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Predicting accidents in the mining industry in Zimbabwe in order to develop preventive measures to reduce them

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Introduction. Industrial accidents are associated with various factors: human, social and economic problems, which we must strive to eliminate, thereby ensuring a safe working environment. Statistics on occupational injuries are necessary to assess the degree of hazard and potential risks associated with occupational factors to protect workers. Labor inspectorate statistics play an important role in developing national policies, systems, programs and strategies to improve safety and working conditions for miners in Zimbabwe. Labor Inspection in Zimbabwe is one of the main safety control mechanisms. Labor inspection statistics enable the government to monitor the mining industry and better analyze mining safety compliance issues.

Problem Statement. The article discusses the prediction of accidents in the mining industry of the Republic of Zimbabwe in order to reduce the incidence of injuries. Economic and social development in the mining industry requires reliable analysis of injury statistics. Statistics of injuries in various production processes are given.

Theoretical Part. In the process of data analysis, interpolation algorithms are used embedded in mathematical software. Statistical reports on occupational injuries provided by the Federal State Statistics Service were used as basic information.

Conclusion. Mathematical forecasting of industrial injuries in the mining industry in Zimbabwe allows us to determine the likely values of the predicted indicators.

Keywords: Zimbabwe, analysis, forecast, injuries, mining industry, extrapolation, safety measures, probable values.

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Introduction. The contribution of the mining industry of Zimbabwe to the country's GDP is about 9 % and continues to increase. According to experts, the dynamics could be even more optimistic if it were not for the acute shortage of qualified engineers, which, as in many other African countries, hinders economic development. Zimbabwe produces more than 40 types of minerals, such as platinum, gold, nickel, copper, diamonds, and coal. The government of Zimbabwe counts on the assistance of Russia and UNESCO in reforming the mining industry by improving the competence of engineers and introducing modern technologies, improving safety and improving working conditions [1].

Artisanal and small-scale mining is one way for workers to survive the economic crisis in Zimbabwe. In the country with limited opportunities and very high unemployment, more than 90% of cooperatives help young people feed their families. Therefore, it is necessary to support miners at the state level in order to avoid deadly mining conditions.

In 2018, miners extracted 21.7 tons of minerals, while mining companies — 11.5 tons, despite the fact that miners use simple tools such as picks, shovels, ropes and buckets [2]. However, despite such a high level of production, the legislation does not regulate regulatory relations with miners working in very difficult and dangerous conditions with violations of labor protection and safety standards, which must be strictly observed in the mining industry [3]. To improve working conditions, the cooperatives of miners want to submit amendments to the law on minerals for discussion. They argue that legal regulation at the national level can improve the situation in the field of labor protection and safety, as well as contribute to the development of mining activities.

Problem Statement. The study of the causes of injuries and occupational diseases will reduce dangerous and harmful working conditions at the workplace. An accident, despite being a stochastic event, is usually affected by dangerous and harmful factors of production, as well as various deviations from its regulations. Accidents at work should be considered as signals of occupational risks, most often associated with the unsatisfactory state of preventive work to prevent injuries at the production site, in the shop, building and in general at the enterprise.

The creation of a mathematical model that can be used to predict accidents will allow the government and the mining industry of Zimbabwe to assess occupational risks and develop measures to preserve the health of workers and reduce all types of costs associated with adverse working conditions. The main goal of the study is to create a mathematical model based on the known statistical data that will allow us to evaluate the most repeated accidents and then take measures to reduce them.

Theoretical Part. For mathematical modeling of the accident forecast, we will use statistics on fatal injuries in Zimbabwe for 1990-2014. (fig. 1) [4]. The most common causes of injuries during mining are presented in (table 1) [5, 6]. Table 2 shows the operations and means that lead to injuries, as well as the corresponding causes.

Table 1

Causes and types of injuries in the mining industry in Zimbabwe

Types	Causes
Electrical injuries	Violation of the integrity and functions of tissues and organs as a result of electric current, exceeding the permissible level of electrical voltage in the network
Getting trapped in mines	Getting a miner trapped as a result of a collapse, violation of the size of passageways for people
Explosions of pressure vessels	Interruptions in the supply of compressed air, exceeding the temperature and volume of the supplied liquids and gases, violation of the integrity of the pipeline
Explosions of materials and substances	Rock fall, close proximity to the site of the explosion
Falling, rolling, or sliding of rocks in the mine	Works without safety belts, landslides, subsidence, violation of the permissible slope, lack of bypasses, bridges
Falling of the facade, edges or sides of rocks in the mine	Works without safety belts, untimely fixing of mine workings, landslides, subsidence phenomena, violation of the permissible slope, lack of bypass workings, bridges
Falling of the roof, rear, or front parts of rocks	Violation of the location and operation of hydraulic equipment, mechanisms, explosions of pressure vessels, violation of the cross-section of workings, untimely fixing of mine workings
Fires and fire injuries	Malfunction of ventilation equipment, untimely ventilation of mines, exceeding the maximum permissible concentration of explosive dust, gas, electrical connection

Table 2

Operations, means and causes of injuries

Operations and means	Causes
Processing of rock	Works with violation of the equipment operating instructions, self-modification of technological equipment without approval from the manufacturer
Hand tools	Use of the tool in the absence of an individual battery lamp, lack of personal protective equipment
Non-driving transportation	Lack of necessary barriers on the way, lack of cargo fasteners when moving, overloading wheelbarrows
Traction carriage	Lack of fencing, lack or failure of signal to start movement of the traction equipment and power supply equipment, violation of the speed of movement of the rolling stock, violation of dimensions of rolling stock
Hoists	Exceeding the truck limit, the lack of or improperly secured cargo, defective mechanism, in the area of lifting mechanisms the presence of people is forbidden, the fault of the winch, bucket, and other mechanisms

The methodological basis of the work is the analysis of accident statistics in the mining industry of Zimbabwe and the use of mathematical modeling to create an adequate model for predicting such statistics. As a result, it is expected to be possible to predict injuries, which will allow mining companies to implement measures to prevent or eliminate accidents that may occur in the future [7].

Injury data is a complex, multi-factor statistical aberration. When analyzing random functions, it is necessary to determine the degree of error in the prediction of a random variable and which part of the sample makes the maximum error.

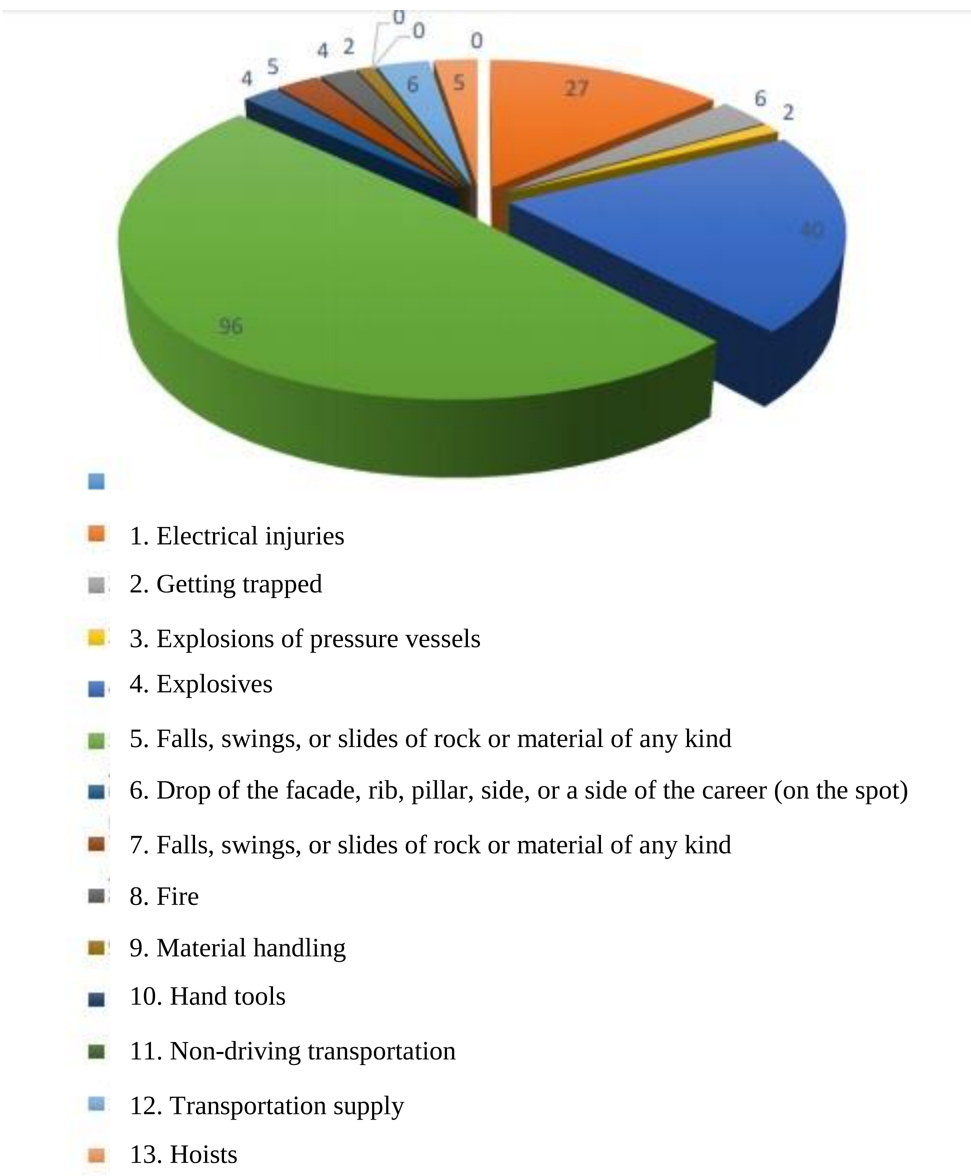

Fig. 1. Statistics on fatal mining injuries in Zimbabwe for 1990-2014

The following methods are used to analyze the statistics on occupational injuries:

— extrapolation — the main method of forecasting, which is based on forecasting events based on indicators of previous years [8];

— regression — an additional method for determining the error of calculations based on predictions in those years that are already available in statistics;

— fractal analysis is used in system diagnostics to solve problems related to the use of time series. [9];

— statistical indicators of random number sampling: arithmetic, geometric, and harmonic averages, as well as variance and coefficient R^2 [7].

In this study, we will use extrapolation (Fig. 2). Extrapolation in MathCAD is the prediction of parameter values by means of functions beyond the scope of definition. In particular, we will use the function predict *(v, m, n)*, where *v* is a vector of real values taken at regular intervals of the argument values; *m* is the number of elements of the data vector *v*, according to which extrapolation is built; *n* is the number of statistical data values that need to be predicted. This function has a built-in linear extrapolation algorithm based on the analysis of the spread of parameter values [10].

Extrapolation in MathCAD allows you to perform calculations in a mode where you can directly detect, localize, and eliminate forecast errors. The first step is to check the optimal number of parameter values for the forecast and set a specific error value. At the next stage, the vector of real values is extrapolated over the selected period, and the value of the argument is taken at regular intervals. To check the adequacy, the coefficient R^2 is used — the ratio of the variances of the original values of the data vector and the debug values calculated for the corresponding time interval.

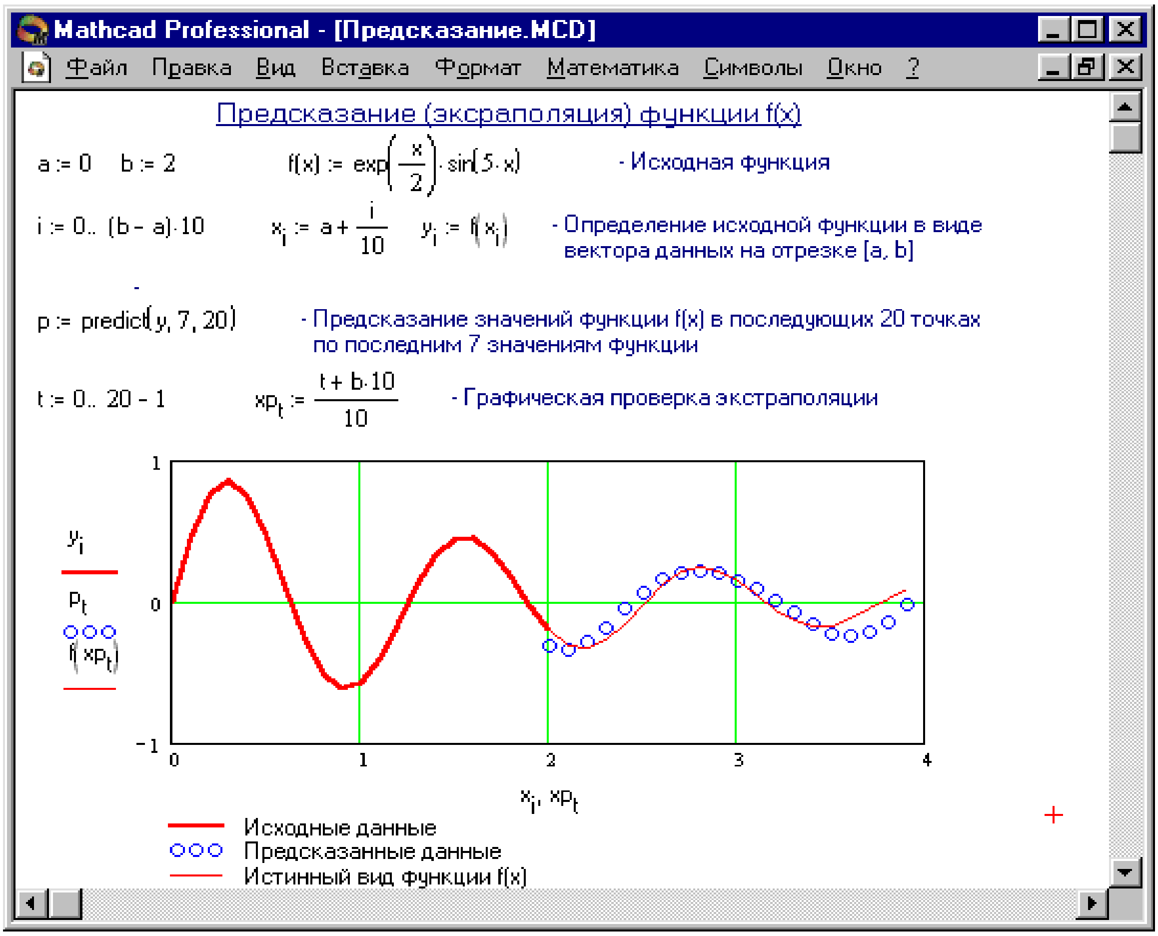

Fig. 2. Example of prediction of the values of the function f (x)

Main results of predictive calculations. Calculations and predictions were made for the types, operations, and means of injury. Figures 3-12 show the results of some calculations.

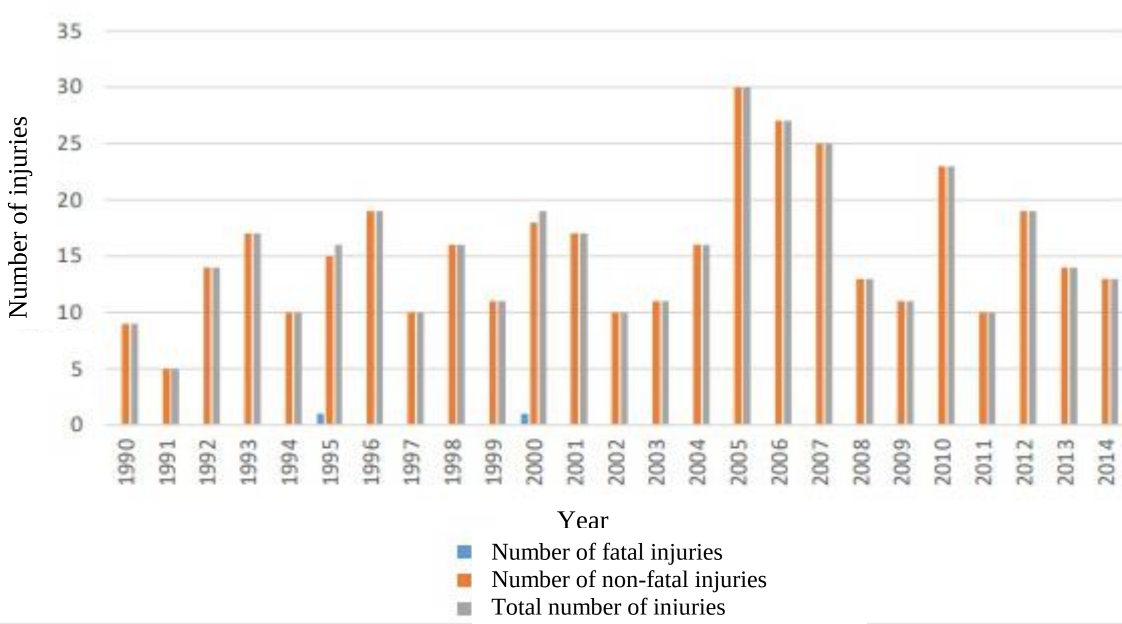

Fig. 3. Statistics of injuries in pressure vessels explosions

$$SR\_VYA := \sum_{m=0}^{4} \frac{VYA_m}{5} \qquad SR\_VP := \sum_{m=0}^{4} \frac{vp_m}{5}$$

$$SR\_VYA = 15.8 \qquad SR\_VP = 16.817$$

$$DISP\_VYA := \sum_{m=0}^{4} \frac{(SR\_VYA - VYA_m)^2}{5} \qquad DISP\_VP := \sum_{m=0}^{4} \frac{(SR\_VP - VYA_m)^2}{5}$$

$$DISP\_VYA = 21.36$$

$$DISP\_VP = 22.395$$

$$R2 := \frac{DISP\_VYA}{DISP\_VP}$$

$$R2 = 0.95377999214$$

Fig. 4. Debugging the forecast by using the coefficient R^2:.:SR_VYA — the arithmetic average of the debug values from the data vector for 2010-2014; SR_VP — the arithmetic mean of the predicted values for 4 years; DISP_VYA, DISP_VP — dispersion of the two analyzed samples; R2 — regression coefficient R^2, which is equal to 5-10 %

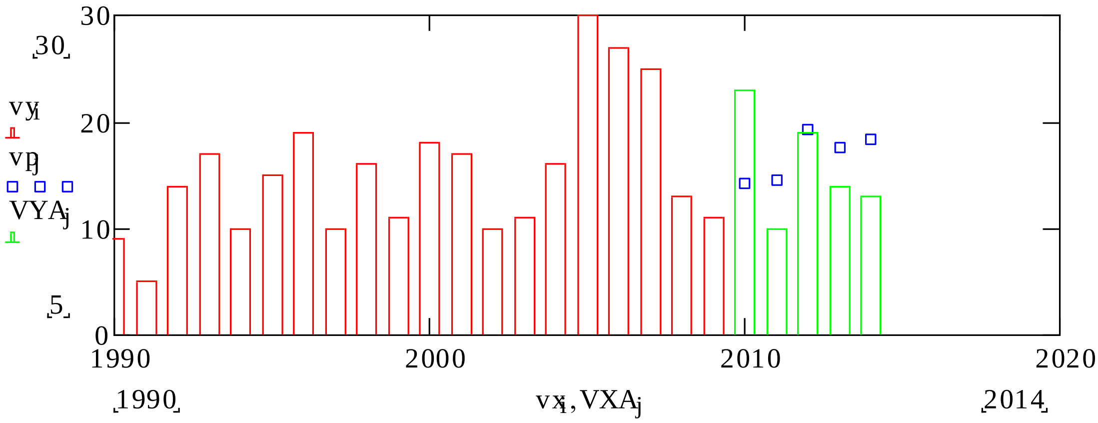

Fig. 5. Debugging the forecast using the R^2 coefficient and the predict *(v, m, n)* function for pressure vessel explosions

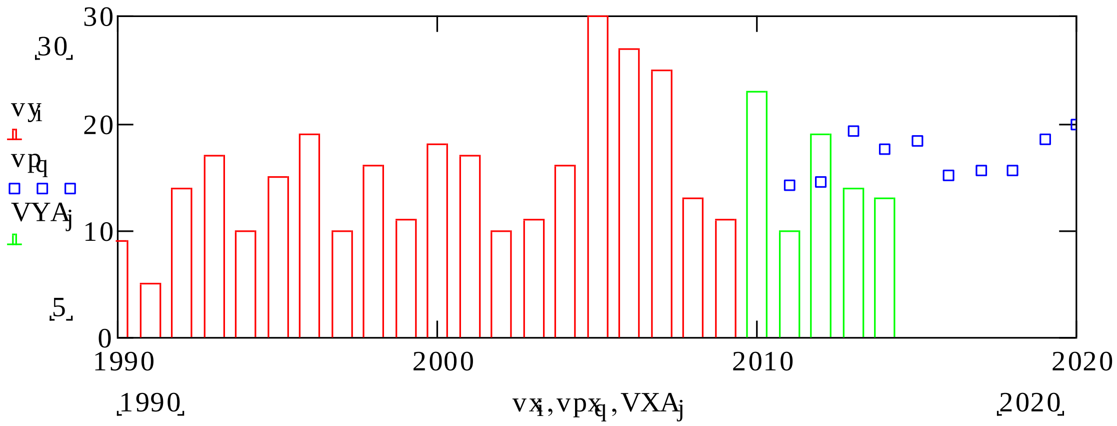

Fig. 6. Result of creating a well-established forecast until 2020 using the predict function for pressure vessel explosions

To calculate the forecast of occupational injuries, we have used statistical data on pressure vessel explosions provided by the Zimbabwe Labor Inspectorate for 2010-2014. The calculations show that the number of statistical data values that need to be predicted (parameter n) is 12 [11].

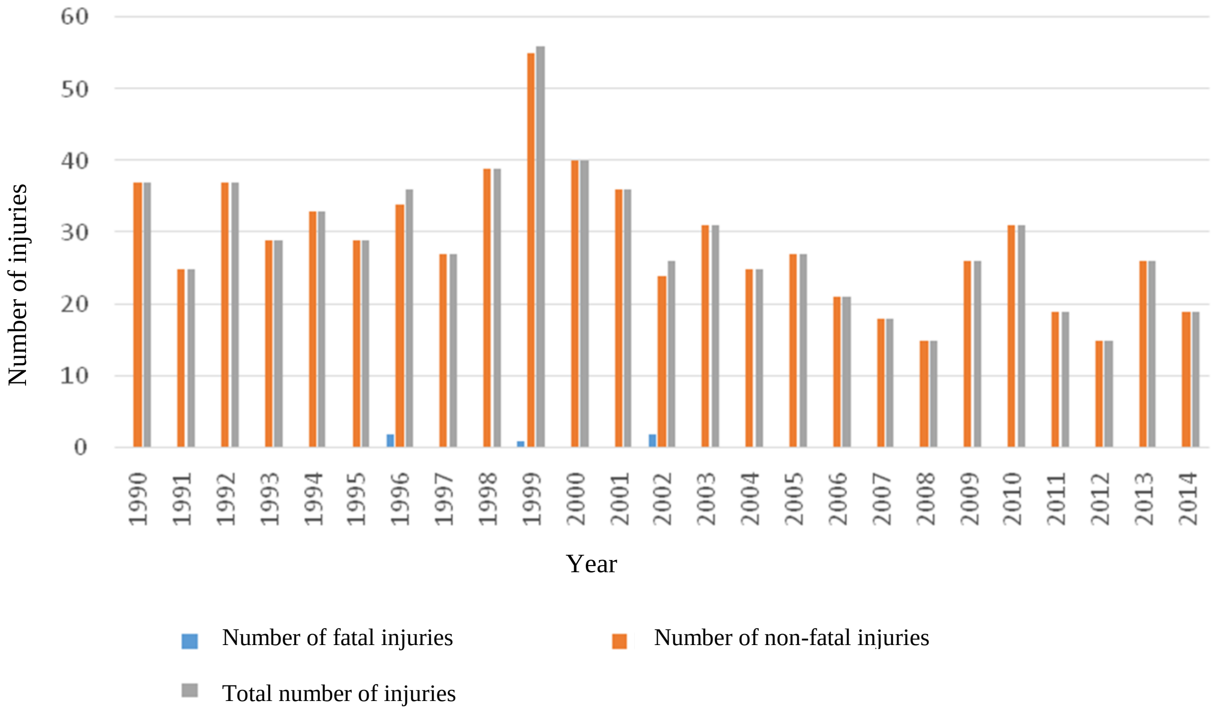

Fig. 7. Statistics of injuries caused by collapses, falls, rolling or sliding of rocks and materials of any kind

In 2016-2017, there was an increase in the number of deaths. 31.01.2018 due to the storm, the power supply to one of the mines stopped, all 955 miners were underground, and they were able to extract people from the mine only on February 2. The production and technical base of the mine was not ready for such an accident. There are many accidents in the mining industry in Zimbabwe. Such accidents are a warning to the relevant companies, which should review and improve the safety measures.

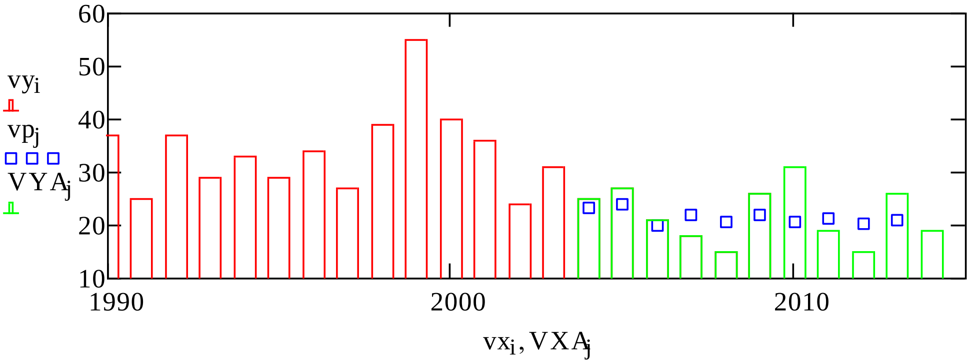

Fig. 8. Debugging the forecast using the R^2 coefficient and the predict *(v, m, n)* function for injuries caused by collapses, falls, rolling, or sliding of any type of rock or material

In February 2019, the Cricket and Silver Moon platinum mines in the small village of Battlefields, 175 km away from Harare, were flooded as a result of heavy rains. 28 miners died. Eight people were saved, but the continuing downpours made rescue efforts difficult, resulting in a large number of victims. [2].

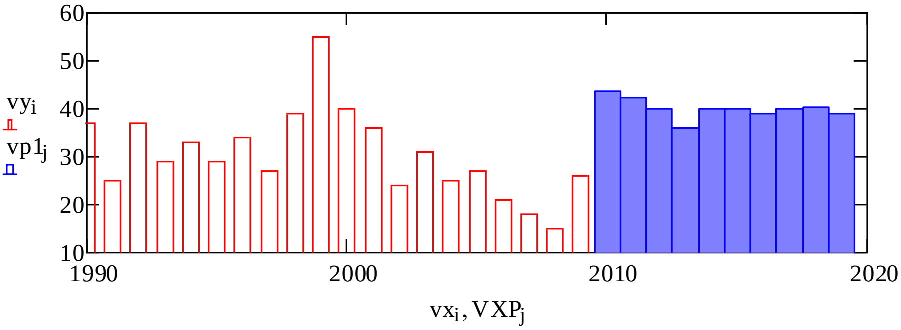

Fig. 9. Forecast for collapses, falls, rolling, or sliding of rock and material of any kind

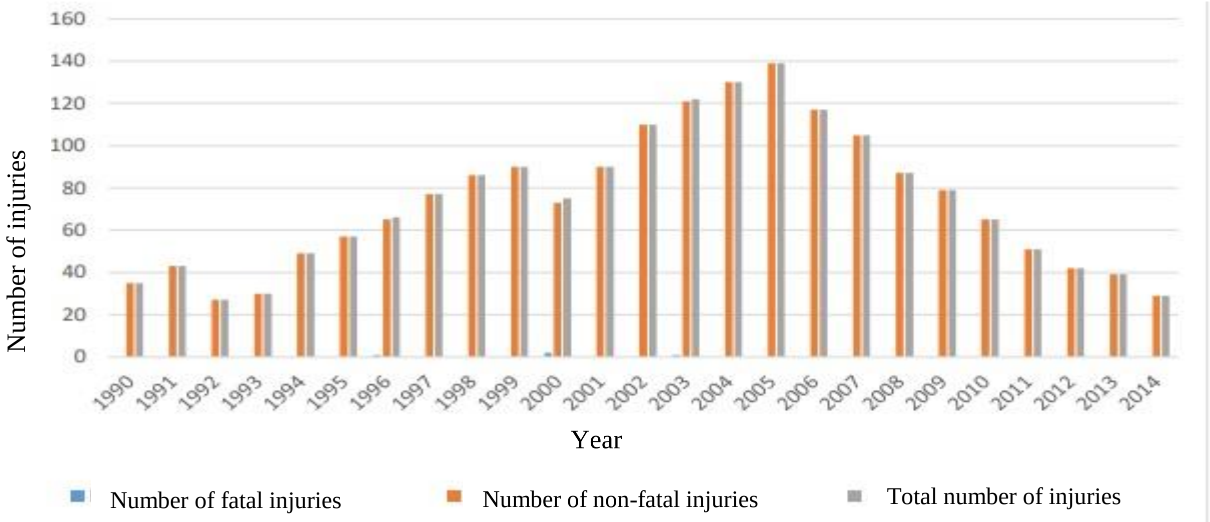

Fig. 10. Statistical data of traumatism in the fall of the facade, edges or the side of rocks in the mine

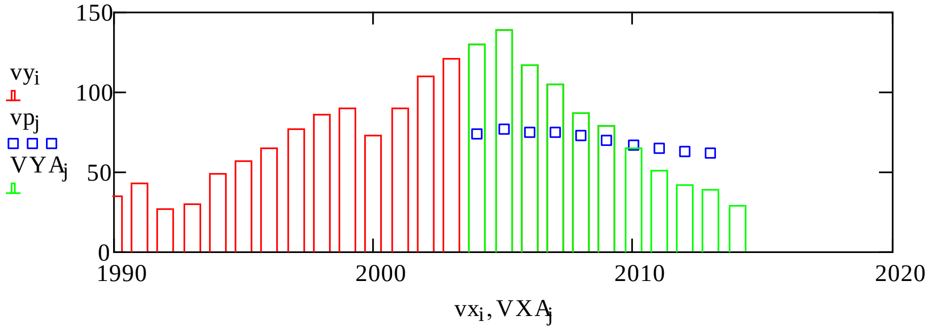

Fig. 11. Debugging the forecast by the coefficient R^2, and the predict *(v, m, n)* function in the fall of the facade, the edges or sides of rocks in the mine

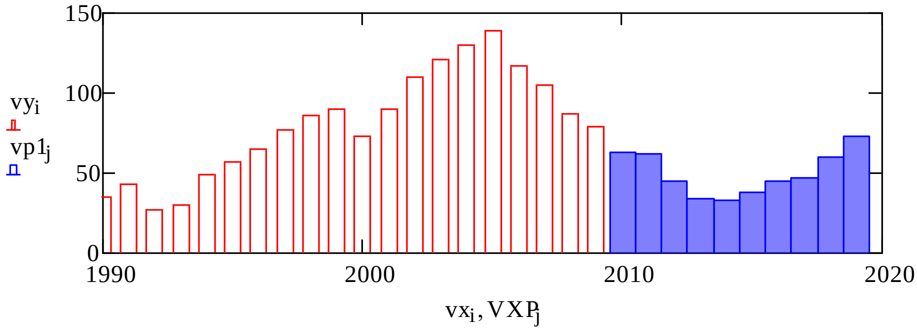

Fig. 12. Forecast of the fall of the facade, the edges or sides of rocks in the mine

Conclusion. For the sample taken as an adequacy testing example, the parameter R^2 was used, the value of which was 95.4 %. In this regard, we can conclude that the forecast error does not exceed 10 %.

Thus, mathematical forecasting of industrial injuries in the mining industry in Zimbabwe allows you to determine the possible number of accidents. This makes it possible to use such data to develop preventive measures, as well as rationally plan the allocation of funds and equipment to improve working conditions in the industry.

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