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# **FUZZY SET THEORY APPLYING TO ACCIDENT OR EMERGENCY FORECAST: CASE STUDY OF SAFETY BREACH IN MINE**

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## **ABSTRACT**

*The paper deals with the problems of industrial accidents on coal-mining enterprises of Russia. Relevance of study is proved since rate of accidents in coal-mining industry is high as compared to that in the countries, leading in volumes of production. The main problem here is the fact that hidden causes for occurring most accidents are still not fully examined. Most accidents being the primary reasons for failed industrial injuries and incidents are not identified so far. Currently there is a task of establishing a system for accounting, analyzing, and predicting probability for violations of industrial safety rules, where the major problem lies in availability of non-identified cases, when the workers use hazardous methods of work.*

*The paper is devoted to a way of solving the problem in question, namely, to use of statistical method of forecasting through fuzzy set theory. The key approach described in the paper involves construction of membership function characterizing frequency of occurrences when workers fail to comply with industrial safety rules, and constituting a tool for assessing dynamics of workers' non-compliances with labor and industrial safety norms thereafter. An example of using the forecast method is presented related to the mine in operation based on data about identified violations.*

*Practical use of accident probability forecast method given in the paper enabled to achieve the following results:*

*- probable amount of labor safety rules violations for subsequent period was predicted to timely develop and introduce preventive measures;*

*- an opportunity for accounting non-identified cases of violations using fuzzy set theory was described.*

*The paper materials may be of advantage for labor safety departments and production control departments as methodological materials to employ proactive approach to decrease the number of industrial violations, and, as a result, facilitate reduction of the number of industrial accidents.*

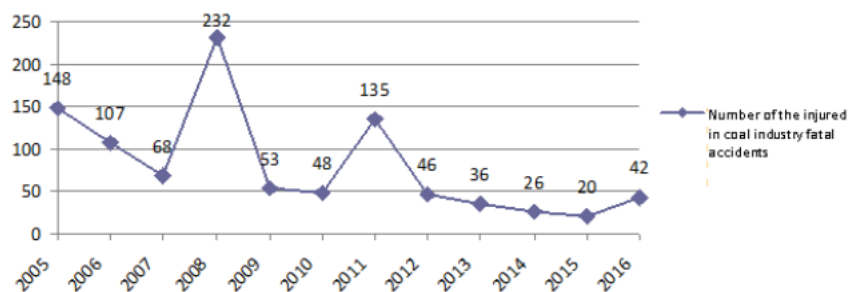
**Keywords:** forecast, fuzzy sets, industrial accidents, non-identified violations, violation of labor safety.

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## 1. INTRODUCTION

Statistics of industrial accidents in coal-mining industry of Russia is not uniform with the common tendency for decreasing over the last 10 years [1-5]. It can graphically be presented as a broken line indicative of repetitive increase in the number of accidents (Fig.1)



**Figure. 1** Statistics of accidents in Russian coal industry

It should also be noted that the results obtained in 2016 shown that fatalities went back to the same level reached 5 years ago. When talking about fatalities in mines, one cannot but mention accidents since they are the main reason for deaths of most workers according to overall statistics.

Statistical analysis is currently the basic method for decreasing rate of accidents. It works through the “consequence and cause” formula. The consequence here is the fact of accident and injury as a result (of varying severity, up to and including fatal degree), the reason constitutes conditions, actions or series of actions and conditions that resulted in the event of fatal accident. The order of “consequence - cause” is the very key feature, since experts infer the reasons and further develop measures to eliminate or prevent thereof from examining the accident that had already occurred [6,7].

The paper describes a method used for decreasing rate of accidents based on the “cause - elimination of cause” formula that facilitates increasing efficiency of accident prevention.

Nowadays, high quality standards of assuring safety, codes of practices, requirements, and rules comprising years of experience in production and work of the best industry and production safety experts have been utilized in Russia and throughout the world. As a result, state rules and standards incorporate maximum number of possible factors causing accidents or emergency situations [8]. Therefore, the given method implies that the “cause” constitutes violation of the above-mentioned rules and codes. With the information about possible future violations at hand, it will be possible to design preventive measures. These measures will allow to focus on identifying, forecasting and preventing violations, excluding “consequence” as an accident rate from the formula. The suggested method is based on predicting possible violations of safety requirements in future and developing preventive measures.

Prediction of events and conditions is not common in the area of labor and production safety. Long-term forecasts to assess economic effect [9] mostly prevail. Incompleteness of statistics, complexity of processing basic data, and multiple factors influencing the result of forecast, unaccountable in “man-technological environment” system [10], most often specify unpredictability to evaluate probability of accident occurrence.

These problems shall be addressed through fuzzy set method, namely, statistical method of linguistic term membership function described by Borisov A.N. and Krumberg O.A. in 1990 [11, 12].

Long-standing problem of safety rules violations, unidentified in the course of industrial inspection, is of particular importance for mines. Length and inaccessibility of excavations slows down their inspection decreasing efficiency and, thus, increasing ratio of violations identified and hidden, in favor of the latter [13-24]. It also hinders the process of forecasting since causes withholding of statistical data and subsequent mispresenting of forecast results. Fuzzy set theory addresses this problem through assigning linguistic terms, hence, avoiding precise quantity parameters, however, creating possibility for making reliable prediction [25].

## 2. MATERIALS AND METHODS

The method is based on processing statistical data. To characterize an element, estimation of using the concept that specifies fuzzy sets is assumed as a degree of the element membership to the set. Here, “RARELY”, “OFTEN”, “VERY OFTEN”, “CRITICALLY OFTEN” will be the linguistic terms, labor safety expert (or a person in charge of in-situ labor safety) will use to describe violations committed by the mine workers. Each value of linguistic variable is described by individual membership function. To apply this method, it is necessary to introduce a system of regular monitoring to collect the required statistical information.

Terms generalize the number of events identified precisely through industrial inspection, and the number of events probably occurred but not accounted for some reasons.

To register unsafe behavior of workers and record labor safety violations, it is suggested to build a membership function of linguistic terms using available statistical data. Function  $\mu_A(u)$  assigns to each element  $u \in U$  the number out of interval [0, 1], characterizing the degree of element  $u$  membership to set  $A$ . Suppose that labor safety specialist monitoring the worker’s operations during certain period of time, focuses  $n$  times its attention on the fact whether there was violation ( $A$ ) committed by the worker or not. Event of inspecting  $n$  times whether violation occurred or not shall be called estimating. Let there be worker’s violations in  $k$  inspections. Then a specialist registers frequency  $p=k/n$  of violation occurrence and estimates it using the above-mentioned terms [8].

To establish the limits used for assigning any given term, the value of maximum allowable amount of violations shall be introduced. It specifies that set of violations when there was no accident, and shall be calculated according to formula:

$$P = \frac{N_{t_s}}{t_s}, \text{ where} \tag{1}$$

$N_{t_s}$  – number of violations over  $t_s$  period

$t_s$  – maximum period of mine operation without accidents.

The terms have the following limits given in Table 1.

**Table 1.**

Ranges of values for linguistic terms

Description of term	Description of violation feasibility	Numerical estimation
Rarely	Violations are recorded rarely, under certain circumstances	$0 < b < 0,75p$
Often	Violations are recorded often, under certain circumstances	$0,75p \leq b < 1,25p$
Very often	Violations are recorded with unfailing regularity	$1,25p \leq b < 1,75p$
Critically often	Violations are recorded in most cases of inspecting.	$1,75p \leq b$

Where  $b$  –number of violations recorded to date;  $p$  – maximum allowable number of violations in mine.

This criterion first and foremost customizes the prediction method for each production since every mine has its individual coal production output, various mining and geological, technical, and organizational conditions influencing anyway the rate of accidents and emergency situations.

Secondly, this parameter ensures self-improvement of forecast method. The prediction results and successful introduction of preventive measures will enable to reduce the number of violations and increase maximum period of mine operation with no accidents, thus, regularly decreasing parameter  $P$ .

Most statistical methods base upon condition that equal amount of information will be collected at each period of time. Our case implies equal number of inspections to identify violations. However, actually this condition is often not met, therefore, an empirical table shall be made, where observation data might be unevenly distributed over time periods.

Statistical data about inspections and number of violations identified are summarized in the table 2.

The table registers how many times the meaning of a term was used, to distinguish how many violations were identified in a certain period of time. The data shall be accumulated based on not only internal department production inspection, but inspection of regulatory authorities. There is also information from the other specialists (site supervisors, foreman, etc.). After making clue matrices, their transformation, use of key features of membership functions, a membership function for each linguistic term to a certain period of time will be obtained.

**Table 2.**

Table of production inspection data

Meaning	Intervals									
	1	2	3	4	5	6	7	8	9	10
Very rarely	$b_{ij}$	$b_{12}$	$b_{13}$							
Rarely	$b_{21}$	$b_{22}$								
Often	$b_{31}$									
Very often										

The above clue matrix can be used to process statistical data. Elements of clue matrices shall be calculated by formula:

$$k_1 = \sum_{i=1}^4 b_{ij} \quad (2)$$

Clue matrix constitutes a certain line, from which maximum element  $k_{\max} = \max k_j$  is selected. Afterwards, all elements of clue matrix are transformed according to formula:

$$c_{ij} = \frac{b_j k_{\max}}{k_j} \quad (3)$$

$i = \overline{1,5}, j = \overline{1,20}$  (depending on clue matrix obtained)

Membership function shall be calculated by formula:

$$\mu = \frac{c_{ij}}{c_{imax}} \quad (4)$$

Construction of the obtained function curve and addition of the certain relationship between occurrence of accident and violation of safe working practices committed by the worker will facilitate forecasting the number of accidents that can occur.

According to the behavior of the function values over various time periods, quality assessment of the taken measures aimed at eliminating (minimizing) labor and industrial safety violations committed by workers can be made. The work done will facilitate identification of both the specific nature of violations and key aspects to develop measures.

### 3. RESULTS

Following is an example of using method of forecasting violations of safety rules based on data obtained in the mine over two months.

**Table 3.**

Data on identified violations of safety rules in the mine

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Number of violations	10		3						17	4	1	3			3	14	month 1

number of violations	10							3	4	7				3	3			10	month 2
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Day	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
Number of violations		3				7	3									month 1
Number of violations				10		4	21				8	4	5			month 2

Maximum period of mine operation without accidents  $t_s - 99$  days.

Number of violations identified in the mine over period  $t_s, N_{t_s} - 254$ .

$$P = \frac{254}{99} = 2,57 \text{ violations/day.}$$

The following table shows the ratio of the number of violations identified to the maximum allowable P.

**Table 4.**

Ratio of the number of violations identified to the maximum allowable P

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
	3,90	0,00	1,17	0,00	0,00	0,00	0,00	0,00	6,63	1,56	0,39	1,17	0,00	0,00	1,17	5,46	month 1
	3,90	0,00	0,00	0,00	0,00	0,00	1,17	1,56	2,73	0,00	0,00	1,17	1,17	0,00	0,00	3,90	month 2

Day	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
	0	0,00	1,17	0,00	0,00	0,00	2,73	1,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	month 1
	0	0,00	0,00	0,00	3,90	0,00	1,56	8,18	0,00	0,00	0,00	3,12	1,56	1,95	0,00	month 2

A week was a period chosen for forecasting. Values from Table 4 with 1-day period shall be transformed into Table 5 values with 1-week period:

**Table 5.**

Week-wise ratio of the number of violations identified to the maximum allowable P

Week No.	1	2	3	4	5	6	7	8	9
	3,90	0,00	1,17	2,73	0,00	0,00	1,17	0,00	0,00
	0,00	6,63	5,46	1,17	0,00	0,00	1,17	3,90	3,12
	1,17	1,56	0,00	0,00	0,00	1,17	0,00	0,00	1,56
	0,00	0,39	1,17	0,00	3,90	1,56	0,00	1,56	1,95
	0,00	1,17	0,00	0,00	0,00	2,73	3,90	8,18	0,00
	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Based on the table data, it shall be calculated how many times any given term was assigned as per table 1.

**Table 6**

Week-wise assignment of linguistic terms

Term\Week	1	2	3	4	5	6	7	8	9
Rarely	0	1	0	0	0	0	0	0	0
Often	1	1	2	1	0	1	2	0	0
Very often	0	1	0	0	0	1	0	1	1
Critically often	1	1	1	1	1	1	1	2	2
Total	2	4	3	2	1	3	3	3	3

Now, it is possible to obtain values of clue matrix using formula 2 and transform them by formula 3.

**Table 7**

Clue matrix ( $c_{ij}; c_j$ )

c	i1	i2	i3	i4	i5	i6	i7	i8	i9
j1	0,00	1,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
j2	2,00	1,00	2,67	2,00	0,00	1,33	2,67	0,00	0,00
j3	0,00	1,00	0,00	0,00	0,00	1,33	0,00	1,33	1,33
j4	2,00	1,00	1,33	2,00	4,00	1,33	1,33	2,67	2,67

Finite membership function is the ratio  $c_{ijk} / c_{max}$  ( $c_{max}=4$  for example)

The following curves shall be constructed for each term (Fig. 2 - Fig. 5).

#### 4. DISCUSSION

When constructing polynomial line of a trend, 10<sup>th</sup> week prediction shall be obtained. Correlation of the trend lines with the four terms shows that “OFTEN” term will be most probable for the forthcoming tenth week. Approximation accuracy is proved by the highest of all the other and close to 1 parameter  $R^2$ .

To sum up: forecast has shown that probable number of violations for the 10<sup>th</sup> week is the “often” term quantity ( $0,75p \leq b < 1,25p$ ), that provides a reason for selecting preventive measures. Measures shall be chosen based on factors specified in such prescriptions for violations over 8-9 weeks as: professional occupation of the person committed violation, area of safety for a particular violation, location of the most frequently committed violations, etc.

The materials are of practical relevance for large enterprises with well-organized production inspection operating in an ongoing way.

#### 5. CONCLUSION

The study presents:

- mathematical model of processing statistical data, allowing to analyze dynamics in detail and forecast violations based on study cases;

- possibility for analyzing the specific nature of violations occurred to increase efficiency of measures taken to decrease rate of accidents;

- example of forecasting using data on violations obtained during industrial inspection in a productive mine.

The method described has the most significant practical implications that involve proactive approach as the most important one for decreasing rate of accidents. After making all stages of forecasting automatic, use of this method in industries will become routine that will simplify analyzing the state of labor and industrial safety and enable to save time when choosing preventive measures.

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