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Method of identification of the ranges of (non)acceptable factor values to reduce the risk of freight car derailment due to broken bogie solebar[1]

Igor B. Shubinsky, *JSC NIIAS, Russian Federation, Moscow*
Alexey M. Zamyshliaev, *JSC NIIAS, Russian Federation, Moscow*
Alexey N. Ignatov, *Moscow Aviation Institute, Russian Federation, Moscow*
Andrey I. Kibzun, *Moscow Aviation Institute, Russian Federation, Moscow*
Evgeny O. Novozhilov, *JSC NIIAS, Russian Federation, Moscow*


Igor B. Shubinsky


Alexey M. Zamyshliaev


Alexey N. Ignatov


Andrey I. Kibzun


Evgeny O. Novozhilov

Abstract. Aim. *According to the Russian freight car crash/derailment investigation records for the period between 2013 and 2016., derailments and crashes during train operations were mostly caused by rolling stock malfunctions, while about a third of such derailments were due to bogie solebar fracture. The average number of derailed units of rolling stock is 4.16 in case of derailment due to solebar fracture against 1.73 in case of derailments due to other rolling stock malfunctions. Previously, a method was developed that allows making decisions to discard a batch of solebars. On the other hand, solebars from batches exempt from discarding can be subject to fractures over time. In this context, it appears to be of relevance to develop a method that would enable timely uncoupling of a car for its submission to depot/full repairs in order to avoid solebar fracture. For this purpose, factor models of fracture hazard estimation should be considered. Such factors may include the number of kilometers travelled from the last maintenance depot (MD), as well as the number of kilometers and days until the next scheduled full/depot repairs. The probability of solebar fracture can be used as the quantitative characteristic of the hazard of solebar fracture. However, probability estimation in the form of, for instance, the frequency of solebar fracture is only possible when observation data is available on when fracture or critical defect of solebar did not occur, yet such data is not collected. Therefore, the hazard index of solebar fracture should be developed. As it is difficult to manage the frequency of car submission to MD, the hazard index must depend only on the number of days and kilometers to repairs. Using the constructed index, the ranges of (non) acceptable factor values must be defined in order to enable decision-making regarding car uncoupling and submission to repairs, should the MD car inspector have doubts regarding the necessity of uncoupling.* **Methods.** *Methods of mathematical programming were used in this paper*. **Results. Conclusions.** *An impact index was built that characterizes the probability of freight car solebar fracture depending on the number of days and kilometers until the next scheduled repairs of such car. Based on that index, two methods of definition of ranges of (non)acceptable factor values were proposed. The first method was based on the values of the impact index. The second one was based on the identification of some parameters of ranges of (non)acceptable factor values and selection – out of all ranges – of the best ones in terms the lowest hazard of solebar fracture. Such selection was made by solving problems of mixed integer programming with quadratic constraint.*

Keywords: *risk, derailment, solebar fracture, impact index, hazard index*

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Introduction

Operation of freight trains is associated with the risk of various adverse events: locomotive fires, uncoupling of cars in transit, collisions involving automotive vehicles and trains in rail crossings, train derailments. According to [1], the risk of the above and other transportation accidents is the functional of probability and damage. Decision-making aimed at maintaining an acceptable level of risk involves building a risk matrix according to the principles described in [2].

Out of the above and other transportation accidents both in Russia, and in the Western countries, derailments are the most common object of research. This type of incidents is characterized by grave consequences and occurs relatively frequently. In [3], the number of derailed cars was estimated using the maximum likelihood method and quantile regression. In [4], the research focused on the estimation of the number of derailed cars depending on the number of the first (counting from the front end of the train) derailed unit of rolling stock. In [5], the effect of switches and particular track geometry on the number of derailed unit of rolling stock was researched. Let us note that an examination of incident records is sufficient for damage estimation, while probability estimation also requires examining the cases when transportation incidents did not occur. For that reason, it is extremely difficult to build factor models that associate the probability of a transportation accident with the values of various factors. In this context, simplified models are normally considered that take into consideration, for instance, the track geometry at the location of derailment: in [6] the probability of derailment depended on the class of track, length of the consist and the number of travelled kilometers, [7] examined the average number of transportation incidents that depends on the number of kilometers travelled by trains and cars. An alternative solution to the above described integral estimation of probability for the purpose of reducing the frequency of derailments is the construction of impact indexes [8] that are based on the frequency of factor manifestation in cases of transportation incidents.

Out of all causes of freight car derailments/crashes due to technical rolling stock malfunctions, the solebar fractures entail the most significant damage. Research of the problem of solebar fracture normally involves the examination of the specific design solutions of such solebar and their effect on the fracture [9-11]. At the same time, we must note [12], that suggested boundaries of allowed frequency of solebar fracture and occurrence of defects that require repairs. However, that method aims to identify batches of solebars to be rejected, not to prevent the fracture of a specific solebar, which is the subject of this paper. As it is impossible to completely eliminate the probability of solebar fracture, the number of such fractures is to be minimized. In this context, it appears to be logical to estimate the probability of solebar fracture of a specific car of a specific train. However, it is impossible to build an estimate of the probability of solebar fracture using, for instance, logistic or probit regression, as there are no available statistics regarding the non-occurrence of solebar fractures. At the same time, similarly to [5], the hazard index of solebar fracture can be built using only data on the occurrence of fractures.

The construction of the hazard index involves identifying the factors that affect the frequency of the transportation incident under examination that can be managed. Three factors can be identified, i.e. the number of kilometers travelled by the train from the last maintenance depot (MD) operation, the number of kilometers a car can travel until the next depot/full repairs, number of days a car can travel until the next depot/full repairs. It is obvious that as the distance from the latest MD operation increases and the number of days and kilometers until the next scheduled repairs decreases, the probability of a defect occurring within a solebar grows. However, the frequency of MD operations is unlikely to change. At the same time, during MD operations, there is always a probability of a car being submitted to unscheduled repairs. For that reason, further on in this paper only the number of kilometers a car can travel until the next depot/full repairs, number of days a car can travel until the next depot/full repairs are considered as factors.

Given the above, the paper builds a hazard index of solebar fracture that depends on the number of kilometers travelled by train from the last MD operation and number of days from the last depot repairs/car manufacture. Based on that index, a risk matrix is constructed for the purpose of preventing solebar fracture.

Construction of the hazard index of solebar fracture

Let there be M records of depot repairs with the indication of required solebar repairs that contain the following information:

d_i, number of kilometers travelled by the train after the latest MD repairs, km;

s_i, number of kilometers travelled by the train from the latest depot/full repairs/car construction, km;

t_i, number of days from the latest depot/full repairs/car construction;

y_i, year of solebar manufacture.

As the quality of casting delivered by the same solebar manufacturer may vary from year to year, let us – out of all available records – choose those that pertain to solebars of a single manufacturer and same year of manufacture and further number and examine them. Let their total number be m. As it is difficult to manage the number of kilometers until the next MD repairs, this factor will not be further considered. As in cars of different types with solebars by the same manufacturer the number of kilometers until the next repairs may differ, we will consider the new value $\hat{s} = f(s)$ that characterizes the remaining number of kilometers until scheduled repairs and is calculated according to [13]. Similarly, we will introduce the value $\hat{t} = g(t)$ that characterizes the remaining number of days until scheduled repairs and is also calculated according to [13].

An accurate assessment of the risk of occurrence of a defect with subsequent solebar fracture requires estimating $P(\hat{s},\hat{t})$, i.e. the probability of a solebar requiring repairs when the number of days until repairs is $\hat{t}$ and kilometers until repairs is $\hat{s}$. Assessing function $P(\hat{s},\hat{t})$ requires the availability of observations data on the absence of defects in a solebar, i.e. it must be known, when exactly a defect occurred in a solebar. However, no such observations are made. In this context, the classical probability estimation in the form of a frequency, logistic or probit regression is impossible. The authors of [8] encountered a similar problem, when they proposed using impact indexes that allow identifying the factors that cause transportation incidents and are based only on transportation incident records. Similarly to [8], let us build a heuristic function

$$I(\hat{s},\hat{t}) \overset{\text{def}}{=} \frac{\sum_{i=1}^{m} \chi_{[\hat{s},+\infty]\times[0,+\infty]\cup[0,+\infty]\times[\hat{t},+\infty]}(s_i,t_i)}{N}, \quad (1)$$

where

$$\chi_A(z) = \begin{cases} 1, z \in A, \\ 0, z \notin A, \end{cases}$$

while N is the total number of solebars of a certain year of manufacture by a certain manufacturer that had been in operation for a year, that replaces function $P(\hat{s},\hat{t})$ that serves the analysis and reduction of the risk of solebar fracture. Function $I(\hat{s},\hat{t})$ characterizes the hazard of defect occurrence and, as a consequence, fracture of a specific solebar of a specific car and depends on the number of kilometers $\hat{s}$ and days $\hat{t}$ until the next repairs of such car. Function $I(\hat{s},\hat{t})$ is calculated as the relation of the number of cases when defects were identified in solebars with the number of days until repairs less than $\hat{t}$ or the number of kilometers until repairs less than $\hat{s}$ to the total number of solebars of a certain year of manufacture by a certain manufacturer that had been in operation for a year. Such choice of this function $I(\hat{s},\hat{t})$ is due to the fact that if, in the past, many failures/solebar fractures with the number of days until repairs less than $\hat{t}$ or number of kilometers until repairs less that $\hat{s}$ were identified, the hazard of solebar fracture is high.

Let us describe the properties of function $I(\hat{s},\hat{t})$:

(i) function $I(\hat{s},\hat{t})$ does not monotonically increase with respect to each of its parameters;

(ii) $I(+\infty,+\infty) = 0$;

(iii) $\forall \hat{s} \geq 0 \;\; \forall \hat{t} \geq 0 \;\; I(\hat{s},0) = I(0,\hat{t}) = \max_{\hat{s}\geq 0, \hat{t}\geq 0} I(\hat{s},\hat{t}) = m/N.$

Let us comment the above properties. Property (i) guarantees that as the number of days or kilometers until repairs decreases, the hazard of occurrence of defects does not decrease. Let us note that function $P(\hat{s},\hat{t})$ also does not monotonously increase with respect to each of its parameters, as the physical properties of a solebar do not improve with travelled kilometers. Property (ii) guaranties that after repairs the hazard will be equal to zero (it is assumed that repairs completely eliminate defects). Property (iii) guarantees that the maximum value of the hazard index is achieved at the maximum possible distance or maximum possible number of days without repairs.

Finding the ranges of (non)acceptable factor values

According to [1], a risk matrix is a tool that allows ranking and representing risks by identifying their frequencies and severity of consequences. Essentially, a risk matrix is a function that is defined over a space composed of the probability of a transportation incident and damage that enables executive decision-making aiming to reduce the risk of such transportation incident. Such function has four values and thus divides the probability space into four connected domains: range of negligible risk, range of acceptable risk, range of undesirable risk, range of critical risk. Each of those ranges characterizes the requirements for measures aimed at reducing the risk of incident. The boundaries of such ranges can be smooth [1] or nonsmooth [14]. Normally, such matrix is used in strategic planning and management, while day-to-day management requires more than the frequency of incidents and specific yearly damage. In this context, of relevance is the construction of ranges of (non)acceptable factor values that affect the frequency and damage caused by transportation incidents, as it was done in [14]. Let us introduce the following designations:

D_1 is the range of negligible risk;

D_2 is the range of acceptable risk;

D_3 is the range of undesirable risk;

D_4 is the range of critical risk.

First, let us construct such ranges based only on the hazard index (1):

$D_1 = \{(\hat{s},\hat{t}) : 0 \leq I(\hat{s},\hat{t}) < i_1\}$;

$D_2 = \{(\hat{s},\hat{t}) : i_1 \leq I(\hat{s},\hat{t}) < i_2\}$;

$D_3 = \{(\hat{s},\hat{t}) : i_2 \leq I(\hat{s},\hat{t}) < i_3\}$;

$D_4 = \{(\hat{s},\hat{t}) : i_3 \leq I(\hat{s},\hat{t})\}$,

where $i_1<i_2<i_3$ are certain numbers. Such numbers can be defined based on economic considerations. Let c_1 be the average cost of depot/full repairs, c_2 be the average loss caused by car idling during repairs, while c_3 is the average damage caused by car derailment/freight train crash due to solebar fracture. It is obvious that if for a certain point $(\hat{s},\hat{t})$ the risk of solebar fracture exceeds the cost of repairs and damage caused by car idling, such point must fall within the range of undesirable or critical risk. In this context, we can assume that $i_1 = \frac{1}{2}\frac{c_1+c_2}{c_3}$, $i_2 = \frac{c_1+c_2}{c_3}$, $i_3 = \frac{3}{2}\frac{c_1+c_2}{c_3}$.

Let us note that another approach to the definition of ranges of (non)acceptable factor values involves locking certain parameters of ranges (for instance, the area) and searching for the best such ranges in plane $\hat{t}O\hat{s}$. For that purpose, we will build ranges of (non)acceptable factor values as shown in Fig. 1.

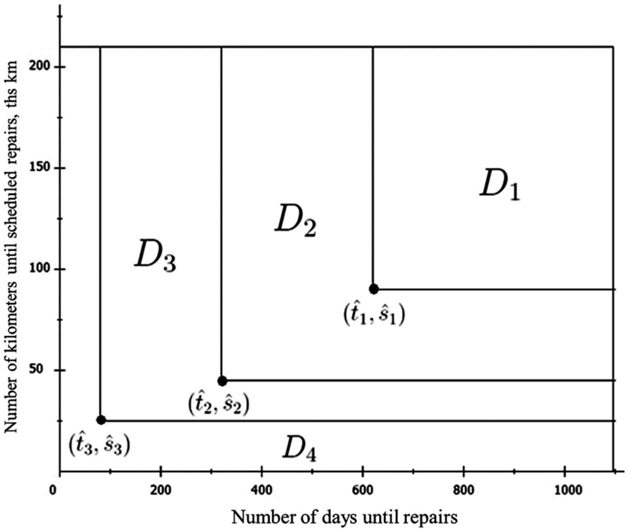

Fig. 1. Special form of the diagram of (non)acceptable factor values

Whereas

$$D_1 = (\hat{s}^1, 210000] \times (\hat{t}^1, 1095],$$

$$D_2 = (\hat{s}^2, 210000] \times (\hat{t}^2, 1095] \cap D_1,$$

$$D_3 = (\hat{s}^3, 210000] \times (\hat{t}^3, 1095] \cap D_1 \cap D_2,$$

$$D_4 = [0, 210000] \times [0, 1095] \cap D_1 \cap D_2 \cap D_3,$$

where values $\hat{s}^1 \geq \hat{s}^2 \geq \hat{s}^3$, $\hat{t}^1 \geq \hat{t}^2 \geq \hat{t}^3$ are to be identified.

In order to identify $\hat{s}^j$, $\hat{t}^j$, or essentially the boundaries of sets D_j, let us note that there is an unlimited number of sets D_j of identical area. Every such set is characterized by a certain value of maximum hazard index within it. Accordingly, we will search for such sets D_j as to

$$S_{D_1} \geq s_1, S_{D_1 \cup D_2} \geq s_2, S_{D_1 \cup D_2 \cup D_3} \geq s_3,$$

where $s_1 < s_2 < s_3$ are certain predefined parameters. Such parameters can be specified, for instance, based on geometric constraints: $s_1 = \frac{1}{4}S$, $s_2 = \frac{2}{4}S$, $s_3 = \frac{3}{4}S$, where $S = S_{D_1 \cup D_2 \cup D_3 \cup D_4}$. On optimal sets D_j the maximum value of the hazard index must be the lowest out of all the remaining sets of the same area. Given the above, the problem of finding parameters $\hat{s}^1$, $\hat{t}^1$ becomes as follows

$$\max_{\hat{s}^1 < \hat{s} \leq 210000, \hat{t}^1 < \hat{t} \leq 1095} I(\hat{s}, \hat{t}) \to \min_{\hat{s}^1 \geq 0, \hat{t}^1 \geq 0}. \tag{2}$$

with constraints

$$(210000 - \hat{s}^1)(1095 - \hat{t}^1) \geq s^1. \tag{3}$$

Problem (2) subject to constraint (3) is a problem of nonlinear programming, which complicates the solution. Let us therefore simplify the task by introducing integer $\delta_i \in \{0,1\}$ variables, $i = \overline{1, M}$. Variable δ_i equals to zero if in the i-th record out of m considered it is stated that $\hat{s}^1 \geq \hat{s}_i$ and $\hat{t}^1 \geq \hat{t}_i$, and to one, if otherwise. Using variables δ_i, we conclude that problem (2) subject to constraint (3) comes down to problem

$$\sum_{i=1}^{m} \delta_i \to \min_{210000 \geq \hat{s}^1 \geq 0, 1095 \geq \hat{t}^1 \geq 0, \delta_i \in \{0,1\}} \tag{4}$$

with constraints

$$(1 - \delta_i)\hat{s}_i \leq \hat{s}^1, i = \overline{1, m}, \tag{5}$$

$$(1 - \delta_i)\hat{t}_i \leq \hat{t}^1, i = \overline{1, m} \tag{6}$$

and constraint (3). Let s_1^* and t_1^* be points that define the boundary of set D_1 obtained out of the solution of problem

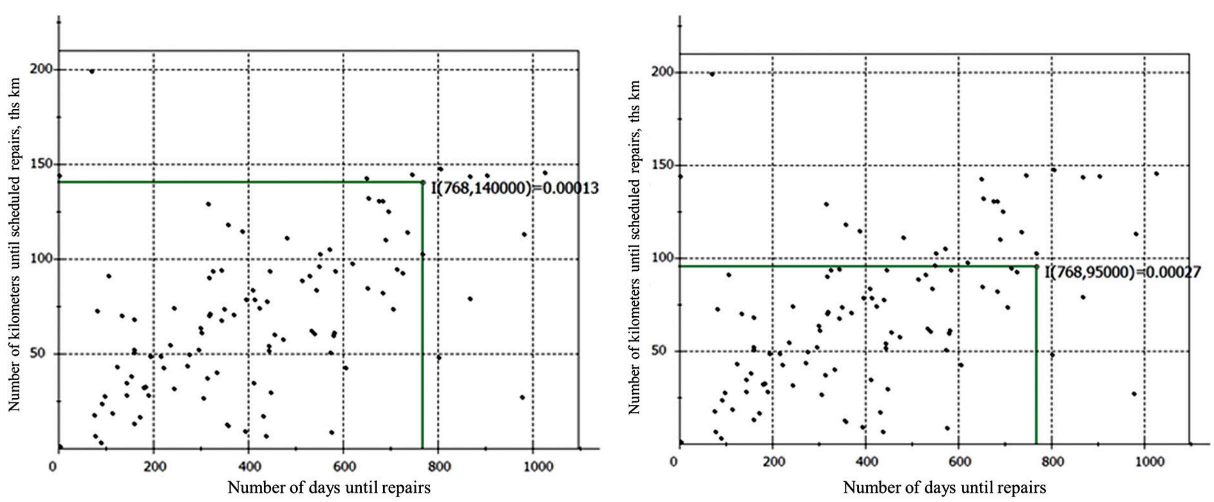

Figure 2. Values of hazard index $I(\hat{s}, \hat{t})$ under N=100000

Table 1. Information on the number of kilometers until repairs

Number of km until repairs	143548	665	198865	17278	6051	72373	2501	23317	27410	90631	18460	42994
Number of days until repairs	2	4	71	77	79	83	90	92	98	106	114	125
Number of km until repairs	69673	34066	27656	37715	50458	67534	12714	51974	16367	31546	32384	27573
Number of days until repairs	135	144	144	154	160	160	161	161	172	180	184	191
Number of km until repairs	48288	48072	42490	54148	31241	73995	43001	49288	51872	63043	60743	26186
Number of days until repairs	195	216	222	236	245	245	272	276	297	300	303	306
Number of km until repairs	36612	128533	69670	89674	70884	93159	93423	39596	93873	67490	73325	12043
Number of days until repairs	314	317	318	318	320	327	327	335	344	345	351	356
Number of km until repairs	117655	11877	70430	114233	8977	78327	83145	34292	78273	73877	16865	6496
Number of days until repairs	358	359	370	389	394	396	410	412	414	425	432	438
Number of km until repairs	77204	51497	53710	93079	29083	59903	57380	110608	88367	90629	61746	60260
Number of days until repairs	441	444	445	447	449	456	475	483	515	530	535	541
Number of km until repairs	83401	95796	102241	104506	50167	8145	59087	60796	93256	42433	97020	142347
Number of days until repairs	545	551	553	573	574	577	581	583	585	606	620	650
Number of km until repairs	84005	131848	130384	81517	130416	109896	124811	73301	94070	92140	113741	144321
Number of days until repairs	652	654	676	684	685	691	697	707	715	726	736	747
Number of km until repairs	102477	47759	147077	78562	143361	143654	26937	112502	145128			
Number of days until repairs	768	803	806	869	869	904	979	983	1026			

(4) subject to constraints (3), (5)–(6). Then, similarly, in order to find the boundaries of set D_2 we must solve problem

$$\sum_{i=1}^{m}\gamma_i \to \min_{s_1^*\ge \hat{s}^2\ge 0,\, t_1^*\ge \hat{t}^2\ge 0,\, \gamma_i\in\{0,1\}} \qquad (7)$$

with constraints

$$(1-\gamma_i)\hat{s}_i \le \hat{s}^2,\, i=\overline{1,m}, \qquad (8)$$

$$(1-\gamma_i)\hat{t}_i \le \hat{t}^2,\, i=\overline{1,m}, \qquad (9)$$

$$(210000-\hat{s}^2)(1095-\hat{t}^2)\ge s^2. \qquad (10)$$

Let s_2^* and t_2^* be points that define the boundary of set D_2 obtained out of the solution of problem (7) subject to constraints (8)–(10). In order to find the boundaries of set D_3 we must solve problem

$$\sum_{i=1}^{m}æ_i \to \min_{s_2^*\ge \hat{s}^3\ge 0,\, t_2^*\ge \hat{t}^3\ge 0,\, æ_i\in\{0,1\}} \qquad (11)$$

with constraints

$$(1-æ_i)\hat{s}_i \le \hat{s}^3,\, i=\overline{1,m}, \qquad (12)$$

$$(1-æ_i)\hat{t}_i \le \hat{t}^3,\, i=\overline{1,m}, \qquad (13)$$

$$(210000-\hat{s}^3)(1095-\hat{t}^3)\ge s^3. \qquad (14)$$

Let t_3^*, s_3^* be the solution of problem (11) subject to constraint (12)-(14).

Problem (4) subject to constraints (3), (5)-(6), problem (7) subject to constraints (8)-(10), problem (11) subject to constraints (12)-(14) are problems of mixed integer programming with quadratic constraints and can be solved using Opti Toolbox in Matlab. Let us note that the search

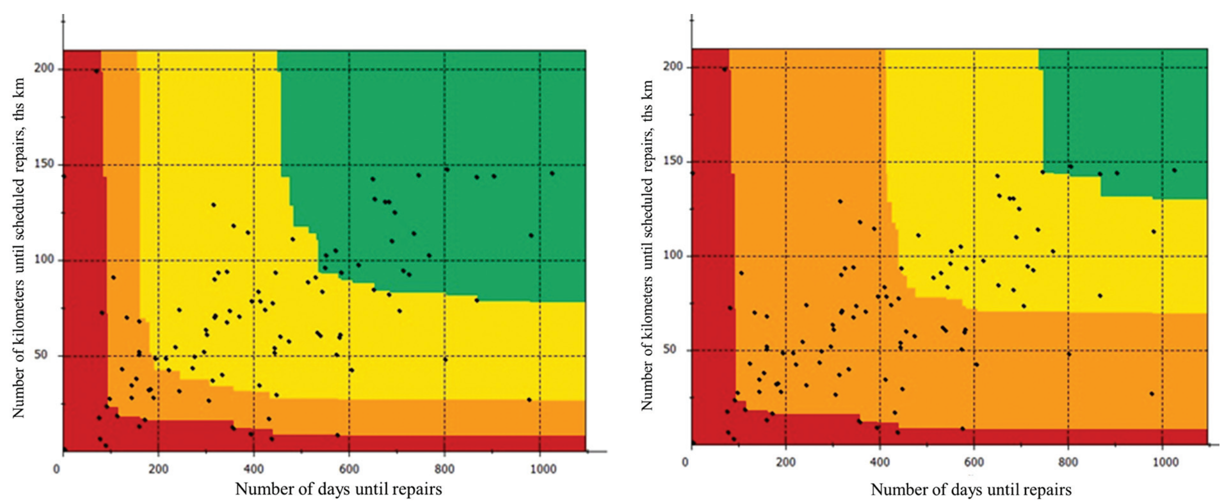

Fig. 3. Diagram of (non)acceptable factor values under i_1=0,0004, i_2=0,0009, i_3=0,001 (left) and i_1=0,0001, i_2=0,0005, i_3=0,001 (right)

for the boundaries of set D_j can be ruled not by the area of the corresponding set, but, for instance, the length of one of the boundaries of such set.

An example

Let there be 105 annual cases when a defect was detected in a solebar, while N=100000. Table 1 shows data on the number of days to scheduled repairs and number of kilometers until scheduled repairs in such cases.

Using the data given in Table 1, let us deduct the value of the hazard index in some points of plane $\hat{t}O\hat{s}$ (Figure 2).

Now, let us construct the ranges of (non)acceptable factor values for various parameters i_1, i_2, i_3 (Fig. 3).

As it follows from Figure 3, changes in the values of parameters i_1, i_2, i_3 significantly affect the ranges of (non)acceptable factor values that contribute to solebar fracture.

By specifying $s_1 = 5 \cdot 10^7$, $s_2 = 1,25 \cdot 10^8$, $s_3 = 1,75 \cdot 10^8$ we obtain $t_1^* = 620,27$, $s_1^* = 104561,9$, $t_2^* = 297$, $s_2^* = 51974$, $t_3^* = 114$, $s_3^* = 27410$ and the next range of (non)acceptable factor values that contribute to solebar fracture (Fig. 4).

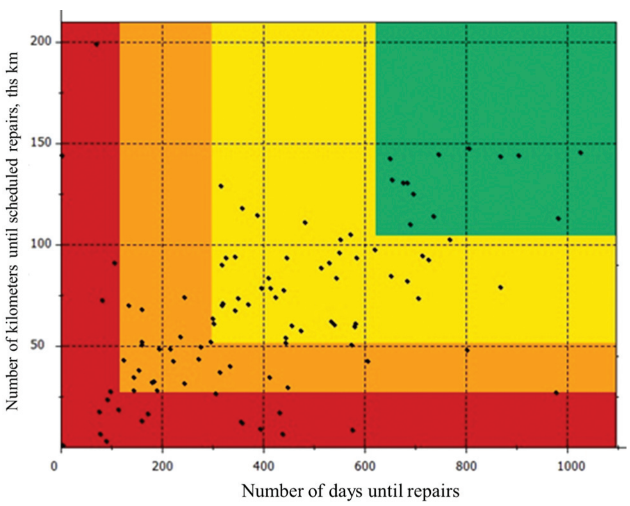

Fig. 4. Diagram of (non)acceptable factor values constructed based on the solution of the optimization problems

Conclusion

The paper examined the problem of identification of the ranges of (non)acceptable factor values contributing to bogie solebar fracture. For that purpose, a hazard index was built that depends on the number of days and kilometers until the next scheduled depot/full repairs. Based on that index, two methods of definition of ranges of (non)acceptable factor values were proposed. The first one was completely based on the values of the hazard index. As the absolute value of the hazard index is not a direct estimation of the probability of solebar fracture, a second method was proposed, that involved identifying the area of a certain range of (non) acceptable values and out of all sets with identical areas such was selected that had the lowest values of maximum hazard index.

References

[1] GOST 33433-2015. Functional safety. Risk management on railway transport. Moscow: Standartinform; 2016 [in Russian].

[2] Novozhilov EO. Guidelines for construction of a risk matrix. Dependability 2015;3:80-86.

[3] Liu X, Saat MR, Qin X, Barkan CPL. Analysis of U.S. freight-train derailment severity using zero-truncated negative binomial regression and quantile regression. Accident Analysis and Prevention 2013;59:87-93.

[4] Bagheri M, Saccomanno F, Chenouri S, Fu LP. Reducing the threat of in-transit derailments involving dangerous goods through effective placement along the train consist. Accident Analysis and Prevention 2011;43:613-620.

[5] Zamyshliaev AM, Ignatov AN, Kibzun AI, Novozhilov EO. Functional dependency between the number of wagons derailed due to wagon or track defects and the traffic factors. Dependability 2018;18(1):53-60.

[6] Anderson RT, Barkan CPL. Derailment probability analysis and modeling of mainline freight trains. Proceedings of the 8th International Heavy Haul Conference, International Heavy Haul Association, Rio de Janeiro; 2005. p. 491-497.

[7] Schafer DH. Effect of Train Length on Railroad Accidents and a Quantitative Analysis of Factors Affecting Broken Rails. MS thesis. University of Illinois at Urbana–Champaign; 2006.

[8] Zamyshliaev AM, Kan YuS, Kibzun AI, Shubinsky IB. Statisticheskaya otsenka opasnosti vozniknoveniya proisshestviy na zheleznodorozhnom transporte [Statistical evaluation of accident hazard in railway transportation]. Dependability 2012;2:104-117 [in Russian].

[9] Lukin VV, Belsky AO. Calculation of the side frame and bolster freight car bogie finite element method. The Trans-Siberian Bulletin 2013;1(13):7-12 [in Russian].

[10] Galiev II, Nikolaev VA, Sergeyev BB, Samohvalov EA, Loucks DY. The reasons for violations of traffic safety of freight cars in operation. The Trans-Siberian Bulletin 2013:3(15):133-141 [in Russian].

[11] Kim JS, Shin KB, Yoon HJ, Lee WG. Durability evaluation of a composite bogie frame with bow-shaped side beams. Journal of Mechanical Science and Technology 2012;26(2):531-536.

[12] Method of categorization of freight cars as having reduced operational safety in terms of dependability and safety of cast parts of bogies (solebars). Approved by the Commission for Rail Traffic Safety of the Railway Transportation Council. Proceedings no. 1 of June 6-7, 2013. Approved by the Commission of Authorized Rolling Stock Specialists of Railway Administrations of the Railway Transportation Council. Proceedings no. 55 of February 19-21, 2013.

[13] Regulations on the service and repair system of freight cars cleared for operation in public tracks on inter-

national routes. Approved by the Proceedings of the Fifty-Seventh Meeting of the Railway Transportation Council of the Members of the Commonwealth of Independent States, October 16-17, 2012.

[14] Kibzun AI, Ignatov AN. Metodika organizatsii profilaktiki transportnogo proisshestviya [Method of organization of transportation accident prevention]. In: Proceedings of the Second Science and Engineering Conference Intelligent Control Systems in Railway Transportation ISUZhT 2013; 2013. p. 177-179.

About the authors

Igor B. Shubinsky, Doctor of Engineering, Professor, Deputy Director of Integrated Research and Development Unit, JSC NIIAS, Moscow, Russian Federation, phone: +7 (495) 786-68-57, e-mail: igor-shubinsky@yandex.ru

Alexey M. Zamyshliaev, Doctor of Engineering, Deputy Director General, JSC NIIAS, Moscow, Russian Federation, phone: +7 495 967 77 02, e-mail: A.Zamyshlaev@vniias.ru

Alexey N. Ignatov, Candidate of Physics and Mathematics, Moscow Aviation Institute, Moscow, Russian Federation, phone: +7 (906) 059 50 00, alexei.ignatov1@gmail.com

Andrey I. Kibzun, Doctor of Physics and Mathematics, Professor, Moscow Aviation Institute, Head of Department, Moscow, Russian Federation, phone: +7 (499) 158 45 60, e-mail: kibzun@mail.ru

Evgeny O. Novozhilov, Candidate of Engineering, Head of Unit, JSC NIIAS, Moscow, Russian Federation, phone: +7 495 967 77 02, e-mail: eo.novozhilov@vniias.ru.

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