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Original Research

Improvement of Methods of Analysis and Forecasting of Industrial Injuries in the Electric Workshop of the Mining and Processing Plant

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Abstract

The study of the causes of injuries and ways to solve them at enterprises and industries of the mining, oil and gas and construction sectors has attracted a lot of attention of researchers in recent years. To study this issue, an analysis of injuries in the electric workshop of the Mining and Processing Plant. The methodological basis of the study was the modern provisions of the theory and practice on occupational safety and health, injuries at enterprises and industries of the mining, oil and gas and construction sectors, as well as at enterprises of the electric power industry. The statistical method, comparative analysis, content analysis of regulatory documentation, modeling are used in the work. Also, a statistical method was used to determine the most traumatic areas, and a quantitative assessment of the risk of danger was determined using the Kinney method. According to the results of the study, it was established that the most traumatic are workers with experience from 1 to 4 years, when a specialist is becoming and adapting to working conditions.

Keywords: electric power industry, environmental, danger, risk, statistical method, Kinney method

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Introduction

Due to the rapid growth of the development of mining and processing, oil and gas and construction industries in the Commonwealth of Independent States (CIS) countries and including the regions of Kazakhstan, it requires a very responsible approach to occupational health and safety in enterprises [1-5].

The study of the causes of injuries and the ways to solve them at the enterprises of the mining, oil and gas and construction sector has attracted much attention of scientists from CIS countries and abroad in recent years, as well as the study of this issue is relevant in the facilities of the power grid economy of Kazakhstan [1, 6-9].

In recent years, much attention of scientists has been attracted by research on accidents at power plants with an installed capacity of 25 MW or more and at the facilities of the electric grid of grid companies and large consumers of electricity, which has a great impact on the work of metallurgical, mining and processing and petrochemical enterprises [1, 10-12].

Various statistical data on accidents in the electric power industry as a whole are contained in the works of [13-20] and other authors.

Data on accidents at power plants and at power grid facilities of grid companies and large consumers of electricity were analyzed using the example of the Russian power system (Fig. 1).

It should be noted that the number of accidents at electric power facilities tends to decrease. However, the number of accidents in most joint-stock companies of generating companies is in the hundreds, and in joint-stock companies of the electric grid economy is in the thousands. Statistical data on accidents in the electric power industry were taken from the works [20, 21].

Among the injury indicators that were widely used back in the USSR, there was an indicator of the number of fatal accidents per ton of coal mined. If we consider the electric power industry, then a similar indicator could be the ratio of the number of fatal accidents associated with the production and transmission of electric energy per 1 TW (1TWT = 1012W) of energy consumed.

Data on occupational injuries were taken from sources and works [1, 22, 23]. For 2014-2019, i.e. for 6 years, electricity consumption in Russia has hardly changed, the total number of accidents during the production and transmission of electric energy has changed significantly, but the number of fatal accidents, most of which occur in electric grid enterprises and are associated with the impact of electric current, has hardly changed.

Thus, this indicator can be used as an indicator indicating the need to use innovative technical means to ensure the safety of employees at a qualitatively higher level.

The greatest number of injuries occurs in electrical networks. A significant number of them, 20% or more, occurs due to the impact of an electric current and (or) an electric arc on the victim (Fig. 1).

Based on the obtained data shown in Fig. 1, using the MS Excel software application in the Windows environment, we found exponential equations describing the dependence of injuries on:

generating enterprises

- $y = -1.5792x^5 + 28.583x^4 - 193.44x^3 + 601.92x^2 - 844.98x + 491$ with an approximation coefficient (R^2) equal to 1;

electric grid enterprises

- $y = -1.9167x^5 + 32.75x^4 - 204.58x^3 + 564.25x^2 - 656.5x + 360$ with an approximation coefficient (R^2) equal to 1;

other enterprises

- $y = -0.8542x^4 + 12.338x^3 - 60.882x^2 + 115.64x - 32.167$ with an approximation coefficient (R^2) equal to 0.9881.

It can be seen from the obtained equations that the found equations describe dependencies with a sufficiently high approximation coefficient ranging from 0.9881 to 1, which does not exceed an error of more than 5%.

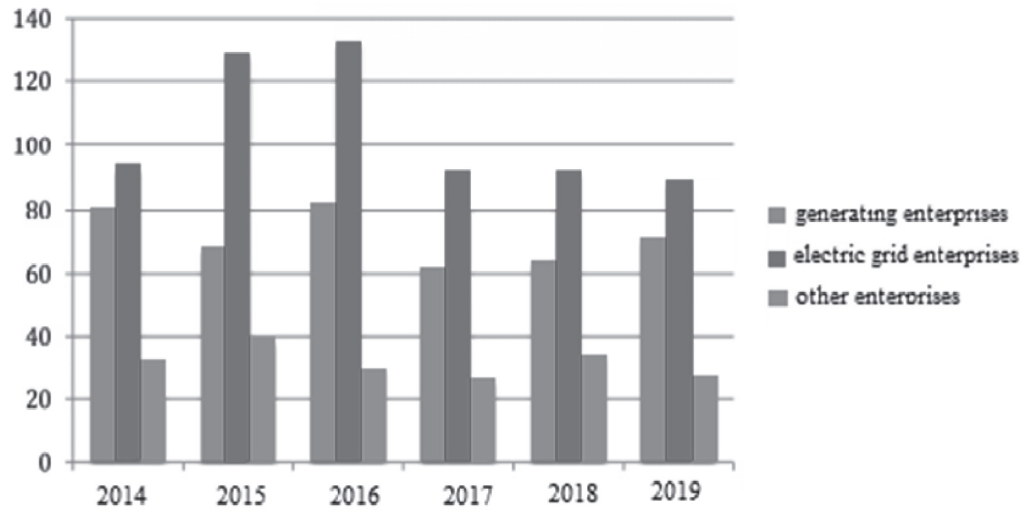

Fig. 1. Dynamics of injuries in the Russian electric power industry.

The largest number of victims are men and women aged 50 to 59 years, who have more than 10 years of professional experience and are workers in the main professions of electric grid enterprises (Figs 2, 3).

Based on the dynamics of injuries by age in the electric power industry, based on Fig. 2, we found polynomial equations of the dependence of injuries by years with an approximation coefficient:

up to 30 years - $y = -0.8542x^4 + 12.338x^3 - 60.882x^2 + 115.64x - 32,167$; $R^2 = 0.9913$;

from 30 to 40 - $y = 0.7963x^3 - 11.075x^2 + 39.128x + 14.333$; $R^2 = 0.9011$;

from 40 to 49 - $y = 1.287x^3 - 14.389x^2 + 39.038x + 29.667$; $R^2 = 0.9614$;

from 50 to 59 - $y = 2.8056x^3 - 30.298x^2 + 87.754x - 1$; $R^2 = 0.9826$;

from 60 and above - $y = 0.3333x^3 - 3.3929x^2 + 7.8452x + 12$; $R^2 = 0.976$.

From the found equations of the dynamics of injuries from age, it can be seen that the equations describe dependencies with a sufficiently high approximation coefficient (R^2) ranging from 0.9011 to 0.9913, which is a high confidence indicator.

Similarly, on the basis of Fig. 3, exponential equations were found describing the dynamics of injuries from work experience, in particular:

up to 1 year - $y= 0.2083x^4-1.8241x^3 + 0.0694x^2 + 21.388x + 1.6667$; $R^2 = 0.8954$;

from 1 to 3 - $y = 0.7315x^3 - 8.877x^2 + 26.677x + 18.667$; $R^2 = 0.9638$;

from 3 to 5 - $y = 1.2685x^3 - 13.73x^2 + 39.573x + 1.3333$; $R^2 = 0.9816$;

from 5 to 10 - $y = 1.0417x^4 - 13.528x^3 + 57.625x^2 - 94.091x + 90$; $R^2 = 0.9987$;

from 10 and more - $y = 2.1019x^3 - 23.23x^2 + 66.668x + 33.333$; $R^2 = 0.939$.

The above equations of injury dynamics from work experience also contribute to a high value of the approximation coefficient (R^2) in the range from 0.8954 to 0.9987, which is a fairly high confidence indicator

This category of workers was injured during repair work or operational maintenance. All employees passed introductory, repeated and targeted briefings, most of the victims of electric current had the 3rd or higher electrical safety group [1, 24].

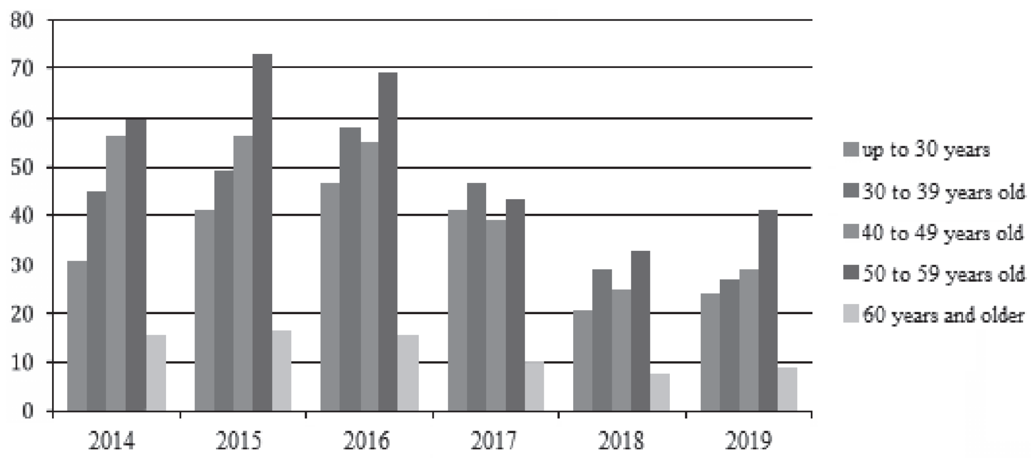

Fig. 2. Dynamics of injuries by age in the Russian electric power industry.

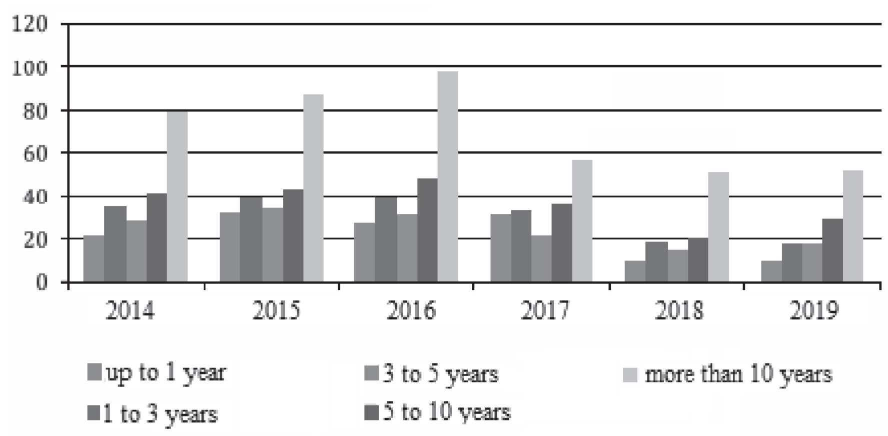

Fig. 3. Dynamics of injuries depending on the length of work by profession of victims in the Russian electric power industry.

This state of affairs leads to the idea of the need to introduce innovative technical means to minimize personnel errors and thereby significantly reduce the number of possible accidents. It is possible to reduce the number of accidents due to special training of employees of electric power enterprises. The program of such training should be developed for each specific joint-stock company, taking into account the frequency of accidents due to improper actions of personnel.

It should be noted that for decades most of the group, severe and fatal accidents occurred in electrical installations due to an insufficient level of organizational and operational characteristics [25, 26].

These reasons indicate the presence of serious shortcomings in the work of managers at all levels of management of a number of subjects of the electric power industry responsible for the fulfillment by workers of the requirements of norms and rules of labor protection [27, 28].

Thus, the purpose of these studies is to develop an algorithm of measures based on the behavior of employees from the return and work experience in certain emergency situations with further forecasting and exclusion of cases with injuries.

Experimental

Materials and Methods

In this paper, the object of the study is the persons affected by industrial injuries in the electric workshop of the Don Mining and Processing Plant of the Aktobe region of Kazakhstan for the period from 2014 to 2019 inclusive. In all cases, the monitoring unit was the workers of the Don Mining and Processing Plant who were injured during the calendar year. A survey of 100 employees was also conducted. The research, analysis and processing of the results were carried out on the basis of the educational institution "Kazakh-Russian International University".

The total volume of the studied material for clarity and the results of statistical data on industrial injuries in the electric workshop of the Don Mining and Processing Plant. The Don Mining and Processing Plant has developed and operates a "General Classifier by types of identified hazards", according to which an identified number is assigned to each type of hazard. The types of hazards that may be the causes of accidents are included.

To study mortality from non-occupational injuries, the section of the electronic card on injury outcomes was selectively filled in. During the study period, 3 cases of disability at work, 4 accidents and 1 fatal case were registered.

The following research methods are used in the work: statistical, comparative analysis, content analysis of regulatory documentation, modeling.

To study mortality from non-occupational injuries, the section of the electronic card on injury outcomes was selectively filled in. To determine the most injury-prone areas, we used a statistical method, and a quantitative assessment of the risk of danger was determined using the Kinney method. To quantify the risks in the electric workshop of the Don Mining and Processing Plant, the Kinney method described in [19] was used. According to which we calculated a potentially dangerous situation, indicated by the risk according index R to i classifier, according to the following formula:

$$Ri = Pi \cdot Ei \cdot Gi \tag{1}$$

where, Pi- is an indicator of the probability of a dangerous event; Ei- is an indicator of the frequency of risk exposure; Gi- is an indicator of the severity of damage caused by the consequences of a dangerous event.

Results

According to the methodology, according to Tables 1 and 3, we will determine the number of accidents (DNA_i) for the main of the identified hazards, for this we will analyze statistical data on 4 accidents among the staff of electrical shop workers for the period from 2014 to 2016.

Table 1. Indicators of industrial injuries in the electric workshop of the Don Mining and Processing Plant in the period from 2014 to 2019.

Item No.	The name of the indicator	Title 3					
		2014	2015	2016	2017	2018	2019
1	The average number of employees in the electrical shop during the study period	137	138	140	141	142	143
2	The number of victims of accidents at work with disability for one day or more, people.			1	1		1
3	The number of accidents	1		1	1		1
	In total including:						
	With a mild outcome			1	1		1
	With a fatal outcome	1					

Table 2. General classifier by types of identified hazards.

Danger code	Name of the hazard
01	Traffic (automobile, railway)
02	Height
03	Falling, collapse, collapses of objects, materials, rock mass, etc.
04	Moving, flying, rotating objects and parts
05	Extreme temperatures
06	Electric current
07	Harmful substances (dust, gas, chemicals)
08	Ionizing radiation
09	Physical overload
10	Neuropsychic stress
11	Contact with animals and insects
12	Drowning
13	Unintentional murder
14	Natural disasters
15	Falling (uneven and slippery surfaces)
16	Unauthorized explosions of explosives during blasting operations
17	Formation of explosive mixtures
18	Vibration and noise
19	Fires
20	Accidents of a natural nature
21	Man-made accidents
22	Hazards, other than those listed, characteristic of the mining industry
23	Other

The assessment of risk indicators R_i for various analyzed hazardous situations is carried out by assigning a score to each of the above parameters, and the corresponding numerical values determined in Tables 3, 4, 5 below.

Table 3 provides data from which the following dangerous events can be distinguished: - No. 6 (exposure to electric current) - 4 cases (1 fatal).

Having analyzed the data on accidents in the electrical shop for the period from 2014 to 2019, we can say that the main danger for the manifestation of injuries at work is a dangerous event No. 6 from the classifier - electric shock. There are 4 cases of this danger.

The calculation will be carried out on dangerous event No. 6. The total number of accidents according to hazard No. 6 will be ANA = 4.

The average number of accidents (ANA) per year:,

$$\mathrm{ANA} = \frac{\mathrm{NAA}}{4} \tag{2}$$

where, T is the reporting study period of 6 years.

$$\mathrm{ANA} = \frac{\mathrm{NAA}}{4} = \frac{4}{6} = 0{,}67$$

The expected frequency of occurrence of the event (FOE) is determined by the formula:

$$\mathrm{ANA} = \frac{\mathrm{NAA}}{n} \tag{3}$$

where, ***n*** is the average number of employees in the electrical shop for the study period

$$\mathrm{FOE} = \frac{\mathrm{ANA}}{n} = \frac{0{,}67}{140} = 0{,}005$$

P – the indicator of the probability of a possible dangerous event occurring is determined according to Table 4.

E is an indicator of the frequency of risk exposure, determined in points from Table 5.

G – the severity of the damage caused by the consequences of a dangerous event is determined in points from Table 6.

According to Table 3, the value of *P* at PTS = 0.005 corresponds to the value of *P* = 3 points (not always, but possible).

Discussion

Based on the actual statistical data of the number of accidents for this dangerous event, we will determine E. During the study period, 4 cases were identified for

Table 3. This is a table. Tables should be placed in the main text near to the first time they are cited.

Item No.	Date	Profession	Type of incident
1	11.10.16	Conveyor operator	6
2	22.04.17	Electrician on duty and equipment repair	6
3	19.07.18	Electrician on duty and equipment repair	6
2	16.08.19	Electrician on duty and equipment repair	6

Table 4. Indicator of the probability of a possible dangerous event *P*.

ANA	Name	Scores
> 1 year-1	High degree of probability	10
$1 – 1 \cdot 10^{-2}$ year-1	Average degree of probability	6
$1 \cdot 10^{-2}$ - $1 \cdot 10^{-4}$ year-1	Not always, but maybe	3
$1 \cdot 10^{-4}$ - $1 \cdot 10^{-5}$ year-1	Low probability	1
$1 \cdot 10^{-5}$ - $1 \cdot 10^{-6}$ year-1	Incredibly, but it is impossible to completely exclude the possibility	0.5
$1 \cdot 10^{-5}$ - $1 \cdot 10^{-7}$ year-1	Almost impossible	0.2
$1 \cdot 10^{-7}$ - $1 \cdot 10^{-8}$ year-1	Virtually impossible	0.1

event No. 6, which is 0.67 cases per year. This value corresponds to the column in Table 4 - Very rarely (less than once a year), then the value of E = 0.5 points.

According to Table 5, we determine the severity of the consequences of dangerous event No. 6, then G = 7 points, which corresponds to the column - Significant consequences (temporary disability). If the risk index calculated according to this formula does not exceed 50, then the risk is considered acceptable. Based on the data obtained , we calculate:

$$R = 3 \text{ x } 0.5 \text{ x } 7 = 10.5 < 50.$$

Thus, the risk level is acceptable.

According to the Kinney method, a quantitative assessment of the risk of danger was established. We have established that the most traumatic profession is an electrician on duty and equipment repair.

Table 5. Indicators of the frequency of exposure to risk *E*.

Name	Scores
Constantly (at least once an hour)	10
Often (at least once a day)	6
Sometimes (at least once a week)	3
Not constantly (at least once a month)	2
Rarely (several times a year)	1
Very rarely (less than once a year)	0.5

Table 6. Damage severity index *G*.

Name	Scores
Tragic consequences (death of several people)	100
Very serious consequences (death of one person)	40
Severe consequences (permanent disability)	15
Significant consequences (temporary disability)	7
Mild consequences (ambulance call)	3
Microtrauma (without disability)	1

According to the analysis of injuries, we also found that the distribution of accidents due to the causes of occurrence in the Don mining and processing plant electrical work-shop for the period 2014-2019 shows that most accidents occur due to violations of safety and labor protection rules.

Which, accordingly, suggests what kind of emotional state this or that employee of the enterprise is in at one time or another, as well as on his character and age category.

The occurrence of an emergency in an electrical shop, including with human casualties, is an extremely rare event, the level of risk in an electrical shop can be considered acceptable.

Thus, today it is necessary to pay considerable attention to the emotional nature, age and inclinations of an employee employed in the production workshops of the Don Mining and Processing Plant, possibly even conducting psychological testing of the behavior of a future employee in emergency situations.

As additional measures to reduce the potential risks of industrial injuries, we recommend the subjects of the electric power industry:

- to improve the quality of staff briefings regarding the use of personal and collective protective equipment by employees, as well as the quality of training in safe methods and skills of performing work;
- ensure the proper quality of labor protection instructions and other production documentation;
- strengthen control over the organization of work by managers at all levels of management and supervision of workers during the execution of work;
- optimize the number and types of work, reducing as much as possible the number of jobs that are not the main ones for employees. At the same time, in case of an urgent need for such work, it is necessary to ensure the safety of employees and continuous monitoring by designated responsible persons [23-28].

At the same time, the concepts of “risk” and “uncertainty” are very close and are even often used as synonyms. The differences between these concepts come down to the amount of information available about a possible situation. The concept of “risk” should be used when we have the opportunity to probabilistically assess the danger, i.e. the retrospective of events is known. In another way, it can be called "probabilistic certainty". The word "uncertainty" is proposed to be used in cases where it is not possible to make a probabilistic assessment due to the lack of knowledge of events.

Thus, in the process of risk assessment, four stages can be conditionally distinguished:

– identification of harmful and dangerous occupational risk factors from the perspective of their potential danger to the health of employees;
– collecting data on the frequency and severity of the consequences of occupational injuries and occupational morbidity;
– economic assessment of the consequences of occupational injuries and occupational morbidity;
– up-to-date "probing" of occupational risks and the choice of an appropriate insurance model for employees at the enterprise.

The results obtained on the basis of the conducted studies of injuries in the electrical shop correspond to the previously conducted studies [29-39] and complement them, allowing a more in-depth analysis of the processes of injury formation in the workplace and their further provision and prevention. The results of the study can be used at the enterprises of the electric power industry of the CIS countries and Kazakhstan in order to minimize injuries and, accordingly, improve the economic climate of the enterprise.

Conclusions

Based on the conducted studies of statistical data of injuries in the electric workshop of the Don Mining and Processing Plant, it was found that:

- the most traumatic dangerous age has been identified, which is indicated by the following age range of 50-59 years and work experience, it was established that the most traumatic are workers with experience from 1 to 4 years, when a specialist is becoming and adapting to working conditions;

– the main danger for the manifestation of injuries in the electric workshop of production is a dangerous event No. 6 from the classifier, directly electric shock;
– the severity of the consequences of dangerous event No. 6 for the study period was G = 7 points, which corresponds to the column – Significant consequences that entail temporary disability, respectively, economic loss;
– the most traumatic profession has been established, which is the duty electrician and equipment repair;
– most accidents occur due to violations of safety and labor protection rules by employees who are in a different emotional state at the time of an emergency;
– injuries at the enterprise are directly related to the level of labor organization, compliance with the norms and rules of work in electrical installations and depends on the personality of the worker, his mental and physical condition, his reaction to emergencies, a tendency to unsafe methods of work;
– it is necessary not only to prevent risks, but also to pay attention to the composition of the staff, take into account the specifics of the work at the planning stage, introduce innovative devices that help the employee in difficult situations for him, as well as ensure control over the correctness of the actions performed by him.

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Conflict of Interest

The authors declare no conflict of interest.

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