MODELING OF TRACK TECHNICAL STATE WHEN OPERATING TIME IN TERMS OF TONNAGE IS HIGHER THAN NORMATIVE

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ABSTRACT

In the current provision on the system of track management of JSC Russian Railways, the existing criteria for assignment of main types of repair of the track do not allow making unequivocal decisions on timing of future repairs. The article discusses a methodology and model that helps to justify the time of overhaul in order to actualize the application of the specified criteria and extend the period of operation of the track in the zone of track sections where tonnage of transported goods has exceeded the standard cumulated value, requiring thus maintenece works (called operating time in terms of tonnage). This methodology is based on forecasting of failures of its elements using the developed model.

<u>Keywords</u>: railway, track, mean tonnage value, mean time between overhauls, residual resource, overhaul, management decision, mathematical model.

Background. *In the strategy of scientific and technological development of JSC Russian Railways the guidelines for innovative development have been defined until 2030. From this strategy, the authors selected two indicators: an increase in the time between capital repairs of sections of the track using closed-haul technology to 1500 million gross tons in 2015 and 2500 million tons gross in 2030; reduction (as compared to 2012 basic year) one year cost of life cycle of the track superstructure by 1,3 times [1]. Proceeding from this, in the article a special place is given to a problem of management of a technical condition of a railway track in a zone of its operation with operating time in terms of tonnage (or simply operating time of tonnage) above normative value.*

The untimely carrying out of such labor-intensive works as overhaul and average repairs leads to additional costs for current maintenance of the track, because the problem remains to maintain it in a state that allows uninterrupted and safe movement of trains with established speeds.

Under the existing conditions, the strategy of integrated management of reliability, safety, risks and resources in rail transport (URRAN) is in demand and is actively applied [1–3]. The most common approach is to maintain reliability in the operation of technical systems.

Objective. *The objective of the authors is to consider modeling of track technical state if operating time of tonnage is higher than normative.*

Methods. *The authors use general scientific and engineering methods, comparative analysis, evaluation approach, mathematical apparatus.*

Results.

Model-based research

Within the framework of the URRAN concept in Pic. 1 a control scheme for planning the repair of a track in a zone with operating time of tonnage above the normative value is presented, taking into account estimation and forecasting of the residual life of track elements.

In modeling the process of operating the track in the zone under study, the following main tasks are solved:

1. Extension of the track lifetime, taking into account forecasting of the residual life of its elements and designation of a deadline for completion of overhaul.

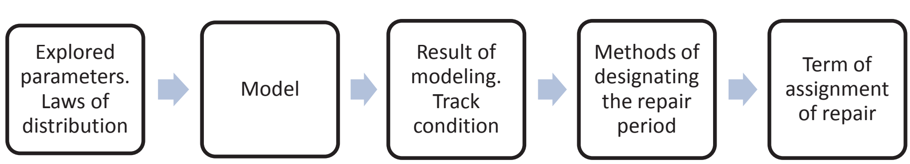
2. Justification of decision-making when assigning track repairs.

In accordance with the Regulations on the Track Maintenance System of JSC Russian Railways when assigning overhaul of the track it is

Table 1

Criteria for selecting track sections to be reconstructed, overhauled on new materials [5]

Track class	Main criteria		Additional criteria			URRAN criteria (not less than)	
	Operating time of track in % of the normative resource (lifetime) of the track	Single output of rails	Number of unsuitable and defective elements per 1 km of the track superstructure, % (from and above)			Frequency of failures, number per year/km	Costs for current maintenance of the track, share of depreciation
			Defective wooden sleepers, %	Defective fastenings, %	Number of sleepers with splashes, %		
1	Not less than 100 %	4 and more	15	15	4	0,2	0,5
2	Not less than 100 %	6 and more	18	2o	5	0,2	0,5



Pic. 1. The scheme for managing the planning of track repair based on the developed methodology and model.

Table 2

Criteria for choosing the track sections subject to RPC

Class of a track	Main criteria		Additional criteria		
	Number of deviations of GRT 2nd degree, pcs/km and more	Pollution of rubble, % by weight	Unsuitable wooden sleepers, % and no more than	Sleepers with splashes, % and no more than	Unsuitable fastenings, % and no more than
1 and 2	25	up to 30	10	3	10
3	30	up to 30	15	5	15
4	40	up to 30	20	10	20
5	At the discretion of the head of track maintenance department				

Table 3

Designation and description of modeled events

No.	Designation of events	Description of events
		Single output of rails
1	A	– rail failure did not occur
2	A0	– rail failure occurred, $n_A < 6$ pcs per km
3	A	– rail failure occurred, $n_A \geq 6$ pcs per km
		Failure of fastenings elements
4	B	– failure of fastenings did not occur
5	B0	– failure of fastenings occurred, $n_B < 736$ pcs per km
6	B	– failure of fastenings occurred, $n_B \geq 736$ pcs per km
		Number of sleepers with splashes
7	C	– splash under the sleeper did not occur
8	C0	– splash under the sleeper occurred, $n_C < 92$ pcs per km
9	C	– splash under the sleeper occurred, $n_C \geq 92$ pcs per km
		Number of deviations of GRT 2nd degree
1o	D	– deviation of GRT 2nd degree did not occur
11	D0	– deviation of GRT 2nd degree occurred, $n_D \leq 25$ pcs per km
12	D	– deviation of GRT 2nd degree occurred, $n_D > 25$ pcs per km

necessary to be guided by the criteria given in Table 1.

As can be seen from Table 1, some parameters (such as a single output of rails, defective fastenings, number of sleepers with splashes) are random variables and fulfillment of all of them simultaneously is a very problematic condition. As a result, there is a residual resource of operating time of tonnage by separate parameters (elements), which must be estimated and predicted when assigning track repair.

For a wider use of the model, one more parameter is added, this is a deviation of the geometry of the rail track (GRT) of the 2nd degree, which allows assigning the track alignment to the assignment of overhaul.

In accordance with the provision on the system of track maintenance [5], the criteria for assigning a regular preventive correction (RPC) are the parameters given in Table 2

As a result of comparison of options for modeling, a list of track parameters characterizing its state at a certain point in time was adopted. This is a single output of rails, the number of unsuitable fastenings, the number of sleepers with splashes, the number of deviations of GRT 2nd degree.

For the decision to assign repair of the track, a system is simulated, in which 12 events that determine the technical state of the track elements are combined. The modeled events and their notation are shown in Table 3.

When modeling railway track conditions, it is assumed that the occurrence of events – rail defect, splash, failure of fastenings, deviation of GRT 2nd degree – is simultaneously possible, therefore we believe that these simple events are joint and independent.

Now we define a complete group of complex incompatible events of the type A•B•C•D, during which the track passes from one state to another during operation.

The total group of all complex events is $N = n^4 = 3^4 = 81$ and is shown in Table 4.

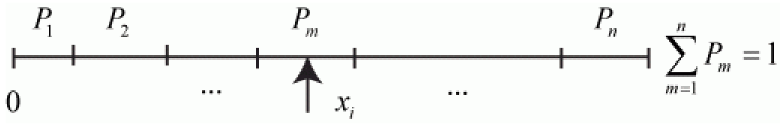
The track in the process of operation deteriorates and passes from one state to another. The order of occurrence of events depends on the failure rate of the track elements.

Based on the criteria in Table 4, overhaul should be scheduled when the following events occur:

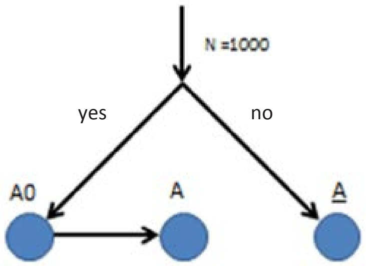
40. (A•B•C•D0) with the number of deviations of GRT 2nd degree $n_D \leq 25$ pcs per km.

41. (A•B•C•D) with the number of deviations of GRT 2nd degree $n_D > 25$ pcs per km.

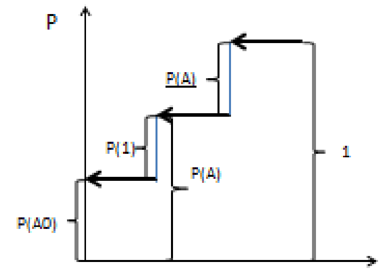
42. (A•B•C•D), the number of deviations of GRT 2nd degree did not occur $n_D = 0$



Pic. 2. Scheme of the algorithm.



Pic. 3. The principle of modeling the event A.



Pic. 4. The probability of occurrence of the event A.

The probability of occurrence of these events will accordingly be equal to:

$P_{40} = P(A) \cdot P(B) \cdot P(C) \cdot P(D0);$

$P_{41} = P(A) \cdot P(B) \cdot P(C) \cdot P(D);$

$P_{42} = P(A) \cdot P(B) \cdot P(C) \cdot P(\underline{D}) = P(A) \cdot P(B) \cdot P(C) \cdot [1-P(D)].$

The algorithm for modeling the parameters under study is based on a theorem, which is interpreted as follows.

In the complete group of incompatible complex events (track states), the model of occurrence of the event A_m occurring with the probability P_m is the hit of the value of X_i on the interval [0, 1] of the uniformly distributed set γ and equal to P_m of the numerical scale,

$$\sum_{m=1}^{n} Pm = 1,$$

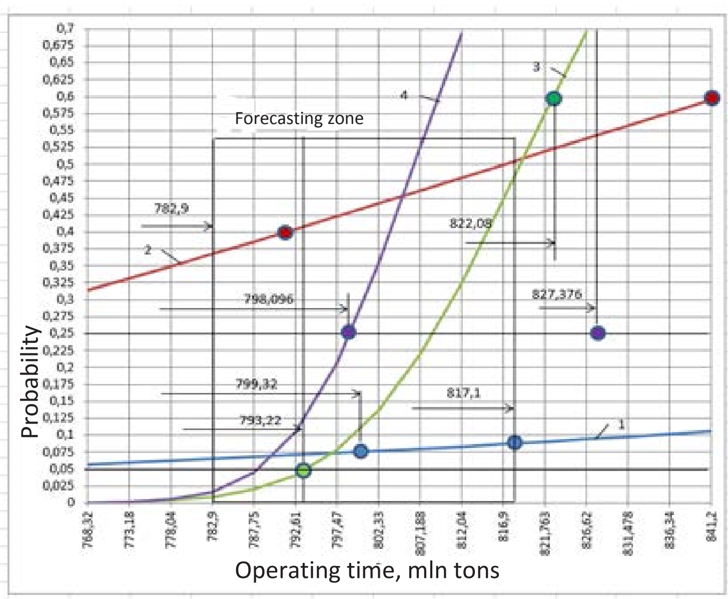
where n is the total number of complex incompatible events; A_m are complex events of the type $(A0 \cdot B0 \cdot C0 \cdot D0)$; P_m is the probability of a complex event; $X_i = (r_1, r_2, r_3, r_4)$ – is a vector consisting of a set of random numbers (r_1, r_2, r_3, r_4), issued by the random number generator and belonging to the interval [0, 1].

Graphically, implementation of one of the complex events looks as shown in Pic. 2.

The principle of modeling is shown on a simple event A (rail defect), which is schematically represented in Pic. 3:

- *Event A0 occurs if the number of defects is $n_{A0} < 6$.*
- *Event A – if the number of defects is $n_A \geq 6$.*
- *Event $\underline{A}$, when no event occurs.*

We write down the general identity that characterizes that the event will necessarily occur.



Pic. 5. Distributions of the parameters under study in the forecasting range:
1– distribution of rail failure; 2 – distribution of failures of fastenings of KB type; 3 – distribution of splashes;
4 – distribution of deviations of GRT 2nd degree.

Table 4

Complete group of complex events

№	Designation of a complex event	Event A occurred			Event B occurred			Event C occurred			Event D occurred		
		yes		no	yes		no	yes		no	yes		no
		A0	A	A	B0	B	B	C0	C	C	D0	D	D
		$0<n_A<6$	$6\le n_A\le N$	$n_A=0$	$0<n_B<736$	$736\le n_B\le N$	$n_B=0$	$0<n_C<92$	$92\le n_C\le N$	$n_C=0$	$0<n_D\le 25$	$25<n_D\le N$	$n_D=0$
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	A0 • B0 • C0 • D0	+			+			+			+		
2	A0 • B0 • C0 • D	+			+			+				+	
3	A0 • B0 • C0 • D	+			+			+					+
4	A0 • B0 • C • D0	+			+				+		+		
5	A0 • B0 • C • D	+			+				+			+	
6	A0 • B0 • C • D	+			+				+				+
7	A0 • B0 • C • D0	+			+					+	+		
8	A0 • B0 • C • D	+			+					+		+	
9	A0 • B0 • C • D	+			+					+			+
10	A0 • B • C0 • D0	+				+		+			+		
11	A0 • B • C0 • D	+				+		+				+	
12	A0 • B • C0 • D	+				+		+					+
13	A0 • B • C • D0	+				+			+		+		
14	A0 • B • C • D	+				+			+			+	
15	A0 • B • C • D	+				+			+				+
16	A0 • B • C • D0	+				+				+	+		
17	A0 • B • C • D	+				+				+		+	
18	A0 • B • C • D	+				+				+			+
19	A0 • B • C0 • D0	+					+	+			+		
20	A0 • B • C0 • D	+					+	+				+	
21	A0 • B • C0 • D	+					+	+					+
22	A0 • B • C • D0	+					+		+		+		
23	A0 • B • C • D	+					+		+			+	
24	A0 • B • C • D	+					+		+				+
25	A0 • B • C • D0	+					+			+	+		
26	A0 • B • C • D	+					+			+		+	
27	A0 • B • C • D	+					+			+			+
28	A • B0 • C0 • D0		+		+		+	+			+		
29	A • B0 • C0 • D		+		+		+	+				+	
30	A • B0 • C0 • D		+		+		+	+					+
31	A • B0 • C • D0		+		+				+		+		
32	A • B0 • C • D		+		+				+			+	
33	A • B0 • C • D		+		+				+				+
34	A • B0 • C • D0		+		+					+	+		
35	A • B0 • C • D		+		+					+		+	
36	A • B0 • C • D		+		+					+			+
37	A • B • C0 • D0		+			+		+			+		
38	A • B • C0 • D		+			+		+				+	
39	A • B • C0 • D		+			+		+					+
40	A • B • C • D0		+			+			+		+		
41	A • B • C • D		+			+			+			+	
42	A • B • C • D		+			+			+				+
43	A • B • C • D0		+			+				+	+		

44	A • B • C • D		+			+				+		+	
45	A • B • C • D		+			+				+			+
46	A • B • C0 • D0		+				+	+			+		
47	A • B • C0 • D		+				+	+				+	
48	A • B • C0 • D		+				+	+					+
49	A • B • C • D0		+				+		+		+		
50	A • B • C • D		+				+		+			+	
51	A • B • C • D		+				+		+				+
52	A • B • C • D0		+				+			+	+		
53	A • B • C • D		+				+			+		+	
54	A • B • C • D		+				+			+			+
55	A • B0 • C0 • D0			+	+			+			+		
56	A • B0 • C0 • D			+	+			+				+	
57	A • B0 • C0 • D			+	+			+					+
58	A • B0 • C • D0			+	+				+		+		
59	A • B0 • C • D			+	+				+			+	
60	A • B0 • C • D			+	+				+				+
61	A • B0 • C • D0			+	+					+	+		
62	A • B0 • C • D			+	+					+		+	
63	A • B0 • C • D			+	+					+			+
64	A • B • C0 • D0			+		+		+			+		
65	A • B • C0 • D			+		+		+				+	
66	A • B • C0 • D			+		+		+					+
67	A • B • C • D0			+		+			+		+		
68	A • B • C • D			+		+			+			+	
69	A • B • C • D			+		+			+				+
70	A • B • C • D0			+		+				+	+		
71	A • B • C • D			+		+				+		+	
72	A • B • C • D			+		+				+			+
73	A • B • C0 • D0			+			+	+			+		
74	A • B • C0 • D			+			+	+				+	
75	A • B • C0 • D			+			+	+					+
76	A • B • C • D0			+			+		+		+		
77	A • B • C • D			+			+		+			+	
78	A • B • C • D			+			+		+				+
79	A • B • C • D0			+			+			+	+		
80	A • B • C • D			+			+			+		+	
81	A • B • C • D			+			+			+			+

Note: The sum of all the complex events given is equal to one, that is $\sum_{n=1}^{n=81} Ai \cdot Bj \cdot Ck \cdot Dm = 1$.

$P(A0) + P(A) + P(\underline{A}) = 1$ or $n_{Ao}/N + n_{\underline{A}}/N + n_{\underline{A}}/N = 1$. It looks graphically, as shown in Pic. 4.

During the modeling, the probability values of the events are obtained: $P(A0) = n_{Ao}/N$; $P(A) = n_A/N$; $P(\underline{A}) = n_{\underline{A}}/N$.

Estimating the probability of occurrence of an event in a model is estimated through frequency – a static probability estimate:

$P(r \leq R) = n / N$,

where n – number of events that occurred; N – number of repetitions of the experiment (in the model it is assumed that N = 1000).

Based on the modeling results, it is possible to determine which of the events will occur earlier, and which later. There is an opportunity to play scenarios for assigning track repairs, that is, to predict them [6–8].

Tasks engaging the model

1. Direct task, determination of the probability of occurrence of individual simple events under study (A, B, C, D) on a selected track section at a predetermined operating time of tonnage (rail defect fastening failure, occurrence of splash, the number of deviations of GRT 2nd degree) and as a consequence – finding the number of these individual events.

2. The inverse problem, the determination of operating time of tonnage by the given value of failure of one of the events.

3. Determination of the probability of occurrence of track states (complex events of the type A•B, A•B•C, A•B•C•D, consisting of simple ones).

4. The ability to determine the sequence of emergence of track states (simple and complex events).

Table 5

The laws of distribution of the parameters under study in a given range

Event	Parameters	Forecasting range	Distribution function
A	Rails	782,9 < t ≤ 817,1	$f(t)=\frac{1}{222\bullet\sqrt{2\pi}}e^{-\frac{1}{2}\bullet\left(\frac{t-1119}{222}\right)^2}$
B	Fastenings	782,9 < t ≤ 817,1	$f(t)=\frac{1}{100,5\bullet\sqrt{2\pi}}e^{-\frac{1}{2}\bullet\left(\frac{t-817}{100,5}\right)^2}$
C	Splashes	782,9 < t ≤ 793,224	$f(t)=0,005+\frac{1}{15,1\bullet\sqrt{2\pi}}e^{-\frac{1}{2}\bullet\left(\frac{t-818,9}{15,1}\right)^2}$
		793,224 < t ≤ 817,1	$f(t)=0,01+\frac{1}{15,1\bullet\sqrt{2\pi}}e^{-\frac{1}{2}\bullet\left(\frac{t-818,9}{15,1}\right)^2}$
D	Deviations of GRT 2nd degree	782,9 < t ≤ 798,096	$f(t)=0,05+\frac{1}{11,06\bullet\sqrt{2\pi}}e^{-\frac{1}{2}\bullet(\frac{t-806,5}{11,06})^2}$
		798,096 < t ≤ 817,1	$f(t)=0,075+\frac{1}{11,06\bullet\sqrt{2\pi}}e^{-\frac{1}{2}\bullet(\frac{t-848,7}{11,06})^2}$

Table 6

The result of modeling of simple single events of type A, B, C, D

Event	Probability	Event	Probability	Event	Probability	Event	Probability
A	0,9280	B	0,6440	C	1,0000	D	0,9860
A0	0,072	B0	0,2000	C0	0	D0	0,0140
A	0	B	0,3560	C	0	D	0

5. Determination of speed of transition of one track state to another (one complex event to another).

6. Determination of the optimal time for assignment of repair work on the selected track section.

To estimate track conditions, the laws of distribution of the investigated parameters are introduced into the database of initial data.

In the model developed at the department of Track and Track Facilities, normal, exponential and general distribution laws, the Weibull law, can be used to study the specified parameters.

To obtain these laws, we took truncated samples of parameters for the kilometer under study from the passport of the track maintenance section and track-measuring cars, as well as information from scientific printed sources.

When modeling the parameters under study in a given range of operating time, the distribution laws are obtained, which are given in Table 5.

Pic. 5 shows the graphs of the distribution laws of the selected parameters for 131 kilometers of the Moscow–Ryazan direction.

Forecasting of failures of the parameters given in Table 5 is carried out in the range of operating time of tonnage 782,9 ≤ t ≤ 817,1 (million tons).

The points in Pic. 5 shows the limiting values of operating time of tonnage of individual parameters, under which the repair of track should be assigned according to the regulations.

As can be seen from Pic. 6, the emergence of the same (with the same operating time) limiting values of the parameters is unlikely, therefore, the authors propose a method for determining the assignment of overhaul of the track when operating time of tonnage is above the limiting normative value.

Tables 6 and 7 show the results of modeling the parameters under study with operating time of tonnage of 782,9 million tons for 131 km of the Moscow–Ryazan direction.

From Table 6 it can be seen that event A for a given operating time of tonnage has not reached its limiting normative value $P_A = 0,075$.

Event B overstepped the limiting value of probability with the value $P_B = 0,356 > 0,2$.

Event C did not occur, so $P_C = 0$.

Event D did not reach its limiting normative value $P_D = 0,25$ and is equal to $P_{D0} = 0,014$.

During the research, it is necessary to understand the state in which the track will be for a given operating time of tonnage, for this, modeling of complex events of the type $A_i \bullet B_i \bullet C_i \bullet D_i$ (see Table 7) is made.

Next, it is necessary to determine which of these events (track states) are the limiting ones, that is, the most appropriate ones for the purpose of repairing the track, for which criteria should be chosen for their evaluation.

For single events, the limiting normative values of the probability of occurrence of each of them are given in Table 8.

To normalize and obtain evaluation criteria, we introduce the concept of a normalized probability, which is expressed for each simple event as follows:

$P_1 = P_A / P_{A0}$; $P_2 = P_B / P_{B0}$; $P_3 = P_C / P_{C0}$; $P_4 = P_D / P_{D0}$.

We consider that it is possible to construct four-dimensional space from these vectors (in the general case, n is a space with its own measure on each axis), in which the limiting values of the diagonals of the n-dimensional space are taken as criteria.

For the case under consideration, the limiting values of the diagonals are given in Table 9.

We determine the value of diagonals of a vector space for their comparative estimation. The non-zero values of the diagonals calculated for 131 km are given in Table 10.

Table 7

The result of modeling all complex events of the type Ai • Bi • Ci • Di (probability of occurrence of a complex event)

No.	Event	Value of Pi	No.	Event	Value of Pi	No.	Event	Value of Pi
1	**A • B • C • D**	0,4828	28	A0 **• B • C • D**	0,0314	55	A • B • C • D	0
2	**A • B • C • D0**	0,0721	29	A0 **• B • C • D0**	0,0047	56	A • B • C • D0	0
3	A • B • C • D	0	30	A0 • B • C • D	0	57	A • B • C • D	0
4	A • B • C0 • D	0	31	A0 • B • C0 • D	0	58	A • B • C0 • D	0
5	A • B • C0 • D0	0	32	A0 • B • C0 • D0	0	59	A • B • C0 • D0	0
6	A • B • C0 • D	0	33	A0 • B • C0 • D	0	60	A • B • C0 • D	0
7	A • B • C • D	0	34	A0 • B • C • D	0	61	A • B • C • D	0
8	A • B • C • D0	0	35	A0 • B • C • D0	0	62	A • B • C • D0	0
9	A • B • C • D	0	36	A0 • B • C • D	0	63	A • B • C • D	0
10	**A • B0 • C • D**	0,1634	37	A0 **• B0 • C • D**	0,0106	64	A • B0 • C • D	0
11	**A • B0 • C • D0**	0,0244	38	A0 **• B0 • C • D0**	0,0016	65	A • B0 • C • D0	0
12	A • B0 • C • D	0	39	A0 • B0 • C • D	0	66	A • B0 • C • D	0
13	A • Б0 • C0 • D	0	40	A0 • B0 • C0 • D	0	67	A • B0 • C0 • D	0
14	A • B0 • C0 • D0	0	41	A0 • B0 • C0 • D0	0	68	A • B0 • C0 • D0	0
15	A • B0 • C0 • D	0	42	A0 • B0 • C0 • D	0	69	A • B0 • C0 • D	0
16	A • B0 • C • D	0	43	A0 • B0 • C • D	0	70	A • B0 • C • D	0
17	A • B0 • C • D0	0	44	A0 • B0 • C • D0	0	71	A • B0 • C • D0	0
18	A • B0 • C • D	0	45	A0 • B0 • C • D	0	72	A • B0 • C • D	0
19	**A • B • C • D**	0,3341	46	A0 **• B • C • D**	0,0217	73	A • B • C • D	0
20	**A • B • C • D0**	0,0499	47	A0 **• B • C • D0**	0,0032	74	A • B • C • D0	0
21	A • B • C • D	0	48	A0 • B • C • D	0	75	A • B • C • D	0
22	A • B • C0 • D	0	49	A0 • B • C0 • D	0	76	A • B • C0 • D	0
23	A • B • C0 • D0	0	50	A0 • B • C0 • D0	0	77	A • B • C0 • D0	0
24	A • B • C0 • D	0	51	A0 • B • C0 • D	0	78	A • B • C0 • D	0
25	A • B • C • D	0	52	A0 • B • C • D	0	79	A • B • C • D	0
26	A • B • C • D0	0	53	A0 • B • C • D0	0	80	A • B • C • D0	0
27	A • B • C • D	0	54	A0 • B • C • D	0	81	A • B • C • D	0

As a criterion for choosing an event, the maximum value of the mathematical expectation is taken, which is determined by the formula [6]:

$$Mi = \sum_{n=1}^{m} Pi \cdot Xi,$$

where Xi – value of the vector, Pi – probability of its emergence.

The calculated mathematical expectations of events are summarized in Table 11.

From the results obtained, it follows that when operating time of tonnage is 782,9 million tons, event № 19 (A • B • C • D)should occur, which should be noted, since the mathematical expectation of this event has a maximum value of M_{19} = 1,78. The probability of its occurrence is P = 35,6 %.

Further, it can be noted that there was only one simple event B (failure of fastening), the probability of which was P_B = 0,356 and which exceeded the limiting normative value P_B = 0,2.

Table 8

Limiting values for probability of occurrence of a simple event

Events	Normative limiting value of probability
A	$P_{A0} = 0{,}075$
B	$P_{B0} = 0{,}2$
C	$P_{C0} = 0{,}05$
D	$P_{D0} = 0{,}25$

Of complex events, the event № 20 (A • B • C • D0) took place, in which the mathematical expectation is M_{19} = 0,07, and the probability of its occurrence is P = 5 %.

After determining and assessing the track state in which it fell at a given operating time of tonnage, it is necessary to designate the period for performing the repair at the selected kilometer. For this purpose,

Table 9

Limiting values of diagonals of n-dimensional space (criteria)

One-dimensional space	Two-dimensional space	Three-dimensional space	Four-dimensional space
$P_1 = P_A / P_{A0} = 1$	$P_{12} = \sqrt{P1^2 + P2^2} = \sqrt{2}$	$P_{123} = \sqrt{P1^2 + P2^2 + P3^2} = \sqrt{3}$	$P_{1234} = \sqrt{P1^2 + P2^2 + P3^2 + P4^2} = 2$
$P_2 = P_B / P_{B0} = 1$	$P_{13} = \sqrt{P1^2 + P3^2} = \sqrt{2}$	$P_{134} = \sqrt{P1^2 + P3^2 + P4^2} = \sqrt{3}$	
$P_3 = P_C / P_{C0} = 1$	$P_{14} = \sqrt{P1^2 + P4^2} = \sqrt{2}$	$P_{234} = \sqrt{P2^2 + P3^2 + P4^2} = \sqrt{3}$	
$P_4 = P_D / P_{D0} = 1$	$P_{23} = \sqrt{P2^2 + P3^2} = \sqrt{2}$	$P_{124} = \sqrt{P1^2 + P2^2 + P4^2} = \sqrt{3}$	
	$P_{24} = \sqrt{P2^2 + P4^2} = \sqrt{2}$		
	$P_{34} = \sqrt{P3^2 + P4^2} = \sqrt{2}$		

Table 10

Values of diagonals of a vector space

No.	Event	Value	No.	Event	Value
			28	$A0 \cdot \underline{B} \cdot \underline{C} \cdot \underline{D}$	1
2	$\underline{A} \cdot \underline{B} \cdot \underline{C} \cdot D0$	1	29	$A0 \cdot \underline{B} \cdot \underline{C} \cdot D0$	1,41
10	$\underline{A} \cdot B0 \cdot \underline{C} \cdot \underline{D}$	1	37	$A0 \cdot B0 \cdot \underline{C} \cdot \underline{D}$	1,41
11	$\underline{A} \cdot B0 \cdot \underline{C} \cdot D0$	1,41	38	$A0 \cdot B0 \cdot \underline{C} \cdot D0$	1,73
19	$\underline{A} \cdot B \cdot \underline{C} \cdot \underline{D}$	1,78	46	$A0 \cdot B \cdot \underline{C} \cdot \underline{D}$	2,04
20	$\underline{A} \cdot B \cdot \underline{C} \cdot D0$	2,04	47	$A0 \cdot B \cdot \underline{C} \cdot D0$	2,27

Table 11

Values of mathematical expectations

No.	Event	Mathematical expectation Mi	No.	Event	Mathematical expectation Mi
			28	$A0 \cdot \underline{B} \cdot \underline{C} \cdot \underline{D}$	0,1
2	$\underline{A} \cdot \underline{B} \cdot \underline{C} \cdot D0$	0,0721	29	$A0 \cdot \underline{B} \cdot \underline{C} \cdot D0$	0,007
10	$\underline{A} \cdot B0 \cdot \underline{C} \cdot \underline{D}$	0,163	37	$A0 \cdot B0 \cdot \underline{C} \cdot \underline{D}$	0,015
11	$\underline{A} \cdot B0 \cdot \underline{C} \cdot D0$	0,034	38	$A0 \cdot B0 \cdot \underline{C} \cdot D0$	0,003
19	$\underline{A} \cdot B \cdot \underline{C} \cdot \underline{D}$	1,78	46	$A0 \cdot B \cdot \underline{C} \cdot \underline{D}$	0,04
20	$\underline{A} \cdot B \cdot \underline{C} \cdot D0$	0,07	47	$A0 \cdot B \cdot \underline{C} \cdot D0$	0,007

the authors propose a technique for assigning overhaul of the track when operating time of tonnage is in excess of the normative value.

Method of assignment of repair

First it is necessary to choose the forecasting range and determine the distribution laws of the parameters under study, for this we use Pic. 6, which shows the distribution of parameters in a given range of operating time and indicates the limiting points in which it is required to repair the track elements to eliminate the resulting failures.

The distribution of rail failure (the appearance of defects) is accepted as the basic distribution, and the value of P_{A0} = 0,075 reflects the limiting probability (at which the entire kilometer of the strings is to be replaced).

In accordance with the normative value, the kilometer of the strings is replaced when more than six defects appear in it. The operating time of tonnage for this number of defects is 799,32 million tons.

We determine the operating time of tonnage before the appearance of the next seventh defect. The value of tonnage for it will be 817,1 million tons.

The assignment of overhaul at this kilometer long section should be made before the appearance of the seventh defect, therefore the boundary of operating time of tonnage 817,1 million tons is taken for the reference line. Further limiting values for the

Table 12

Limiting values of operating time of tonnage for the parameters under study

Event	Limiting normative probability, P_i	Limiting estimated operating time of tonnage, T_i (mln tons)
A (rail failure)	P_{A01}= 0,075	T_{A0} =799,32
Up to the seventh defect	P_{A02}= 0,0875	T_{A02} =817,10
B (failure of fastenings)	P_{B01} = 0,2	T_{B01} =731,58
	P_{B02} = 0,4	T_{B02} =790,87
C (number of splashes)	P_{C0} = 0,05	T_{C0} =793,32
D (number of deviations of GRT 2nd degree)	P_{D0} = 0,025	T_{D0} =798,096

remaining parameters are found. They are listed in Table 12.

The term of assignment of repair of the track is determined by the formula [6]:

$$Tn = \frac{\sum Pi \cdot ti}{\sum Pi},$$

where Pi – limiting normative probability; Ti – limiting estimated operating time of tonnage.

Thus, for the reference frame, the total operating time of tonnage T_{A02} = 817,1 mln tons is taken.

t_A = 0; t_B = 817,1–790,87 = 26,23 (mln tons); t_C = 817,1–793,32 = 23,78 (mln tons);

t_D = 817,1–798,096 =19 (mln tons); ∑Pi = 0,4+0,05+0,025 = 0,475.

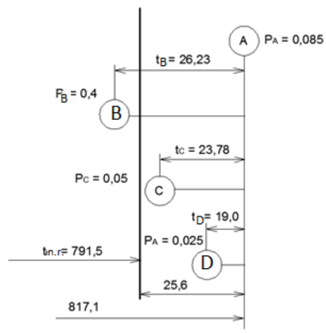
Relative period of assignment of repair:

T_n = (0,4·26,23+0,05·23,78+0,025·19) / 0,457 = 25,6 (mln tons).

The term of assignment for total operating time of tonnage will be:

$T_{n\,r}$ = 817,1–25,6 = 791,5 (mln tons).

Graphically the calculation scheme is shown in Pic. 6.



Pic. 6. The calculation scheme.

Conclusion. *When operating the selected kilometer long section in the range of operating time of tonnage 782,9 ≤ t ≤ 817,1 (mln tons), in accordance with the considered methodology, overhaul should be assigned for operating time of tonnage $t_{n.r.}$ = 791,5 (mln tons).*

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