cdot L\left[t_{\text{o}}+\left(1-\frac{v_0}{v_{\text{des}}}\right)\cdot t_0\right]\end{array}\right)}{T_{\text{o}}}, \quad (13)$$

where p_i is the number of planned possessions granted for the i^{th} ($i = 1\ldots n$) track of the section over the observation time T_{o};

$\Delta t'_{plik}$ is the effective period of the k^{th} ($k = 1\ldots p_i$) planned possession for the i^{th} track, h;

$\Delta l'_{plik}$ is the length of the part of track section of the i^{th} track, for which the k^{th} ($k = 1\ldots p_i$) possession is planned, km.

The results of test calculation of the values of actual and standard technical availability coefficient through the means described above are given in Table 1, where the following parameters are used: $t_{\text{r}} = 2$ h; $v_0 = 25$ km/h; $t_0 = 10$ h; $q = 4$.

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Conclusions

Upon an examination of the factors that cause partial operability and non-operability of railway track, the authors suggest a method for evaluation of the technical availability coefficient of a railway line subject to the effects of speed restrictions on the capacity and thereby the availability of track. Aspects of standardization of the technical availability coefficient were examined. Formulas were obtained that allow calculating the actual availability coefficient of a railway line subject to partial operability, as well as the standard value of this indicator. The approaches and methods that are considered in this paper aim to improve the objectivity of evaluation of track availability to enable well-founded decision-making in operation.

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