On the results of applying fuzzy logic in the analysis of industrial injury rates aspects for the magnesium silicate waste treatment

B V Sevastyanov, R O Shadrin
Department of Technosphere Security, Kalashnikov Izhevsk State Technical University, Studencheskaya 7, bld. 1, Izhevsk 426069, Russia

E-mail: sbv47@mail.ru

Abstract. The paper discusses the application of fuzzy logic and the Mamdani Method for analyzing the statistical information of occupational injury rates in the Udmurt Republic, and justifies the use of this method against classical modeling methods. The stages of building a model are shown, involving the formation of a base of fuzzy input rules, a procedure for fuzzing input data, finding truth degrees and finding a truncated membership function. Statistical data on occupational injuries and indicators of the socio-economic development of Udmurt Republic were used as input parameters. The results of the creation of an algorithm for analyzing industrial injuries applying fuzzy logic in the Matlab environment are presented; an integral index of industrial injuries is proposed as an output parameter. The links of the integral index with indicators of industrial injuries and indicators of socio-economic development of Udmurt Republic are shown.

1. Introduction and background

The current trend of development and expansion of enterprises contributes to the growth of the number of workers, which is directly related to the increased load of the labor protection service. In accordance with [1], one of the tasks of labor protection at work is the collection, processing and transmission of information on occupational health and safety issues and ensuring the reduction of occupational risk levels, taking into account working conditions. Scientifically based analysis and processing of information will make it possible to objectively plan preventive measures aimed at reducing industrial injuries.

To ensure the reduction of occupational risk levels, reliable knowledge and objective consideration of a number of criteria that are indirectly related to the level of injury are necessary. Existing methods are not able to give an accurate assessment and prediction of injury level, since most of the methods include certain criteria and mathematical calculations, but do not provide reliable information. In this regard, there is a need to identify a mathematical model that reflects the influence of all criteria on the injury level.

2. Materials and methods

To successfully solve a problem of a complex object controlling, including industrial injuries, applying fuzzy logic methods, one should build not an object model, but an object controlling model [2].
Fuzzy logic is a generalization of Aristotelian logic in the case when truth is viewed as a linguistic variable that takes on values like: “very true”, “more or less true”, “not very false” [3-5].

Using the methods of fuzzy logic, it is possible to build logical-linguistic models that reflect the general semantic setting of the problem, using qualitative representations corresponding to “human” methods of reasoning and decision-making [2,6-9].

3. Experimental section
Modeling was carried out for the Udmurt Republic. Statistics of industrial injuries and socio-economic indicators for 2000–2016 for the region were used as initial data ($L$ is the average number of workers (people); $m_1$ is the number of people injured with further disability per working day or more and fatal outcome (people); $m_2$ is the number of workers injured with fatal outcome (people); $m_3$ is the number of workers with occupational diseases (people); $N$ is the number of days of disability for injured with a loss of working ability per working day or more and fatal outcome; $S$ is funds spent on labor protection measures per worker (rubles); $d$ is share of workers employed in conditions that do not meet sanitary and hygienic standards out of the total number of workers in the studied economic activities,%; $e$ is the number of workers trained in labor protection field in organizations of the Udmurt Republic (people); $I$ is investments in fixed capital in actual gross prices (billion rubles); $V$ is gross regional product (billion rubles); $V_p$ is gross regional product per capita (rub.)) [10-14].

Logical rules were set in analogy with:

$$R_1: \text{IF } x_1 \text{ is } A_{11} \ldots \text{AND... } x_n \text{ is } A_{1n}, \text{ THEN } y \text{ is } B_1$$

$$R_m: \text{IF } x_1 \text{ is } A_{i1} \ldots \text{AND... } x_n \text{ is } A_{im}, \text{ THEN } y \text{ is } B_m$$

where $x_j, j = 1,n$ are input variable names; $y$ is the output variable name; $A_{ij}, i = 1,m, j = 1,n$ are certain membership functions.

Each of the indicators was used as a linguistic variable. For the variable, 4 terms were introduced: Low, Below average, Above average, High. The quantifier “AND” was used for writing.

The development of the algorithm was carried out in the matlab environment. In the fuzzy logic application, 11 indicators were set: $L, m_1, m_2, m_3, N, S, d, e, I, V, V_p$. An integral index reflecting the level of injury – $T$, is set at the output.

For the linguistic variable of the number of workers injured with further disability per 1 working day or more and fatal outcome, the range is set (477; 2780). The numeric parameters of the indicator of the number of workers injured with further disability per 1 working day or more and fatal outcome are presented in Table 1.

| Table 1. Parameters of membership functions |
|--------------------------------------------|
| Membership function            | Function numeric parameters |
|---------------------------------|-----------------------------|
| Low                             | (326.1  477)               |
| Below average                   | (325.8  1245)              |
| Above average                   | (326.1  2012)              |
| High                            | (326.1  2780)              |

4. Results and discussion
The sensitivity of the system, namely the integral index, was determined by changing each indicator by an insignificant value. With the help of such a technique, it was revealed that the integral index changes significantly as the quantitative values of $m_1$ and $e$ vary, followed in terms of communication by $S, N, m_2, I$ indicators, followed next by $m_3, N, d$ and the most insignificant indicators are $V$ and $V_p$.

To build the integral index, we apply the following variations of the indicators, which are defined as the X and Y axes: $L - m_1, S - e, m_2 - m_1, m_3 - m_1, N - m_1, I - S, I - e, I - d, V - V_p$. The some results of the findings are presented in Figures 1-4.
Figure 1. Correlation of $L$ and $m_1$ indicators with integral index.

With an increase in the number of workers and in the number of workers injured with further disability per 1 working day or more and fatal outcome, an increase in the integral index reflecting the level of injury occurs. The $m_1$ correlation is greater than the $L$ correlation.

Figure 2. Correlation of $m_1$ and $m_2$ indicators with integral index.

With the growth of indicators, an increase of the integral index occurs. $m_1$ shows a significant correlation with the integral index, since with the maximum value of each of the indicators in the case of $m_2$, the integral index almost does not change, while $m_1$ increases the integral index.
With an increase in the quantitative value of the indicators, the level of the integral index increases. The $m_1$ indicator correlates with the end result more.

The indicator $N$ does not correlate, while $m_1$ has a significant correlation with the integral index.
5. Conclusion
The development of an algorithm for analyzing indicators of industrial injuries has been carried out. The first stage is the drafting of rules. Each of the indicators was set as a linguistic variable. Four terms were introduced for the variable: Low, Below average, Above average, High. The quantifier “AND” was used for writing the rules. The second stage is the selection and setting of membership functions. Four membership functions were set by trial and error. The third stage is the output of the result. Gaussian functions were applied in the amount of four with given terms: Low, Below average, Above average, High. Functions crosscutted at 0.5 point. The result of the verification of the work and the system response to changes in each of the indicators has been obtained – the tendency of a decrease in the integral index of industrial injuries over the years is determined, which allows objectively planning labor protection measures. The output of the surface of the integral index was carried out by setting the X and Y axes with two specific indicators and the tendency of the integral index behavior with an increase in the quantitative value of the indicators was revealed. The surface corresponded to a valid logical inference, which indicates the possibility and correctness of setting and applying Gaussian membership functions. It is recommended to take into account the human factor as an indicator for more accurate analysis in further researches [15-20].

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