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Estimation of risks related to stop signal passed by shunting loco or passenger train[1]

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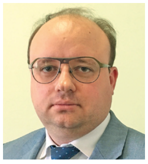
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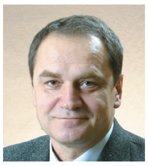
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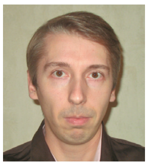
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Purpose *is to develop a procedure for estimating risks that occur as the result of a signal passed at danger (SPAD) by a shunting or train locomotive, as well as to develop recommendations for reducing risks of train collisions when performing shunting movement at a station.* **Methods.** *In oder to achieve the stated purpose, it is necessary to define the average number of points burst open by shunting locomotives without derailment, as well the average number of derailments of shunting locomotives per year. The availabile statistics are used to calculate the average amount of damage from one collision, from a point burst open without subsequent derailment, as well as a point burst open with subsequent derailment. To calculate the average number of damage as the result of a certain injury caused by collision, different types of injuries are considered. Injuries are classified by the level of consequences that are calculated in money terms using a minimum wage. To consider the variability in choosing a route, as well as to obtain the probability of a passenger train collision when passing through a station, the formula of total probability is used. To obtain the probabiity of at least one collision per year, the formula of multiplication of probability is used. To obtain the average number of points burst open and derailments, it is necessary to define the total number of points that are crossed by shunting locomotives at a station per point, the formula of multiplication of probability is used. To define the level of risk caused by the respective unfavorable event, it is necessary to construct risk matrices to define whether there is a necessity in immediate actions to reduce a risk level.* **Results.** *We have studied the task of calculation of unfavorable events caused by stop signal violation by a passenger train or a shunting locomotive. It provides the formulas used to calculate the probability of at least one collision of a passenger train at a station per year, the average number of points burst open by a shunting locomotive without subsequent derailment, as well as the average number of derailments per year. It also contains the formulas used to calculate the average damage from unfavorable events. Risk matrices for all unfavorable events have been constructed. The article gives the example of application of the obtained results which is based on hypothetical data, real data and expert analysis.* **Conclusion.** *Using the developed procedure we demonstrated its practical functionality. It was obtained that for the set of input data which were analyzed, there should not be any measures taken to reduce risks occurred as the result of points burst open and derailments at the station under consideration. At the same time the collision risk is in the orange area – the area of undesirable risks, and therefore, the measures on risk reduction should be taken. And a quantitative value of the risk occurred as the result of points burst open turns out to be higher than that of the collision risk. The matter is that in case of collision JSC RZD bears additional reputational expenses, doubled by the fact that a derailment occurs at a station with large numbers of people.*

Keywords: *probability of train collision, bursting open of point, derailment, damage, risk matrix.*

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Introduction

In case of signal violation by a shunting locomotive several unfavorable events are possible: the collision of a shuntng locomotive with a passanger or freight train, bursting open of a point without a derailment of a shunting locomotive, derailment of a shunting locomotive. Each of these events occurs with a certain rate or probability. And each of these events is specified by a certain damage. That is why it is very important to perform quantitative estimation of risks to maintain their tolerable level [1].

Paper [2] describes the calculation of probability of a side collision of a shunting locomotive with a passenger train, when one of the trains passes a signal at danger on route of a passenger train, where a route is a set of points that are crossed by a passenger train when passing through a station. Isolated switch is a switch at which there could be no collision caused by a signal violation, non-isolated switch is a switch where there could be a collision. However, when passing through a station, a passenger train has several possible routes thay are used with a certain rate.

In this paper the formula of total probability is used to consider the variability in choosing a route, as well as to obtain the probability of at least one passenger train collision when passing through a station. To obtain the probability of at least one collision per year, the formula of multiplication of probability is used. To obtain the average number of points burst open and derailments, it is necessary to define the total number of points that are crossed by shunting locomotives at a station per year, and to define the probability of bursting open of a point and derailment at one crossing of a switch, the formula of multiplication of probability is used.

We consider the accidents at a railway station and it means that at the collision of a passenger train with a shunting locomotive there may be fatalities at a station itself, as well as on a passenger train. That is why in this paper the average damage from one collision of a passenger train with a shunting locomotive is composed of the damage from the defects of railway infrastructure: railway bed, cars and etc., and of the damage from the consequences of fatalities that is quantitatively expressed based on [1]. Damage from bursting open of points and derailments is formed based on the consequences of defects of railway infrastructure, and fatalities here is unlikely, as shunting works are carried out at a low speed. Risk matrices are constructed based on the approach described in [1].

Calculation of probability of at least one collision of a shunting locomotive with a passenger train per year

According to the schedule received from AS Express for a time period under consideration (a year), let us assign the numbers for passenger trains crossing a station under consideration on a first-come basis, i.e. the first coming train is given number 1, the second one is 2, etc. Let us consider the *i*-th passenger train from this row.

Let A_i be a collision of a passenger train with number *i* when it is passing through a station, and $P(A_i \mid R_k)$ be a probability of the collision of a passenger train with number *i* when it is crossing a station by routeR_k, where k=1, …, K, and K is the total number of possible routs for train with number *i*. Then a probability of the collision of a passenger train with number *i* when it is passing through a station is [2]

$$P(A_i) = \sum_{k=1}^{K} P(A_i \mid R_k) P(R_k),$$

where $P(R_k)$ is a probability of route R_k that is defined by formula

$$P(R_k) = \frac{m_{R_k}}{n},$$

where m_{R_k} is the number of passenger trains with number *i* passed by route R_k, and *n* is the totatl number of passenger trains with number *i* passed through a station during the period of observation. If there are no data about last passings of a passenger train with number *i* through the station, and the monitoring of traffic is not possible, then the probability of use of all routes can be equally probable, i.e.

$$P(R_k) = \frac{1}{K}.$$

Probability $P(A_i \mid R_k)$ is defined using the following formula derived in [2],

$$P(A_i \mid R_k) = P(A_{k:1}) + (1 - P(A_{k:1})) \cdot P(A_{k:2}) + \\ +(1 - P(A_{k:1})) \cdot (1 - P(A_{k:2})) \cdot P(A_{k:3}) + \ldots,$$

where $P(A_{k:j})$ is a probability of collision of the train with number *i*, passing through the station by route R_k, on the *j*-th point. Whereas $P(A_{k:j})$ is calculated by formula

$$P(A_{k:j}) = \begin{pmatrix} \lambda_{sh}\left(\dfrac{l_p}{v_p} + \dfrac{l_{sh}}{v_{sh}}\right)(P_{sh}(1+P_p) + P_p) + \\ +\lambda_s P_p \tau_s + \lambda_{sh} P_{sh} P_{ps} \tau_{ps} \end{pmatrix} \cdot k_s,$$

where k_s is the coefficient of a switch's isolation (1 if a switch is non-isolated, and 0 if a switch is isolated);

λ_{sh} is the rate of shunting locomotives passing through the *j*-th switch in the direction under which a side collision is possible (for simplicity we can assume that $\lambda_{sh} = \tilde{\lambda}_{sh} / 4$, where $\tilde{\lambda}_{sh}$ is the total rate of shunting locomotives passing through the *j*-th switch in all directions);

λ_s is the rate of shunting groups that stop at the *j*-th switch, which did not violate safety when passing through the switch;

τ_s is the average time of a shunting group being at the *j*-th switch, which did not violate safety when passing through a switch, provided there was a stop at a switch;

l_p is the average length of a passenger train;

v_p is the average speed of a passenger train passing through a station;

l_{ch} is the average length of a shunting group;

v_{sh} is the average speed of a shunting group passing through a station;

P_p is the probability of signal violation by a passenger train;

P_{ps} is the probability of stop of a passenger train at a switch;

τ_{ps} is the average time of standing of a passenger train at a switch;

P_{sh} is the probability of signal violation by a shunting locomotive calculated by formula [2]

$$P_{\text{sh}} = P_{two} \cdot P_{sh(two)} + (1 - P_{two}) \cdot P_{sh(one)},$$

where P_{two} is the probability of assigning a shunting locomotive crew to a driver and his assistant;

$P_{sh(two)}$ is the probability of signal violation by a shunting locomotive driver when working with an assistant driver;

$P_{sh(one)}$ is the probability of signal violation by a shunting locomotive driver when working without an assistant driver ("driver-only operation").

Let I of trains pass through a station per year in different directions. Let us consider the i-th train from this row, i=1, …, I. If it is coordinated with probability $P(A_i)$ of a collision when passing through a station, the probability of collision of at least one train from I trains is [2]

$$P(A_{year}) = P(A_1 + A_2 + \ldots + A_I) = 1 - \prod_{i=1}^{I}(1 - P(A_i)). \quad (1)$$

Calculation of the average number of points burst and derailments of a shunting locomotive per year

Let L be the total number of locomotives working at a station, and N_l is the average number of switches crossed per hour by a shunting locomotive with number l. Then the total number N_{year} of switches that are crossed by shunting locomotives at a station is calculated by formula

$$N_{year} = 365 \cdot 24 \cdot \sum_{l=1}^{L} N_l. \quad (2)$$

Let us consider several accidents: A_{sh} is SPAD by a shunting group, A_{bop} is a point burst open by a shunting group after signal violation, A_{drl} is derailment after a point burst open. Let the following probabilities be known: the probability of a point burst open after SPAD P_{bop} and the probability of derailment after a point burst open P_{drl}. Then the probability of a point burst open with a subsequent derailment of the rolling stock is defined by formula of multiplication of probabilities [3]

$$P_{bop(drl)} = P(A_{sh} A_{bop} A_{drl}) = P_{sh} P_{bop} P_{drl}, \quad (3)$$

and the probability of a point burst open without a subsequent derailment of the rolling stock is defined using the same formula

$$P_{bop(no\ drl)} = P(A_{sh} A_{bop} \overline{A}_{drl}) = P_{sh} P_{bop}(1 - P_{drl}). \quad (4)$$

Due to the fact that at each switch crossing, derailment or bursting open of a point may occur, the number of points burst open without a subsequent derailment is a random variable with a binomial distribution with parameters N_{year} and $P_{bop(no\ drl)}$, and the number of derailed trains is a random variable with a binomial distribution with parameters N_{year} and $P_{bop(drl)}$. That is why the average number of points burst open without a subsequent derailment is defined by multiplicating the number of cheks by the number of "successes", i.e. is defined by formula [3]

$$\overline{N}_{year}^{bop} = N_{year} \cdot P_{bop(no\ drl)}, \quad (5)$$

and the average number of points burst open with a subsequent derailment is defined by formula

$$\overline{N}_{year}^{drl} = N_{year} \cdot P_{bop(drl)}. \quad (6)$$

Determination of the average damage from unfavorable events

Let us firstly consider the damage that occur after derailment. Damage caused by the derailment at the station consists of four parts. The first part is a material damage that occurs as the result of the destruction of cars, tracks, station infrastructure, freight, etc. These types of damage are recorded in the protocols of traffic accidents and they can be calculated as average variables. The second part of damage is a damage connected with possible fatalities or injuries.

Let there be M_{col} of the collision protocols. Then the average material damage calculated by all accidents is defined by formula

$$\overline{C}_1 = \frac{\sum_{i=1}^{M_{col}} C_{col}^i}{M_{col}}, \quad (7)$$

where C_{col}^i is the material damage caused by the collision recorded in the i-th protocol.

Let us define the average damage connected with possible fatalities or injuries. We shall break all injuries occurred in case of an accident, into classes: moderate injuries; serious injuries; fatalities. Let N_{fat}^i is the number of fatalities in the i-th collision, N_{si}^i is the number of people with serious injuries in the i-th collision, N_{mi}^i is the number of people with moderate injuries in the i-th collision, C_{mi} is the damage caused by one moderate injury, C_{si} is the damage caused by one serious injury, C_{fat} is the damage caused by one fatality. Therefore, average damage caused by probable fatalities or injuries at one collision is

$$\overline{C}_2 = C_{fat} \frac{\sum_{i=1}^{M_{col}} N_{fat}^i}{M_{col}} + C_{si} \frac{\sum_{i=1}^{M_{col}} N_{si}^i}{M_{col}} + C_{mi} \frac{\sum_{i=1}^{M_{col}} N_{mi}^i}{M_{col}}.$$

Variables C_{mi}, C_{si}, C_{fat} shall be found based on [1]. A fatality is equated with material damage that is 5000 of minimum wage, a serious injury is equated with material damage that is 1000 of minimum wage, a moderate injury is equated with material damage that is 500 of minimum wage. From January 1, 2016 minimum wage is 6204 RUB. [4]. Therefore,

C_{mi}=6,204·500=3102 kRUB.,

C_{si}=6,204·1000=6204 kRUB.,

C_{fat}=6,204·5000=31020 kRUB.

Therefore,

$$\overline{C}_2 = 3102 \cdot \frac{\sum_{i=1}^{M_{col}} N_{mi}^i}{M_{col}} + 6204 \cdot \frac{\sum_{i=1}^{M_{col}} N_{si}^i}{M_{col}} + 31020 \cdot \frac{\sum_{i=1}^{M_{col}} N_{fat}^i}{M_{col}} = = \frac{1}{M_{col}} \left(3102 \cdot \sum_{i=1}^{M_{col}} N_{mi}^i + 6204 \cdot \sum_{i=1}^{M_{col}} N_{si}^i + 31020 \cdot \sum_{i=1}^{M_{col}} N_{fat}^i \right). \quad (8)$$

As the total damage caused by collisions $\overline{C}_{col}$ is composed of the material damage and the damage from injuries then

$$\overline{C}_{col} = \overline{C}_1 + \overline{C}_2 = \frac{\sum_{i=1}^{M_{col}} C_{col}^i}{M_{col}} + + \frac{1}{M_{col}} \left(3102 \cdot \sum_{i=1}^{M_{col}} N_{mi}^i + 6204 \cdot \sum_{i=1}^{M_{col}} N_{si}^i + 31020 \cdot \sum_{i=1}^{M_{col}} N_{fat}^i \right). \quad (9)$$

Let us now consider the damage that occurs in case of bursting open of points and derailments. Let there be M_{bop} of protocols of bursting open of points without derailments that fixed certain damage. Then the average material damage calculated by all accidents is defined by formula

$$\overline{C}_{bop} = \frac{\sum_{i=1}^{M_{bop}} C_{bop}^i}{M_{bop}}, \quad (10)$$

where C_{bop}^i is the material damage caused by bursting open of a point fixed in the *i*-th protocol. Similarly, if there are M_{drl} protocols of bursting open of points with a subsequent derailment, that fixed certain damage, the average material damage calculated by all accidents is defined by formula

$$\overline{C}_{drl} = \frac{\sum_{i=1}^{M_{drl}} C_{drl}^i}{M_{drl}}, \quad (11)$$

where C_{drl}^i is the material damage caused by bursting with derailment fixed in the *i*-th protocol.

Estimating the risk value

To define the level of risk after the analysis of frequencies and analysis of consequences, quantitative and qualitative estimation is performed. Generally, according to [1] the risk is a certain combination of two values – the probability (or frequency) of an undesirable event P(A) and its consequences C(A). In this paper we shall consider a quantitative value of risk as the multiplication of probability (frequency) by the damage. Thus, the risk caused by collisions as the result of signal violation by one of the trains is defined by formula

$$R_{col} = P(A_{year}) \cdot \overline{C}_{col}, \quad (12)$$

where $P(A_{year})$ is calculated by formula (1), and $\overline{C}_{col}$ is calculated by formula (9) respectively. Risks caused by bursting open of a point without a subsequent derailment are defined by formulas

$$R_{bop} = \overline{N}_{year}^{bop} \cdot \overline{C}_{bop}, \quad (13)$$

$$R_{drl} = \overline{N}_{year}^{drl} \cdot \overline{C}_{drl}, \quad (14)$$

where $\overline{N}_{year}^{bop}$, $\overline{N}_{year}^{drl}$, $\overline{C}_{bop}$, $\overline{C}_{drl}$ are defined by formulas (5), (6), (10), (11) respectively.

Constructing risk matrices

The results of risk estimation can be represented using a risk matrix which has a form of cell table that represents the combination of the frequency of an undesirable event and the severity of its consequences (figure 1), and makes it possible to provide authorized decision-makers with visual information on risk levels for event in question. The form (parameters) of a matrix depends on the field of its application.

A risk matrix is constructed as follows:

— on the vertical axis, the frequencies (probabilities) of the event are calculated. They are represented in accordance with an accepted (normally, logarithmic) scale of frequencies;

— on the horizontal axis, the degrees of the event's consequences are calculated. They are represented in accordance with an accepted (normally, logarithmic) scale of severity of consequences;

— the risk level for each matrix cell is defined and rated.

The main problem when constructing the risk matrices is the correct definition of boundaries for the matrix cells. One and the same cell contains the points with different values of risk, and some points refer, for instance, to the field of "tolerable" risk, and some points refer to the field of "undesirable". In the most unfavorable case, a cell may be divided into two segments of equal space, this preventing us from precisely defining what range of risk values most of points allocated inside this cell belong to.

Probability levels	**Risk levels**			
Frequent	Tolerable	Undesirable	Intolerable	Intolerable
Probable	Tolerable	Undesirable	Undesirable	Intolerable
Occasional	Tolerable	Tolerable	Undesirable	Intolerable
Remote	Negligible	Tolerable	Undesirable	Undesirable
Improbable	Negligible	Negligible	Tolerable	Undesirable
Incredible	Negligible	Negligible	Tolerable	Undesirable
	Insignificant	Marginal	Critical	Catastrophic
	Level of severity of consequences			

Fig. 1. Form of risk matrix

Article [5] offers a procedure to define the boundaries for the cells of a risk matrix, which helps to solve this problem.

Standard [1] recommends a scale with 6 levels (gradations) as a typical probability scale. A scale with 4 levels (gradations) is recommended as a typical scale of consequences.

Let us choose the boundaries for the risk matrix cells in accordance with approach described in [1].

Minimum and maximum values of the probability are assumed 0 and 1 from the condition of classifying an accident event. The most unfavorable event (frequent) is set by a boundary 0,5, i.e. a traffic accident rather occurs than does not occur. Boundaries for an improbable and remote event are chosen in the logarithmic scale in such a way, so that they are an order less, i.e. 0,05 and 0,005 respectively. Value 0,05 is the most common for the probability of a random event. Intermediary boundaries between already set values are chosen in the logarithmic scale in such a way, so that these cells are nearly equal. That is why the boundary that indicates a transition from a probable event to an occasional event is set as 0,15 (approx. three times less than 0,5 and three times more than 0,05). The same is for the boundary of transition form a remote event to an improbable event.

Levels of probabilities for collisions are listed in table 1.

If instead of the probability of an undesired event we estimate the average frequency of a dangerous case, Table A.5 in [1] offers the following frequency levels. For our case this variant of choosing the level is often justified as well.

Boundaries for the severity of consequences shall be chosen based on the damage that will be caused by a fatality. According to Table 2 of GOST R 54505, catastrophic risk occurs in case of one or more fatalities, which is 5000 of minimum wage = 30000 kRUB. Two other boundaries are chosen in the logarithmic scale and differ by one and two orders, respectively (table 3).

Table 1 – Levels of probabilities for collisions

Probability levels	**Probability of events per year, *P(A)***	**Description**
Frequent	$P(A)>0,5$	Hazard is permanent
Probable	$0,15\leq P(A)<0,5$	Frequent occurrence of a dangerous event is expected
Occasional	$0,05\leq P(A)<0,15$	Repeated occurrence of a hazardous event is expected
Remote	$0,015\leq P(A)<0,05$	There is a probability that an event will sometimes occur throughout an object's life cycle
Improbable	$0,005\leq P(A)<0,015$	A hazardous event is assumed to occur in exceptional case
Incredible	$P(A)\leq 0,005$	A hazardous event is assumed not to occur

Table 2 – Levels of frequencies

Levels of frequency	**Value, *P*(A)*, 1/per year**	**Description**
Frequent	$P^*(A)\geq 100$	Hazard is permanent
Probable	$40\leq P^*(A)<100$	Frequent occurrence of a hazardous event is expected
Occasional	$15\leq P^*(A)<40$	Repeated occurrence of a hazardous event is expected
Remote	$6\leq P^*(A)<15$	There is a probability that an event will sometimes occur throughout an object's life cycle
Improbable	$2\leq P^*(A)<6$	A hazardous event is assumed to occur in exceptional case
Incredible	$P^*(A)<2$	A hazardous event is assumed not to occur

Table 3 – Levels of severity of consequences

Levels			
Insignificant	**Marginal**	**Critical**	**Catastrophic**
less than 300 kRUB.	from 300 to 3000 kRUB.	from 3000 to 30000 kRUB.	More than 30000 kRUB.

Let us rate the matrix cells. In this regard let us multiple the upper values of frequency and severity of consequences, corresponding to each cell, and, depending on the result, let us assign a category to it (figures 2 and 3).

Example

According to the data of the Automated System of Traffic Safety (ASRB) for the period 2011-2015 there were 64 traffic accidents of collision, with recorded damage (its amounts are listed in Table 4), as well as 78 traffic accidents with no fixed damage.

According to formula (7) we obtain

$$\bar{C}_1 = \frac{\sum_{i=1}^{64} C^i_{col} + \sum_{i=65}^{142} 0}{78+64} \approx 488 \text{ kRUB.}$$

Let $\sum_{i=1}^{142} N^i_{mi} = 23, \sum_{i=1}^{142} N^i_{si} = 10, \sum_{i=1}^{142} N^i_{fat} = 1$, thus, according to formula (8) we obtain

$$\bar{C}_h = \frac{1}{142}(3102 \cdot 23 + 6204 \cdot 10 + 31020 \cdot 1) = 1158 \text{ kRUB.}$$

Therefore, the total damage from a collision calculated by formula (9) is

$$\bar{C}_{col} = \bar{C}_1 + \bar{C}_2 = 488 + 1158 = 1646 \text{ kRUB.}$$

According to the data of the Automated System of Traffic Safety (ASRB) for the period 2013-2015 there were 17 burstings open of a point with fixed damage listed in Table 5.

Using formula (10) we obtain

$$\bar{C}_{bop} = \frac{\sum_{i=1}^{17} C^i_{bop}}{17} = 78 \text{ kRUB.}$$

According to the data of the Automated System of Traffic Safety (ASRB) for the period 2013-2015 there were 221 burstings open of a point with a subsequent derailment with the damage listed in Table 6.

Using formula (11) we obtain

$$\bar{C}_{drl} = \frac{\sum_{i=1}^{221} C^i_{drl}}{221} = 225 \text{ kRUB}$$

Like in work [2] let there be two locomotives working at a station, each of them crosses 36 switches on the average

	Probability levels	**Risk levels**			
	Frequent	300	3000	30000	
1 0,5	Probable	150	1500	15000	
0,15	Occasional	45	450	4500	
0,05 0,015	Remote	15	150	1500	
0,005	Improbable	4,5	45	450	
0	Incredible	1,5	15	150	
		Insignificant	Marginal	Critical	Catastrophic
		300	3000	30000	
		Level of severity of consequences			

Fig. 2. Risk matrix for collisions

	Levels of frequencies, 1/per year	**Risk levels**			
	Frequent				
100	Probable	30000	300000	3000000	
40	Occasional	12000	120000	1200000	
15	Remote	4500	45000	450000	
6	Improbable	1800	18000	180000	
2	Incredible	600	6000	60000	
0		Insignificant	Marginal	Critical	Catastrophic
		300 3000 30000			
		Level of severity of consequences			

Fig. 3. Risk matrix for derailments and bursting open of a point

per hour, and the probability of signal violation by a shunting locomotive is P_{sh}=1,4·10^{-4}, the probability of a point burst open is equal to the probability of a derailment after a point burst open P_{drl}=P_{bop}=0,1, then the probability of a point burst open with subsequent derailment is calculated by formula (3)

$$P_{bop(drl)} = P_{sh} P_{bop} P_{drl} = 1,4 \cdot 10^{-4} \cdot 0,1 \cdot 0,1 = 1,4 \cdot 10^{-6},$$

And the probability of a point burst open without subsequent derailment is calculated by formula (4)

$$P_{bop(no\ drl)} = P_{sh} P_{bop} (1 - P_{drl}) =$$
$$= 1,4 \cdot 10^{-4} \cdot 0,1 \cdot (1 - 0,1) = 1,26 \cdot 10^{-5}.$$

Table 4 – Damage from collisions, kRUB. (per each accident)

207,67	19,56	440	156,81	65,17	21,8	76,7	54,1	35,05	445,92
61,31	5,11	1717	149,75	378	65,12	14,46	422,28	74,5	2264,62
226,3	1,3	326,7	645,25	57,86	1067,27	43,64	0,2	3,63	226,28
4,5	1,02	1082,27	1	1,35	21	195,75	923,35	1	2,45
9,44	11,4	800	41,06	2	2,04	4,49	173	19,35	9,9
66,9	393,4	0,9	2332,72	115,87	5,9	5,9	263	85,7	1612
22	42,7	654,38	51139						

Table 5 – Damage from burstings open of a point, kRUB. (per each accident)

8,49	110,88	49,04	1	18,78	102,39	64,39	85,3	21,61	174,11
4,25	389,48	132,01	91,01	2,57	72,04	0,35			

Table 6 – Damage from derailments, kRUB (per each accident)

79	14,8	422,3	158,03	7,66	28,83	3	215	503,67	9,13
328,07	3,86	133,18	3	20,31	573,44	363,42	263,69	261,9	251,7
247,26	27,05	34	180,75	219,6	322,76	262,5	5123,35	266,45	2027,08
59,75	281,74	228,38	193,5	474,3	75,5	33,93	52,9	82,35	38,96
29,13	1,44	68,07	1,38	1	150,62	970,07	33,3	15	117,3
3,2	375,95	200	192,82	45,64	45,3	349,47	28,31	78,9	33,3
579,26	338,46	479,17	13	43,37	152	525,22	920,84	203,77	2411,23
2	88,52	109,31	408,65	1007,25	1,99	10	608,29	137,7	113,24
7	16,63	11,7	102,78	15	15,89	23,6	25	18,97	34
48,74	48,69	2	15	309,05	223,68	66,28	993,66	42,76	30
155,06	163,25	56,06	43,48	73,67	19,28	36,6	67,9	46	112
71,65	149,05	76,7	33,13	12,34	491,8	1460	32,25	220,61	3,2
9,37	19,2	118,53	703,44	72	124,52	7,73	146,78	188,04	150,47
142,3	179,12	306,86	3,6	717,69	29,5	149,7	254,01	94,77	2
34	309,21	116	10	30	93,9	110	40,77	103,85	1147,05
483,05	89,73	12	340	34	420,16	3,6	24	6,49	139,53
899,9	1	31,67	55,27	22,2	106,76	1,68	129,9	118,61	160
150,8	256,63	374,41	29,62	74,8	98,21	20	292,99	80,46	162,72
1446	544,06	37,56	1610,54	55,1	79,77	101	93,46	125	260,3
3,1	46	773,55	24,5	27,03	203	13,92	655,1	72,49	216
303,89	24,47	58,49	256	447,55	41,43	37,9	8,3	247,99	0,52
704,67	26,5	80,74	494,73	174,99	16,15	58,89	154,81	8,56	17,79
62,82									

The total number of switches crossed by shunting locomotives per year is calculated by formula (2)

$$N_{year} = 365 \cdot 24 \cdot \sum_{l=1}^{L} N_l = 365 \cdot 24 \cdot (36 + 36) = 630720.$$

Therefore, the average number of points burst open by formula (5) is

$$\overline{N}_{year}^{bop} = N_{year} \cdot P_{bop(no\ drl)} = 630720 \cdot 1,26 \cdot 10^{-5} = 7,947,$$

And the average number of points burst open with subsequent derailment by formula (6) is

$$\overline{N}_{year}^{drl} = N_{year} \cdot P_{bop(drl)} = 630720 \cdot 1,4 \cdot 10^{-6} = 0,883.$$

Using formula (1) let it be obtained that

$$P(A_{year}) = 0,3.$$

Let us define quantitative values of risks caused by all unfavorable events and the respective risk areas.

Risk caused by collisions is calculated by formula (12) and it is

$$R_{col} = P(A_{year}) \cdot \overline{C}_{col} = 0,3 \cdot 1646 = 493,8 \text{ kRUB}.$$

And we enter orange area – area of undesirable risk. Thus it is necessary to take measures to reduce risk. Among such measures there can be the installation of Shunting Automatic Cab Signalling (MALS system).

Risks caused by bursting open of points and derailments are calculated by formulas (13) and (14)

$$R_{bop} = \overline{N}_{year}^{bop} \cdot \overline{C}_{bop} = 7,947 \cdot 78 = 620 \text{ kRUB},$$

$$R_{drl} = \overline{N}_{year}^{drl} \cdot \overline{C}_{drl} = 0,883 \cdot 225 = 199 \text{ kRUB}.$$

And we enter green area – area of negligible risk. Therefore, no measures to reduce the risks caused by bursting open of points and derailments are required at this station. We shall note that the risk caused by bursting open of points is higher than the risk from derailments. Nevertheless, measures to reduce the risk from derailment are required, and measures to reduce the risk from bursting open of points are not required. The matter is that under the collision JSC RZD bears additional reputational expenses, doubled by the fact that a derailment occurs at a station with large numbers of people.

Conclusion

This paper describes the task of calculation of unfavorable events caused by SPAD by a passenger train or a shunting locomotive. It provides the formulas used to calculate the probability of at least one collision of a passenger train at a station per year, average number of points burst open by a shunting locomotive without a subsequent derailment, as well as the average number of derailments per year. It also contains the formulas used to calculate the average damage from unfavorable events. Risk matrices for all unfavorable events have been constructed. The article gives the example of application of the obtained results which is based on hypothetical data and expert analysis.

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