

Analysis of industrial injuries and assessment of the risk of injury to railway power supply workers

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Abstract. The purpose of this study is to analyze industrial injuries and assess the risk of injury to railway power supply workers based on mathematical statistics. It is shown that the level of injuries of this category of employees is at a significant level (the frequency coefficient of general injuries is higher by 2.6 times, and the frequency coefficient of fatal injuries is 5.7 times relative to the corresponding frequency coefficients in general for JSC “Russian Railways”). Based on the research results, the main causes of accidents with a fatal outcome were: poor organization and planning of work, violations of the technological process, violations in the use of personal protective equipment, lack of supervision on the part of the contractor, violation of work rules at the height, the extension of work place. The assessment of the risk of injury of contact network of electricians showed two possible types of accidents with them: electric shock and falling from a height. The probability of accidents is 0.031 and 0.051, respectively, with the number of injuries for each of the received scenarios on the five-year planning horizon being 7.85 and 12.75, respectively. The presented approach to assessing injury risks, supplemented by the method of expert assessments, will allow identifying and evaluating specific hazards at the workplace of linear level enterprises, respectively, to increase the effectiveness of developing of programs to improve working conditions and safety, and the effectiveness of implementing of tools for managing professional risks in order to reduce industrial injuries of employees of power supply divisions.

1 Introduction

One of the most traumatic industries is the electric power industry, which is characterized primarily by the risk of electric injuries for working personnel [1-3]. A similar situation is developing in the structural divisions of JSC “Russian Railways”, which are engaged in the operation and repair of power supply systems and are among the most traumatic.

The introduction of a professional risk management system (PRMS) is one of the ways to reduce occupational injuries [4-9]. In railway transport, the company began to actively implement the PRMS through the modernization of the occupational safety management system in 2013, and in 2018, JSC “Russian Railways” adopted the Vision Zero concept of zero injuries [10, 11], aimed at achieving the goal of zero injuries with a fatal outcome.

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Despite the current trend of reducing accidents in power supply divisions - linear structural divisions of Transenergo - a branch of JSC “Russian Railways”, 21 employees were injured in 2018, 6 of them fatally. 24 employees were injured in 2017, 6 of them were fatal.

The purpose of the study is to analyze industrial injuries and assess the risk of injury to railway power supply workers based on mathematical statistics.

2 Materials and methods

The object of research was the risk of injury to employees of power supply divisions. Currently, a significant number of risk assessment methods have been developed, including professional ones [12-15]. To assess the risks of injury, JSC “Russian Railways” has developed a Methodology for analyzing and evaluating professional risks for employees of JSC “Russian Railways”, which allows calculating risks based on existing statistics of industrial injuries. The calculation was made as follows. At the first stage, statistics were collected on cases of occupational injuries for a given profession (table 1).

When referring to the sources of the activation of harmful and dangerous production factors (HDPF column 5 of table 1) the following symbols are used:

- I1 – the man himself, his labor, the means of labor;
- I2 – human interaction with technology and the environment;
- I3-interaction of people of different professions;
- I4-other.

Table 1. Non-group injury statistics

Year	Profession	Type of incident	Cause of injury	HDPF	Type of injury	Activation source of HDPF
2018	electrician	road accident	run over	I3	fractures	I3
2018	electrician	fall from height	strong wind	I2	fractures	I2
2018	electrician	electric shock	personal protective equipment	I1	burn	I1
2018	electrician	fall from height	icing	I2	fractures	I2

The following scenarios described the occurrence of injury (table 2).

Table 2. Describe the scenarios of occurrence of injury

Scenarios No	Activation source of HDPF	Accident	Type of injury
1	2	3	4
1	I3	road accident	fractures
2	I2	fall from height	fractures
3	I1	electric shock	burn

Based on data from these tables, the statistics of injury occurrence for each scenario were described. Injury statistics for scenario No 1 are shown in table 3.

Table 3. Injury statistics for scenario No 1

Injury scenario No 1											
Source of HDPF	Accident					Type of injury					
	electric shock					burn					
	Year										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Number of injuries	3	2	2	1	3	1	1	2	0	1	0

The probability calculation for the *i*-th scenario is performed in two steps:

Step 1. Calculation of the value of the parameter $\hat{\lambda}_i$.

The parameter $\hat{\lambda}_i$ is calculated using the formula (1):

$$\lambda_i = \frac{m_i}{T \cdot N} \tag{1}$$

where m_i – is the number of injuries in the i -th scenario;

T-observation period (10 years);

N – average number of employees per year (50 people).

Step 2. Calculation of the probability P_{ci} of injury occurrence in the i -th scenario.

Probability P_{ci} is calculated using the formula (2):

$$P_{ci} = 1 - 2.718^{-\lambda_i}. \tag{2}$$

The calculation results are presented in table 4.

The probable number of injuries per year for the i -th scenario is calculated using the formula (3):

$$K_{1i} = P_{ci} \cdot N. \tag{3}$$

The probable number of injuries for 5 years in the i -th scenario is calculated using the formula (4):

$$K_{5i} = 5 \cdot P_{ci} \cdot N. \tag{4}$$

Table 4. Summary table on the probability of injuries and consequences for the contact network electrician

Type of injury	Type of source HDPF	Type of incident	Scenarios No, i	P_{ci} probability	K_{1i} injuries for year	K_{5i} injuries for 5 years
slight	I1	-	-	-	-	-
	I2	-	-	-	-	-
	I3	-	-	-	-	-
	I4	-	-	-	-	-
serious	I1	electric shock	1	0.031	1.57	7.85
	I2	fall from height	2	0.051	2.55	12.75
	I3	-	-	-	-	-
	I4	-	-	-	-	-
fatal	I1	-	-	-	-	-
	I2	-	-	-	-	-
	I3	-	-	-	-	-
	I4	-	-	-	-	-
group injuries	I1	-	-	-	-	-
	I2	-	-	-	-	-
	I3	road accident	3	0.022	1.1	5.5
	I4	-	-	-	-	-

3 Results and discussion

Table 5 shows the analysis of industrial injuries of employees of power supply divisions in the context of regional directorates of Transenergo – a branch of JSC “Russian Railways” for the period 2017-2018.

Of the 21 workers affected in 2018:

7 were injured by electric shock, 3 of them were fatal;

6 - as a result of falling from a height (including 1-fatally);

2-fatally injured as a result of the collapse of the structure;

- 2 - as a result of the impact of flying objects;
- 2-as a result of falling while moving,
- 1 - as a result of being beaten by third parties;
- 1 - as a result of hand pressure during loading of supports.

Table 5. Analysis of industrial injuries by the severity of injuries received for the period 2017-2018.

Directorate	Total injured			Fatal			With a severe outcome		
	2017	2018	+/-	2017	2018	+/-	2017	2018	+/-
October	1		-1	1		-1			
Moscow	3	2	-1		1	+1	1		-1
Gorkov	4	1	-3	1		-1	2	1	-1
North		1	+1						
The North Caucasus		1	+1						
South East		2	+2					2	+2
Privolzhye	3		-3	1		-1	1		-1
Kuybishev	2	6	+4		3	+3	1		-1
Sverdlovsk		1	+1						
South Ural	4		-4	1		-1	1		
West Siberian	3	2	-1				1	2	+1
Krasnoyarsk		3	+3		1	+1		2	+2
West Siberian	1	1	0		1	+1	1		
Transbaikalian	2		-2	1					
Far eastern	1	1	0	1				1	+1
Subtotal	24	21	-13%	6	6	0%	8	8	0%

The frequency coefficient (FC general) of injuries in Transenergo, which takes into account the average number of employees, for 2018 was 0.59, which is 2.36 times more than the frequency coefficient for JSC “Russian Railways” as a whole (0.25). The frequency coefficient of fatal injuries (FC fatal) in 2018 was 0.17, which is 5.7 times higher than the coefficient of JSC “Russian Railways” (0.03).

The dynamics of the coefficient of frequency of industrial injuries is presented in table 6.

Table 6. Dynamics of the coefficient of frequency of industrial injuries for the period 2014-2018.

Directorate	2014		2015		2016		2017		2018		2014-2018	
	FC general	FC fatal	FC general	FC fatal	FC general	FC fatal	FC general	FC fatal	FC general	FC fatal	FC general	FC fatal
October	0.32	0.32	-	-	-	-	0.28	0.28	-	-	0.12	0.12
Moscow	0.57	0.29	0.57	-	0.53	-	0.8	-	0.52	0.23	0.6	0.10
Gorkov	0.46		0.47	-	0.42	-	1.68	0.42	0.43	-	0.69	0.08
North	1.19	0.6	1.19	0.6	-	-	-	-	0.56	-	0.59	0.24
The North Caucasus	0.79	0.39	0.4	-	0.37	-	-	-	0.4	-	0.39	0.08
South East	0.58		-	-	1.38	1.38	-	-	1.08	-	0.61	0.28
Privolzhye	0.85		-	-	-	-	2.38	0.79	-	-	0.65	0.16
Kuybishev	0.74	0.74	1.19	0.79	0.37	-	0.78	-	2.36	1.18	1.09	0.54
Sverdlovsk			0.36	-	1.6	0.56	-	-	0.35	-	0.46	0.11
South Ural	0.84		0.85	-	0.76	-	1.6	0.4	-	-	0.81	0.08
West Siberian	0.7		0.72	-	0.66	-	0.99	-	0.65	-	0.74	0
Krasnoyarsk	2.1	0.7	0.7	-	3.2	1.69	-	-	1.86	0.62	1.57	0.6
West Siberian	0.98	0.49	0.98	-	-	-	0.44	-	0.48	0.48	0.58	0.19
Transbaikalian	1.7		2.17	-	0.8	0.53	0.78	0.39	-	-	1.09	0.18
Far eastern	0.43		0.87	0.43	0.4		0.42	0.42	0.42	-	0.51	0.17
Subtotal	0.74	0.23	0.67	0.12	0.64	0.16	0.64	0.16	0.59	0.17	0.66	0.17

The main types of industrial accidents that occurred in 2018 were mechanical and electrical injuries (table 7).

Table 7. Distribution of accidents by type of injury for the period 2014-2018 (total / including fatal)

Type of injury	2014	2015	2016	2017	2018	2014-2018
Electrical	13/6	7/2	7/4	12/5	7/3	46/20
Mechanical	13/2	17/2	17/2	12/1	14/3	73/10
Subtotal:	26/8	24/4	24/6	24/6	21/6	119/30

The main types of the damaging factor of mechanical injuries (bruises, fractures, etc.) are given in table 8.

Table 8. Types of mechanical injuries for the period from 2014 to 2018 (total/including fatal)

	Basic types of mechanical injuries	2014	2015	2016	2017	2018	2014-2018
1	Employee falling from a height, total including:	5	7/1	9	6	6/1	33/2
1.1	From a support, searchlight mast, construction, stairs	3	5	6	3	4	21
1.2	When working with an isolated removable tower	1	-	-	3	1/1	5/1
1.3	When working with ADM, AutoFill	1	2/1	3		1	7/1
2	Eye injury	2	2	2			6
3	Road accident	3/1	3/1	5/2			11/4
4	Injuries when felling trees, cutting down small woodlands	2	3				5
5	Impact of flying objects		1		3/1	2	6/1
6	Collapse of the structure, mechanical pressure of the load			1	1	3/2	5/2
7	Beating by third parties					1	1
8	Falling when moving		1		2	2	5
9	Arrival of rolling stock	1/1					1/1

The most traumatic positions and professions continue to be the electrician of the ECHK, ECHS (table 9).

Table 9. Distribution of victims by their positions for the period 2014-2018 (total/including fatal) (ECHE-traction substations, ECHK - areas of the contact network, ECHS-areas of power supply, RRU-repair and revision section, ECH- power supply division)

Position, profession	2014	2015	2016	2017	2018	2014-2018
Electrician ECHK	11/5	14/2	12/3	14/2	10/2	61/14
Electrician ECHK		1	2	1/1	1	5/1
Chief ECHK		1/1	1			2/1
Electrician ECHS	5	5	2/1	2/1	3/1	17/3
Electrician ECHS	2	-	2			4
Electrician of line department		1	1			2
Electrician ECHE	1	-	1/1	2	1/1	5/2
Electrician ECHE	2	1	-	2	2	7
Chief ECHE	1/1				2/2	3/3
Chief of road electrical laboratory		-	1			1
Electrician RRU	1/1	1/1	2/1	1/1	2	7/4
Chief RRU	1/1					1/1
Driver	1					1
Driver of the aerial platform				1/1		1/1
Director ECH	1			1		2
Subtotal	26/8	24/4	24/6	24/6	21/6	119/30

The largest number of workers affected in the production during the analyzed period had

a work experience of more than 15 years (table 10), on the other hand, the age of the largest group of injured people is in the range from 21 to 30 years (table 11).

Table 10. Length of service as a victim in 2014-2018 (total/including fatal)

Length of service	2014	2015	2016	2017	2018	2014-2018
less than 1 year	2/2	2	1	1/1	2	8/3
from 1 year up to 3 years	6/2	5/1	1	3	3/1	18/4
from 3 years up to 5 years	6	3	3/1	2	8/3	22/4
from 5 years up to 10 years	4/1	5	4	8/3	1	22/4
from 10 years up to 15 years	2/1	7/2	4/1	1	1	15/4
more than 15 years	6/2	2/1	11/4	9/2	6/2	34/11
Subtotal	26/8	24/4	24/6	24/6	21/6	119/30

Table 11. The age of the workers injured in 2014-2018 (total/including fatal)

Age	2014	2015	2016	2017	2018	2014-2018
from 21 up to 30 years	12/3	9/1	5/1	8/1	10/3	44/9
from 30 up to 40 years	7/2	9/3	10/3	4/1	2	32/9
from 40 years up to 50 years	3/1	2	6	5/3	4/2	20/6
more than 50 years	4/2	4	3/2	7/1	5/1	23/6
Total:	26/8	24/4	24/6	24/6	21/6	119/30

Based on the research results, the main causes of accidents with a fatal outcome were: poor organization and planning of work, violations of the technological process, violations in the use of personal protection equipment, lack of supervision on the part of the contractor, violation of work rules at the height of the extension place of work.

An analysis of the inspections revealed systemic weaknesses in the organization of work on labor protection: unsatisfactory performance requirements telegrams, protocols for occupational injuries, disorders in the design of operational-technical documentation, the power supply circuit, and partitioning, conduct formal monthly and quarterly monitoring of labor protection in linear units, the poor quality checking of outfits by the heads and specialists of energy divisions.

The results of the assessment of the risks of injury to employees of power supply divisions can be used to improve the targeting of corrective measures in the field of labor protection.

However, the presented approach to risk assessment has a number of limitations.

Using historical data on industrial injuries allows you to assess risks only within the company's existing statistics (usually at the central or regional management levels). There is not enough data at the linear level. There are a significant number of linear enterprises with zero level of industrial injuries for 10 years or more.

This approach does not allow identifying and evaluating specific hazards in line-level workplaces.

In our opinion, it is possible to remove these restrictions by supplementing the approach presented above with the method of expert assessments. The working group formed in the structural division, using the methods of expert assessments, can analyze and assess the risks of specific technological processes and jobs at the linear level.

4 Conclusion

Industrial injuries of employees of railway power supply divisions remain at a fairly high level. A typical accident is an electrical or mechanical injury to a contact network electrician under the age of 30 or with more than 15 years of experience. The presented approach to assessing the risk of injury, supplemented by the method of expert assessments, makes it possible to increase the effectiveness of developing injury prevention programs by improving

the system of labor protection management. The latter allows the occupational safety specialist to increase the effectiveness of implementing tools for managing occupational risks in order to reduce occupational injuries of employees at power supply divisions.

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