Coefficients determination of fuzzy products rules in a fuzzy model for excavators' ergonomics estimation

Vladimir Velikanov[1,*], *Natalja* Dyorina[1], *Igor* Usov[1], and *Igor* Usov[1] (jr)

[1]Nosov Magnitogorsk State Technical University, Magnitogorsk, Russia

Abstract. The article substantiates the necessity of setting the coefficient of determination for each of the sub-clauses when creating a rule base that takes into account the degree of influence of ergonomic properties in the study on the integrated assessment of the mine excavators' ergonomics. A generally accepted scheme of ergonomic properties of mine excavators is performed, the weight coefficients of each of the properties are determined using the paired-comparison method. A fuzzy model has been implemented that allows determining the resulting level of ergonomics of the mine excavator cabs due to more precise adjustment of the input variables of the model.

1 Introduction

This publication refers to the cycle of works devoted to the assessment and management of ergonomics of mining excavators using the mathematical apparatus of fuzzy logic and fuzzy sets theory.

Recently, there has been a change in the structure of the excavator park in Russian mining industry due to intensive purchases of imported mining excavators, which negatively affects the volume of investments in domestic mining machinery, and as a result, the pace of economic development of the country's mining industry as a whole. The main reason for this situation is the unsatisfactory competitiveness of domestic mine excavators, which is determined by their quality.

In order to increase the competitiveness of traditional and new models of excavator technology, it is important to ensure a given level of consumer properties based on the effective management of ergonomic quality indicators, to increase the reliability of quarry excavators, sanitary and hygienic conditions and operator comfort.

On the basis of the analysis of scientific and technical literature, it is determined that the ergonomics of a career excavator is a criterial category of product quality, considered in the concept of management of the ergonomic quality level (ergonomics) of products as a management object. In accordance with the basic principles of the concept, ergonomic evaluation of the excavator is necessary to determine the degree of implementation of

---

* Corresponding author: rizhik_00@mail.ru

ergonomic requirements and the development of control actions that must be achieved, in accordance with customer requirements, the ergonomics level of excavator cabs [1].

The use the mathematical apparatus of the theory of fuzzy sets in the study is determined by the nature and specificity of the operation of the elements of the operator-excavator system for the evaluation and management of the ergonomics of mine excavators. Information about the system elements can be represented either by subjective opinions or judgments, or by inaccurate data, or by errors in measurements and calculations of parameters. Therefore, it becomes necessary to use mathematical tools considering quantitative and qualitative information performed in a linguistic form.

2 Methodology

There is a generally accepted scheme of ergonomic properties of mine excavators including the following: controllability, habitation, servability, adaptability and manufacturability. This scheme determines the dependence and hierarchy of ergonomic properties and establishes the relationship of complex indicators with the level of excavator quality (Figure 1) [1-5].

The method of paired comparisons is used in order to determine the influence degree of each of the ergonomic properties in forming a complex assessment of ergonomics. The method of paired comparisons, to be more exact, it is modification by T. Saati. In this modification, a comparison of the studied factors is made as in the classical version of the paired comparisons. However, in this method, the factors are compared in pairs in relation to their effects ("weight", or "intensity") on a common characteristic. The method of paired comparisons assumes a phased implementation of calculations.
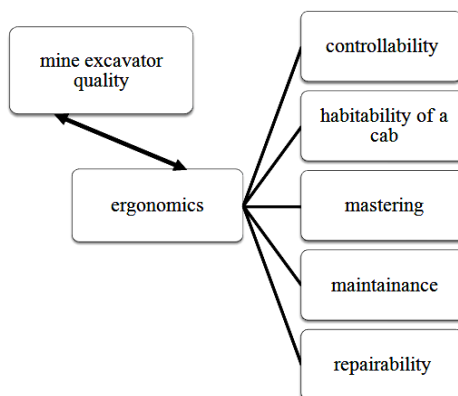

Fig. 1. Structure of ergonomic properties of mine excavators.

When determining the degree of ergonomic properties influence on ergonomics, two tasks are being solved: expert groups are being formed, and a system of criteria (ergonomic properties) is being developed according to which the analysis will be performed.

The number of experts in groups is 7 people. These are qualified specialists who are directly involved in the operation and maintenance of mine excavators: operators of excavators, mechanics of plots, senior mechanics, commissioners, and engineering and technical workers - site managers, repair service managers, operational service managers, chief engineer of the enterprise, technical director.

The assessment is carried out on the following properties: controllability, habitation in the operator's cab, serviceability, digestibility and manufacturability.

Each of the listed properties has a different degree of significance. Accordingly, at the first stage it is necessary to assess the significance of each one, from the point of view of

the expert group members. Each expert should, firstly, conduct paired comparisons of the used properties importance, and then perform pairwise comparison of the properties in terms of the effect of each of them on the ergonomics of the mining excavator. Similarly, other experts are interviewed and the consistency of their opinions is assessed. Then the results of the surveys are averaged, and the collective opinion of the expert group members is formed (according to the formula of the arithmetic simple average). The results of the work of the expert groups are demonstrated in Fig. 2.
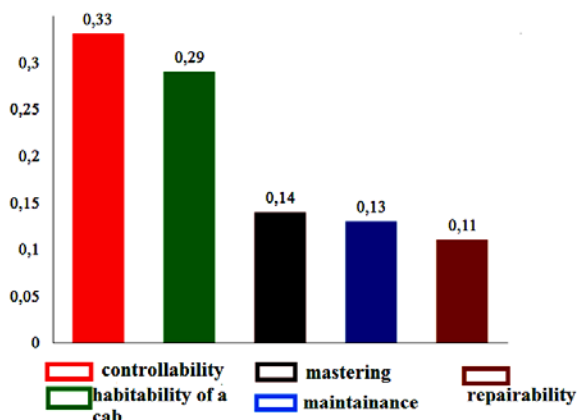

Fig. 2. Weight coefficients of ergonomic properties.

The analysis of the current state of the scientific provision of ergonomics of mine excavators and publications on the problems of the man-machine systems functioning made it possible to conclude that a great amount of scientific work has been done in this field in recent years. However, unresolved problems include the possibility of a mathematical description of the qualitative and quantitative characteristics of heterogeneous ergonomic properties and indicators, which determines the need for using new approaches in order to determine the level of excavators ergonomics.

The studies [3-12] substantiate the possibility of using the mathematical apparatus of fuzzy sets theory to research the ergonomics of mining machines. The given papers present the development of a complex of fuzzy models and algorithms for intellectual decision support based on the formalization of information in terms of fuzzy mathematics, characterized by the possibility of aggregating heterogeneous ergonomic indicators, using specialized software on a computer in the Matlab environment.

It is necessary to note that fuzzy inference is central to fuzzy logic and fuzzy control systems. The process of fuzzy inference is a procedure or algorithm for obtaining fuzzy conclusions based on fuzzy conditions or assumptions using the concepts of fuzzy logic. This process combines all the basic concepts of fuzzy sets theory: membership functions, linguistic variables, fuzzy logical operations, methods of fuzzy implication and fuzzy composition. In systems of fuzzy inference, the rules of fuzzy products are used, in which conditions and conclusions are formulated in terms of fuzzy linguistic utterances. A set of such rules is called bases of fuzzy product rules [13].

Most often, the rules base is presented in the form of a structured text:

$$\text{RULE\_1: IF "Condition\_1" TO "Conclusion \_1" } (F_1)$$

$$\text{RULE\_2: IF "Condition\_2" TO "Conclusion \_2" } (F_2)$$

$$\dots \tag{1}$$

$$\text{RULE\_n: IF "Condition\_n" TO "Conclusion \_n" } (F_n).$$

Here, Fi (i {1, 2, ..., n}) denote the determination coefficients or weight coefficients of the corresponding rules taking values from the interval [0, 1].

3 Results

Figure 3 presents an example of creating a system of fuzzy inference for a comprehensive assessment of the mining excavator ergonomics using the graphical tools of the Fuzzy Logic Toolbox of package Matlab, and Table 1 shows a fragment of the logical rules base of the fuzzy inference system for a comprehensive assessment of the excavator ergonomics.
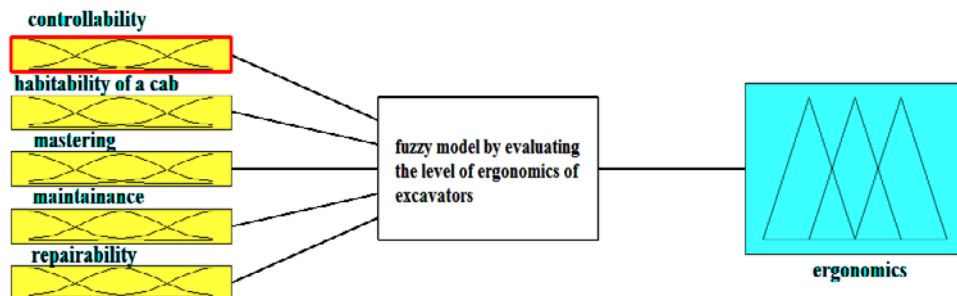

Fig. 3. FIS editor view of the developed model

Table 1. Fragment of the logical rules base of the system of fuzzy inference on the complex evaluation of the excavator ergonomic

№	Input variables of the fuzzy inference system					System output
	Controllability	Habitability	Serviceability	Mastering capability	Manufacturability	Ergonomics
R₁	poor	poor	poor	poor	poor	unfavorable
R₂	good	poor	poor	poor	poor	satisfactory
Rₙ	…	…	…	…	…	...
R₅₀	good	good	good	good	good	preferred

In the developed model the weighting coefficients of the corresponding rules were assumed to be equal to 1 by default. In the Matlab environment, there is the possibility of analyzing the results of fuzzy inference and the adequacy of the created model, with the possibility of changing existing rules or adding new ones, changing the form and parameters of the membership functions and setting the coefficients of the fuzzy product rules.

The carried out researches and the saved up experience of creating fuzzy models allowed to substantiate the approach in setting the determination coefficient for each of the subconclusion when creating the rules base, taking into account the influence degree of each of the factors in the formation of a comprehensive ergonomics assessment (Table 2).

Table 2. Correspondence of the influence degree of factors in setting the determination coefficient

Ergonomic indicators	Values of weighting factors	Linguistic assessment of the influence degree	A mark on the scale of certainty	
			range	average value
Controllability	0,33	Very high	> 0,95	0,970
Habitability	0,29	high	0,87-0,95	0,912
Serviceability	0,14	medium	0,69-0,87	0,783
Mastering capability	0,13	Low than medium	0,36-0,69	0,530
Manufacturability	0,11	poor	0,06-0,36	0,217

Activation in fuzzy inference systems is a procedure for finding the truth degree of each of the subconclusion of fuzzy product rules. It is performed as follows. Before the beginning of this stage, the truth values of all conditions of the fuzzy inference system are assumed to be known, i.e. the set of values of $B'' = \{b_1'', b_{2,...}'' b_n''\}$ and the values of the coefficients of the definition of F_i for each rule. Next, each of the conclusions of the rules of the fuzzy inference system is considered, if the rule conclusion is an indistinct statement of the form (1), then the degree of its truth is equal to the algebraic product of the corresponding value b_i'' on F_i [13].

In this example, the rule base consists of complex conclusions of the form (2), i.e. the conclusion includes several subconclusions, and the linguistic variables in the subconclusions are not mutually equal to each other, then the degree of truth of each subconclusion is equal to the algebraic product of the corresponding value b_i'' on F_i. Thus, all the values of c_k of the truth levels of the subconclusions for each rule which are included in the base of the rules of the system of fuzzy inference, we denote this set of values by $C=\{c_1, c_2, ... c_g\}$, where g is the total number of subconclusions in the database.

RULE <#>: IF "β₁ is α", then "β₂ is α" AND "β₃ is ν"

or   (2)

RULE <#>: IF "β₁ is α", then "β₂ is α" OR "β3 is ν".

In the future, the functions of belonging to each of the subconclusions for the considered output linguistic variables are determined after finding the set C. For this purpose one can use one of the methods, which is a modification of one or another method of fuzzy composition: min-activation: $\mu'(y) = min\{c_i, \mu(y)\}$; prod-activation: $\mu'(y) = c_i * \mu(y)$; average-activation: $\mu'(y) = 0,5 * (c_i + \mu(y))$.

In order to implement the process of fuzzy modeling in the Matlab environment, there is an opportunity to develop and adjust interactively with the help of graphical editing and visualization of all the components of fuzzy inference systems. Features of the process of developing systems of fuzzy inference, recommendations for the implementation of the required sequence of actions are described in [10].

Concerning the subject of this research, let's dwell on the Rule Editor, being used to define and edit individual rules. In accordance with the proposed approach, the developed model was modified, for this purpose the values of the determination coefficient were set in the Weight input field and the text and rule bundles (Connection switch) were adjusted (Table 2). The model contains 50 logical rules, so the definition of the termination coefficient for the corresponding rule is carried out in a simplified procedure.

The output linguistic variable "ergonomics" is given in the form:

T = (<unfavorable, satisfactory, preferred>, [0 - 100%]).

In the created model for a particular fuzzy variable, $\alpha 1$ = <unfavorable> corresponds to the minimum value of the determination coefficient Fi = 0.217, $\alpha 2$ = <satisfactory> - Fi = 0.783 and $\alpha 3$ = <preferred> - Fi = 0.970 of the corresponding R_n rules of the base of logical rules of the fuzzy inference system.

4 Conclusion

Thus, as a result of a more fine-tuning of the model, it becomes possible to determine the ease degree of the mining excavator operation by displaying the resulting level of ergonomics due to changing the values of the individual input variables.

References

1. V.I. Danilyak, *To the concept of the human factor in the management of product quality: Proceedings of the All-Russian Scientific and Practical Conference "Quality Management and Certification" Proceedings of the All-Russian Scientific and Practical Conference "Quality Management and Certification"* (MATI-RGTU, Moscow, 2002)
2. V.G. Khusainov, *Justification and calculation of ergonomic indicators of mining crawler excavators produced by OJSC "Uralmash"* (USMU, Ekaterinburg, 2006)
3. V.S. Velikanov, E.A. Ilina, N.V. Dyorina, Procedia Engineering. **150** (2016)
4. V.S. Velikanov, A.V. Kozyr, I.G. Usov, I.I. Usov, A.A. Abdrakhmanov, Mining industry. **1** (2017)
5. V.S. Velikanov, I.G. Usov, A.A. Abdrakhmanov, I.I. Usov, Mining Journal. **12** (2017)
6. V.S. Velikanov, A.V Kozyr, N.V. Dyorina, Procedia Engineering. **206**(2017)
7. V.S. Velikanov, N.V. Dyorina, A.A. Abdrakhmanov, Matec web of conferences, **129** (2017)
8. V.S. Velikanov, A.A. Shabanov, Socio-economic and environmental problems of mining, construction and energy.**1** (2012)
9. V.S. Velikanov, Mining Journal. **9** (2012)
10. V.S. Velikanov, Mining Information Analytical Bulletin, **9** (2010)
11. V.S. Velikanov, A.A. Shabanov, Mining Information Analytical Bulletin, **5** (2011)
12. V.S. Velikanov, Mining industry, **5** (2011)
13. A.V. Leonenkov, *Fuzzy modeling in MATLAB and fuzzyTECH* (BHV-Petersburg, St. Petersburg, 2005)