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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ

Satbayev University

# ХАБАРЛАРЫ

# ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ
НАУК РЕСПУБЛИКИ
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# MODELING OF INJURY PROGNOSIS IN FERROALLOY PRODUCTION

**Abstract.** Metallurgical enterprises, in particular, metal production plants are among the most dangerous from the point of view of ensuring safe working conditions. The issues of the state of occupational injuries at industrial enterprises are of paramount importance in assessing the efficiency of production activities of enterprises, the degree of technical equipment and the organization of their production. Ferroalloy production is characterized by exposure to dangerous and harmful factors, which, in turn, is associated with the occurrence of risks of occupational injuries. In order to reduce the risks of occupational injuries, it is advisable to use modern methods of accounting, analysis and forecasting of injury indicators. As practice and experience shows, statistical methods of data processing are more responsible for this. This paper shows the possibility of determining the probability of injury at the Aktobe ferroalloy plant using the Poisson probability distribution law.

The study takes into account statistical materials on injuries for the period from 2012 to 2020. The obtained polynomials of the fourth degree make it possible to make a short-term (1-2 years forecast of injuries with a reliability of 93%. According to the obtained probability values for a period of 9 years, the average probability value was determined, which, according to short-term forecasting, can be taken as the forecast value of the probability of injury at the Aktobe ferroalloy plant for the next 3 years. This probability value corresponds to the number of accidents per year, equal to about 3 cases. In fact, in 2021, there were 3 accidents at the Aktobe ferroalloy Plant. Therefore, the forecast for 2021 was 100% reliable. From the above, it can be concluded that the forecast of the probability of injury using the probability distribution of Poisson can be used quite effectively as a forecast of injuries in the metallurgical complex of ferroalloy production of the Republic of Kazakhstan.

**Key words:** injury, danger, ferroalloy production, injury forecast, mathematical model.

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# ФЕРРОҚОРЫТПА ӨНДІРІСІНДЕГІ ЖАРАҚАТТАНУ БОЛЖАМЫН МОДЕЛЬДЕУ

**Аннотация.** Металлургия кәсіпорындары, атап айтқанда, металл өндіретін зауыттар қауіпсіз еңбек жағдайларын қамтамасыз ету тұрғысынан ең қауіпті болып саналады. Өнеркәсіптік кәсіпорындардағы өндірістік жарақаттанудың жай-күйі мәселелері кәсіпорындардың өндірістік қызметінің тиімділігін, техникалық қамтамасыз етілу дәрежесін бағалау және оларды өндіруді ұйымдастыру кезінде ең бірінші кезектегі маңызға ие. Ферроқорытпа өндірісі қауіпті және зиянды факторлардың әсерімен сипатталатын өндіріс, бұл өз кезегінде өндірістік жарақаттану тәуекелдерінің пайда болуымен байланысты. Тәуекелдерді азайту мақсатында жарақаттану көрсеткіштерін есепке алудың, талдаудың және болжаудың заманауи әдістері талап етіледі, және оған деректерді өңдеудің статистикалық әдістері жауап береді. Бұл жұмыста Пуассонның ықтималды таралуын пайдалану арқылы Ақтөбе ферроқорытпа зауытында жарақат алу ықтималдығын анықтау сипаттамасы келтірілген.

Зерттеу 2012-2020 жылдар аралығындағы жарақаттану бойынша статистикалық материалдарды негізге алып, төртінші дәрежелі полиномнан алынған жарақат туралы қысқа мерзімді (1-2 жыл), сенімділігі 93% болатын болжам жасауға мүмкіндік береді. 9 жыл кезеңінде алынған ықтималдық мәндері бойынша ықтималдықтың орташа мәні анықталды, және ол қысқа мерзімді болжамға сәйкес Ақтөбе ферроқорытпа зауытында келесі 3 жылға жарақаттану ықтималдығының болжамды мәні ретінде қаралды. Ықтималдықтың бұл мәні жылына шамамен 3 жағдайға тең болатын жазатайым оқиғалардың санына сәйкес келеді. Іс жүзінде 2021 жылы Ақтөбе ферроқорытпа зауытында 3 жазатайым оқиға болды. Сондықтан 2021 жылға жасалған болжам 100% құрады. Жоғарыда айтылғандарға қарап, Пуассонның ықтималды таралуын пайдалана отырып, жарақаттану ықтималдығының болжамы Қазақстан Республикасының ферроқорытпа өндірісінің металлургиялық кешенінде жарақаттану болжамы ретінде жеткілікті түрде тиімді қолданылуы мүмкін деген қорытынды жасауға болады.

**Түйін сөздер:** жарақаттану, қауіп, ферроқорытпа өндірісі, жарақаттану болжамы, математикалық модель.

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# МОДЕЛИРОВАНИЕ ПРОГНОЗА ТРАВМАТИЗМА В ФЕРРОСПЛАВНОМ ПРОИЗВОДСТВЕ

**Аннотация.** Металлургические предприятия, в частности, заводы по производству металлов относятся к разряду наиболее опасных с точки зрения обеспечения безопасных условий труда. Вопросы состояния производственного травматизма на промышленных предприятиях имеют первостепенное значение при оценке эффективности производственной деятельности предприятий, степени технической оснащенности и организации их производства. Ферросплавное производство характеризуется воздействием опасных и вредных факторов, что, в свою очередь, сопряжено с возникновением рисков производственного травматизма. С целью уменьшения рисков появления производственных травм целесообразно использование современных методов учета, анализа и прогнозирования показателей травматизма. Как показывает практика и опыт, этому в большей мере отвечают статистические методы обработки данных. В данной работе показана возможность определения вероятности травматизма на Актюбинском заводе ферросплавов с использования закона распределения вероятности Пуассона.

В исследовании учтены статистические материалы по травматизму за период с 2012 по 2020 г.г. Полученные полиномы четвертой степени позволяют делать краткосрочный (1-2 года) прогноз травматизма с надежностью 93%. По полученным значениям вероятности за период в 9 лет определили среднее значение вероятности, которое, согласно краткосрочного прогнозирования, может быть взято за прогнозное значение вероятности травматизма на Актюбинском заводе ферросплавов на последующие 3 года. Этому значению вероятности соответствует количество несчастных случаев в год, равное около 3 случаев. Фактически же в 2021 году на Актюбинском заводе ферросплавов было 3 несчастных случая. Поэтому на 2021 год прогноз в достоверности составил 100%. Из изложенного можно сделать вывод, что прогноз вероятности травматизма с использованием вероятностного распределения Пуассона может достаточно эффективно применяться в качестве прогноза травматизма в металлургическом комплексе ферросплавного производства Республики Казахстан.

**Ключевые слова:** травматизм, опасность, ферросплавное производство, прогноз травматизма, математическая модель.

**Introduction.** Occupational injuries (hereinafter referred to as OI) as a consequence of accidents and accidents at industrial enterprises is one of the urgent problems in all countries of the world. According to the International Labor Organization (ILO), more than 2 million people die, which is almost 5% of the total mortality rate on the planet, 270 million people are injured, 160 million people suffer from various diseases related to production. To date, the level of OI in Kazakhstan, as one of the CIS countries, is an order of magnitude higher than similar indicators in countries such as the UK, Germany, Canada, Japan, and the level of fatal injuries at work in our country is 2.5 times higher than in the USA, 7 times higher than in Japan, 8.7 times - than in England (Imangazin M.K. 2014).

Occupational injuries pose a serious danger to the health and life of people, especially workers of hazardous production facilities. In our country in recent years, according to statistics, there has been a slight decrease in the level of occupational injuries in the industry as a whole. Enterprises of the metallurgical industry, characterized by a high level of mechanization and automation of technological processes of production, are distinguished by a significant level of indicators of the danger of industrial injuries.

Moreover, in the metallurgical industries, there is an increase in injuries, in some cases with a fatal outcome. In this regard, the task of developing methods of preventive protection of workers from accidents and reliable prediction of the likelihood of injury at enterprises becomes relevant.

Practice shows that the main causes of injuries and accidents in the workplace are most often associated with engineering omissions, shortcomings in the organization of work on the operation of equipment, incorrect assessment of the state of affairs at work. That is, there are grounds to assert that the reason lies in the person himself, the so-called “human factor”. Both his own safety and the industrial safety of the enterprise as a whole depend on the psychological stability of the employee. Only when using an integrated approach to predicting injuries, taking into account the psychological stability of production personnel, it is possible to significantly reduce injuries at the enterprise and improve occupational safety, since psychological stability is the reserve that is currently not fully used in practice. (Uakhitova et al., 2022:2).

In the production enterprises of the mining and metallurgical industries, there is an established system of safe working conditions and the protection of the vital activity of workers. Metallurgical enterprises, in particular, metal production plants, are among the most dangerous from the point of view of ensuring safe working conditions. The issues of the state of occupational injuries at industrial enterprises are of paramount importance in assessing the efficiency of production activities of enterprises, the degree of technical equipment and the organization of their production. The risks of the likelihood of industrial injuries of varying severity increase significantly at enterprises with low culture and production technology. Ferroalloy production is characterized by exposure to dangerous and harmful factors, which, in turn, is associated with the occurrence of risks of occupational injuries. In order to reduce risks, modern methods of accounting, analysis and forecasting of injury rates are required, which is met by statistical methods of data processing.

The use of probabilistic methods for predicting injuries allows us to quantify the degree of randomness of injuries. Probabilistic methods of injury analysis are based on some initial statistical material. The more extensive this material is, the more reliable the conclusions obtained.

**Materials and methods.** One of the approaches to solving this issue is to use the fact that all dangerous events leading to injuries belong to groups of events that do not overlap in time (with the exception of group accidents) and are not related to each other

Therefore, we can consider the sum of a given number of events that led to injury over a certain period of time (decade, month, quarter, year, etc.) as a stream of random events. An event stream is a sequence of events that occur one after another at a certain point in time. The simplest (Poisson) is an event stream with the following three properties:

1) stationarity;
2) "lack of consequences";
3) ordinariness.

Like any random process, traumatism can be stationary (unchanging in time) and non-stationary (changing in time). The condition of no consequences, which is most characteristic of the simplest flow, means that events occur independently of each other. The ordinariness property means that the probability that more than one event will occur in a short period of time is negligible compared to the probability that only one event will occur. This means that events occur singly, and not in pairs or threes at the same time.

When adding (overlapping) a large number of ordinary, stationary or non-stationary flows with almost any consequence, a flow is obtained, arbitrarily close to the simplest. In practice, it is usually enough to add 4-5 threads to get a thread that can be operated on as the simplest.

Let $\lambda$ - be the density of the flow (the average number of events per unit of time).The probability that exactly m events will occur during the time $\tau$:

$$P_m(\tau) = \frac{(\lambda\tau)^m}{m!} \cdot e^{-\lambda\tau} = \frac{a^m}{m!} \cdot a^{-a}, \qquad (1)$$

In particular, the probability that the site will be empty (not a single event will occur) will be

$$P_t(0) = e^{-\lambda\tau} \qquad (2)$$

The physical meaning of the parameter $a = \lambda \cdot \tau$ is the average number of dangerous events during the time of $\tau$, that is, their mathematical expectation.

Consider the case when $\lambda$ = const. Indeed, the intensity of injuries is not constant over time. But even in this case, if the other two properties hold, we apply Poisson's law. If the event flow is non-stationary, its main characteristic is the instantaneous probability density over a time interval $(t, t + \Delta t)$.For such a flow, the number of events on a segment of length $\tau$, starting from the point t0, obeys Poisson's law:

$$P_m(\tau, t_0) = \frac{a^m}{m!} \cdot e^a, \quad (m = 1,2,3 \ldots .) \qquad (3)$$

where a is the mathematical expectation of the number of events in the area from t0 to t0 + τ, equal to

$$a = \int_{t_0}^{t_0+\tau} \lambda(t)\, \partial t, \qquad (4)$$

Figure 1 shows graphs of the distribution of a random variable X distributed according to Poisson's law, corresponding to different values of the parameter a.

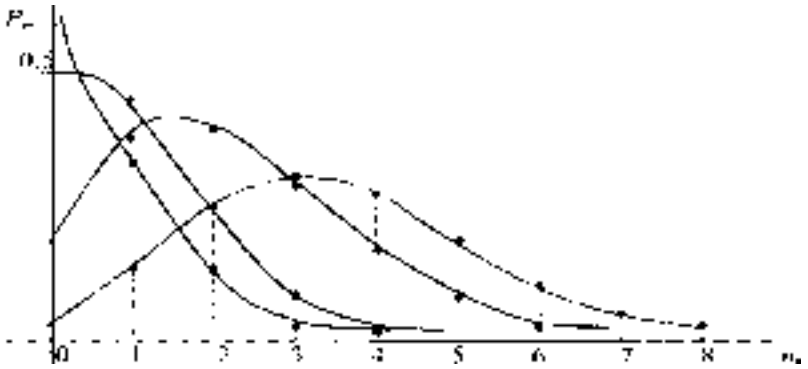

Figure 1 - Graphs of the distribution of a random variable X, where: a = 3,5; 2; 1; 0,5.

This shows that the Poisson distribution can be applied if it is used to predict the probability of injury for ferroalloy enterprises. The analysis of the above graph allows us to establish the possibility of determining the probability of the distribution of dependence on parameter a, i.e. the probability of industrial injuries.

Mathematical model of injury prognosis in ferroalloy production. The classical Poisson formula from has the form:

$$P_n(k) = \frac{\lambda^{\kappa}}{k!} \cdot e^{-\lambda} \qquad (5)$$

where λ = n·p is the constant average number of occurrence of an event, which, regardless of the number n, retains one value; n is the total number of employees of the enterprise (average annual composition); k is the number of accidents per year.

**Discussion.** According to formula (5), injury probabilities were determined for the enterprises of JSC "TNC "Kazchrome" in the period from 2012 to 2020. The data are presented in the following tables 1, 2. (Uakhitova et al., 2022:1).

The essence of short-term forecasting lies in the fact that the calculated values of injury probabilities for the period under study, i.e. for 9 years, determine the average possible probability of injury $p_{cp}$., which can be used to determine the expected number of accidents in the next 1-2 years. Then, according to Table 1, an approximate value of the number of accidents is selected corresponding to the value of the average probability obtained, and this number is inserted into a computer program to determine the probability of injury. It is possible that such a selection will be carried out several times until it completely coincides with the average probability. And when the output value of

the probability coincides with the expected average probability, these calculations end, the corresponding value of the expected number of accidents is taken as final and used as the received expected forecast value of the number of accidents – $k_{ож}$.

**Results.** Table 1 shows the actual values of injuries at the Aktobe ferroalloy Plant in the period from 2012 to 2020 (Uakhitova et al., 2022:1).

These data were used to compile a probabilistic Poisson distribution in order to obtain a functional dependence for short-term (no more than 3 years) forecasting of injuries at this enterprise. For this purpose, on the basis of the above formulas, the values of injury probabilities for these years were determined and by using the Microsoft Office Excel program, the functional dependence for short-term forecasting of injury probability at the Aktobe ferroalloy Plant for 2012-2020 was determined by the least squares method.

Table 1

Information on injuries at the Aktobe ferroalloy Plant in the period from 2012 to 2020

| № п/п | Indicators | The value of the indicator by year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| 1 | Number of employees in organizations, B, people. | 3161 | 3311 | 3784 | 3872 | 3991 | 4236 | 4278 | 4402 | 4286 |
| 2 | Number of accidents, A | 7 | 4 | 2 | 1 | 1 | 2 | 2 | 6 | 7 |

Table 2

Information on the probabilistic Poisson distribution for injuries at the Aktobe ferroalloy plant in the period from 2012-2020 years

| № п/п | Name of parameters | The value of the indicator by year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | **X** | 7 | 4 | 2 | 1 | 1 | 2 | 2 | 6 | 7 |
| 2 | **p** | 0,149 | 0,195 | 0,27 | 0,367 | 0,367 | 0,27 | 0,27 | 0,16 | 0,149 |

Table 2 shows the values of these probabilities or the Poisson distribution for 2012-2020 is given. Using the data from the second row of Table 2, we will plot the functional dependence of the probability of injury p on time T (Fig. 2), i.e. the period from 2012 to 2020 and determine the functional dependence in an analytical form (in the form of a formula).

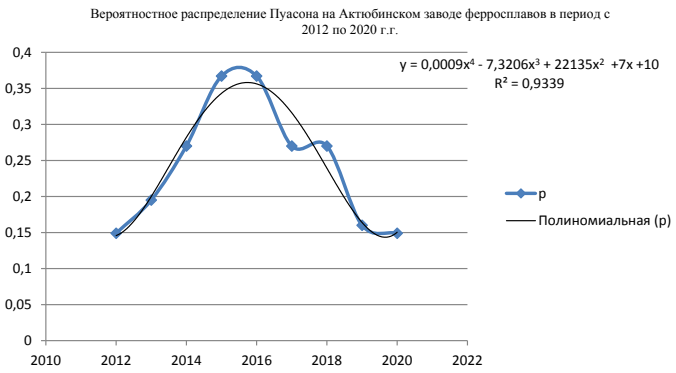


Figure 2 - Probabilistic Poisson distribution at the Aktobe ferroalloy plant in the period from 2012 to 2020

Fig.2 shows the functional polynomial dependence of the probability of injury at the Aktobe ferroalloy plant in the period from 2012 to 2020. As we can see, the approximation coefficient is quite high (R=0.9339), which indicates the high reliability of a certain formula - a polynomial of the 4th degree:

$y=0{,}0009x^4-7{,}3206x^3+22135x^2+7x+10$

**Conclusions.** In conclusion, we note that the Poisson distribution is a fairly common method.The special property of equality of expectation and variance is often used in practice to determine whether a random variable is distributed according to Poisson`s law. Important is the fact that Poisson`s law allows you to find the probability of an event independent repeated trials with a large number of repetitions of the experiment with a small unit probability

It is established that the probability of industrial injuries at enterprises of the metallurgical industry can be represented as the simplest flow of events characterized by stationarity; "absence of consequences"; ordinariness and is described by Poisson's law of probability

It is found that the probability of industrial injuries during the study period is approximated by a fourth-degree polynomial of the form y=0.0009x4-7,3206x3+22135x2+7x+10.

During the study period, the average probability of industrial injuries at the enterprise $\mathbf{p_{cp.}} = 0.244$, which corresponds to the forecast value of the probability of injury at the Aktobe ferroalloy Plant for the next 3 years.

The data obtained correspond to the actual values of the number of industrial injuries at the Aktobe ferroalloy Plant for 2021, equal to three.

From the above, it can be concluded that the prediction of the probability of injury at the enterprises of the metallurgical complex of ferroalloy production of the Republic of Kazakhstan is recommended to use the Poisson probability distribution law.

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