About the influence degree of ergonomic properties on the generalized ergonomic indicator of an excavator using a set of methods

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Abstract. The work considers the issue of using various methods for expert assessments in determining the influence degree of ergonomic properties on the ergonomics of a mining excavator. It is established that owing to the variety of the used methods the final result is quite comparable and acceptable.

1. Introduction

The quality of any industrial product is characterized by three components: technical, aesthetic and ergonomic indicators [1].

It has been established from the experience of leading foreign machine-building enterprises that improving the ergonomic and aesthetic parameters of products is increasingly becoming the main direction of increasing its competitiveness.

Research of the following Russian scientists G.I. Malt, Ya.M. Radkevich, M.S. Ostrovsky, B.I. Laktionova, S.P. Karaseva, E.G. Shcherbiny, A.G. Frolov, and et al are devoted to issues of assessing the quality of mining machines. It is proved that there are features in the assessment due to the difficulty of comparable consideration of difficult operating conditions and the variety of design features of mining machines. The quality assessment of mining machines is carried out according to methods based on industry-specific methods developed in the mid-20th century, in which the quality level of machines is determined by absolute, relative or specific indicators. Due to the complexity of accounting for a large number of constantly changing factors of operating conditions, the variety of mining machines, their small seriality and rapid change of samples, methods for assessing the quality of mining equipment require improvement and adaptation to the conditions of modern mining [1].

In [2] the authors proposed an original methodology for assessing quality, which involves assessing the efficiency of mining machines using a range of technical and economic indicators. Operational efficiency is determined by their quality and operation organization. The machine quality consists of the main groups of indicators that determine the effectiveness of its use: the volume of work performed by the machine (destination, ergonomic, etc.), the costs of its acquisition (economic) and operation (reliability, manufacturability, standardization and unification, patent law, environmental and etc.).

The authors of the study [3] developed a methodology for an expert-free quality assessment of mining machines and give the concept interpretation of a functional criterion for machines. The paper
considers the principles of machine quality management at various stages of the life cycle: in the design, manufacture and operation.

2. Methodology
In accordance with the Russian standard, the term “ergonomics” refers to the totality of ergonomic properties of the system “man - machine - environment”.

To date, ergonomic examination is an obligatory stage in the research, design and operation of elements of the “man - mining machine - environment” system. The purpose of the examination is to determine the compliance of the achieved quality indicators with general and private ergonomic requirements and establish the ergonomic quality level of the entire system. As a rule, the results of the examination have a qualitative and subjective nature, and are largely determined by the professional level and experience of the person conducting the assessment [4-10]. The obtained results are very difficult to use in developing the main directions for increasing the level of ergonomic support of mining equipment to the required level. The analysis of literary sources and information materials indicates that there has been some progress in the field of ergonomic support of domestic excavation equipment.

Expert assessments reflect the experience and knowledge of specialists regarding the object under the study. The essence of expert methods is to use the experience, knowledge, intuition of experts to extract objective truth from subjective judgments. There are many varieties of expert methods, but most of them can be reduced to two classes: direct ranking methods and pairwise comparison methods. Direct ranking methods are the best in terms of conclusion accuracy; however, they are limited by human capabilities: with the number of comparison objects 12-15 no expert is able to rank them correctly.

3. Implementation
In the future, we will use the representative theory of measurements, which serves as the basis for the theory of expert estimates, especially the part that is associated with the analysis of expert conclusions [1, 7-10].

The expert assigns rank 1 to the most important integrated indicator, which dominates the ergonomics of the excavator and, accordingly, rank 5 to the indicator with the least influence of table 1.

Table 1. Ranks of complex indicators according to the degree of influence on $k_{\text{org}}$.

| Expert | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ |
|--------|-------|-------|-------|-------|-------|
| 1      | 2     | 1     | 3     | 5     | 4     |
| 2      | 1     | 2     | 4     | 3     | 5     |
| 3      | 1     | 3     | 5     | 2     | 4     |
| 4      | 3     | 1     | 2     | 5     | 4     |
| 5      | 4     | 5     | 1     | 2     | 3     |
| 6      | 1.5   | 1.5   | 2     | 4     | 3     |
| 7      | 1     | 4     | 3     | 2     | 5     |
| 8      | 2     | 1     | 3     | 5     | 4     |
| 9      | 1     | 3     | 2     | 4     | 5     |
| 10     | 2     | 1     | 5     | 4     | 3     |
| 11     | 1     | 3     | 5     | 4     | 2     |
| 12     | 1.5   | 1.5   | 2     | 3     | 4     |

*Footnote.* Expert No. 6, No. 12 believes that the complex indicators $K_1$, $K_2$ are equivalent, so they should have been in first and second places and get points 1 and 2. Since they are equivalent, they get an average score of $(1 + 2) / 2 = 3/2 = 1.5$. 


Analyzing the results of the experts’ work, it can be stated that there is a lack of consistency in expert estimates, because the data given in the table undergo a more thorough mathematical analysis.

In order to assess the impact on the generalized ergonomic indicator $k_{erg}$ of complex indicators, the method of arithmetic mean ranks is used. For this, the sum of the ranks assigned to the complex indicators was calculated, then this sum was divided by the number of experts, as a result, the arithmetic average rank was calculated. Based on the average ranks, the final ranking or ordering is built on the basis of the principle that the lower the average rank, the better the integrated indicator.

The lowest average rank is 1.75, for a comprehensive indicator of manageability, and therefore in the final ranking, he gets rank 1. The next largest amount is 2.25, for a complex indicator of manageability, final rank 2. Further results are shown below in table 2. Ranking by sum of ranks has the form:

$$K_1 < K_2 < K_3 < K_4 < K_5,$$  \hspace{1cm} (1)

**Table 2.** Results of calculations by the method of arithmetic mean ranks and the method of medians.

|                | $K_1$ | $K_2$ | $K_3$ | $K_4$ | $K_5$ |
|----------------|-------|-------|-------|-------|-------|
| Sum of ranks   | 20    | 26    | 37    | 43    | 46    |
| Arithmetic mean of grades | 1.75  | 2.25  | 3.08  | 3.58  | 3.83  |
| Total rank in arithmetic mean | 1     | 2     | 3     | 4     | 5     |
| Medians of Ranks | 1.25  | 1.75  | 3     | 4     | 4     |
| Final Median Rank | 1     | 2     | 3     | 4     | 4     |

The answers of experts are measured on an ordinal scale, and therefore it is unlawful for them to carry out averaging using the arithmetic mean method. We use the median method. It is necessary to take the answers of experts corresponding to one comprehensive indicator, for example, a comprehensive indicator of manageability - K1. These are the ranks 2; 1; 1; 3; 4; 1; 1; 2; 1; 2; 1; 1.5, then arrange them in ascending order. We get the sequence: 1; 1; 1; 1; 1; 1; 1.5; 2; 2; 2; 3; 4. In the central places - the sixth and seventh - are 1 and 1.5. Therefore, the median is 1.25.

The medians of populations of 12 ranks corresponding to certain complex indicators are shown in table 2. Moreover, the medians are calculated according to the usual rules of statistics - as the arithmetic mean of the central members of the variational series. The final ordering by the median method is:

$$K_1 < K_2 < K_3 < \{K_4, K_5\},$$  \hspace{1cm} (2)

A comparison of the rankings according to the arithmetic mean method and the median method (2) and (3) shows their proximity. It can be argued that the complex indicators of K4 development and design and manufacturing of K5, due to errors in expert estimates in one method, are recognized as equivalent - ranking (3).

Using the correlation analysis, we calculate the tightness of the linear relationship of $k_{erg}$ with the totality of $K_1$, $K_2$, $K_3$, $K_4$, and $K_5$, considered as a whole. In order to study the relationship between the generalized ergonomic indicator and complex indicators, we will make a sample of 12 models of excavators of domestic and foreign production.

This tightness is measured using the multiple (or cumulative) correlation coefficient $R_{i,12...p}$, which is a generalization of the pair correlation coefficient.

Selective multiple, or cumulative, correlation coefficient $R_{i,12...p}$, can be calculated by the formula:
where \( q_p \) - determinant of matrix, \( p=1,...,6 \) (coefficients of ergonomics, controllability, habitability, serviceability, masterability, and designability);

\( q_\alpha \) - algebraic complement of an element \( r_{ii} \) of the same matrix (is 1);

\[
q_\alpha = \begin{pmatrix}
1 & r_{12} & \cdots & r_{1p} \\
r_{21} & 1 & \cdots & r_{2p} \\
\vdots & \vdots & \ddots & \vdots \\
r_{p1} & r_{p2} & \cdots & 1
\end{pmatrix}
\]

- sample correlation coefficients.

As a result of the calculations, a multiple correlation coefficient of \( R_{i,12...p} = 0.59 \) was obtained, which indicates that there is a noticeable relationship between \( k_{\text{erg}} \) and the aggregate \( K_1, K_2, K_3, K_4, K_5 \). And at the same time, the obtained \( R_{i,12...p} \) sample multiple correlation coefficients in absolute value is not less than any of the pair correlation coefficients \( r_{ij} \), which, in turn, in the approximation to hundredths turned out to be equal to 0.57.

We calculate a value \( R_{i,12...p}^2 \) called the coefficient of determination, which shows how much of the variation in the variable under the study is explained by the variation of the remaining variables \( R_{i,12...p}^2 = (0.59) \), which is used to calculate the value of the statistics \( F \) and estimates the significance \( R_{i,12...6} \).

The value of statistics \( F \) can be calculated by the formula

\[
F = \frac{R^2(n-p)}{(1-R^2)(p-1)} > F_{\alpha ;k_1,k_2},
\]

where \( F_{\alpha ;k_1,k_2} \) - tabulated value \( F \)- criterion on the significance level \( \alpha \) at number of freedom degree \( k_1 = p-1, k_2 = n - p \), for our case \( \alpha = 0.05, k_1 = 6 - 1 = 5, k_2 = 381 - 6 = 375 \).

As the results of the calculations we received \( F > F_{0.05;5,375} = 40.0483>2.21 \), the result indicates that the value obtained \( R_{i,12...6} \) is significant for research. Thus, it can be concluded that there is reasonable influence \( K_1, K_2, K_3, K_4, K_5 \) on \( k_{\text{erg}} \).

In developing further research, we will use the method of pairwise comparisons. The method of pairwise comparisons is widely used to determine indicators of the significance of objects relative to the selected qualitative criterion with minor differences. As for the modification of the paired comparison method according to T. Saati, the studied factors are compared with each other in this modification, as in the classical version of the method of pairwise comparisons. Moreover, in this method, the factors are compared in pairs with respect to their effect (“weight”, or “intensity”) on their common characteristic [11, 12].

This method is described in sufficient detail in the scientific and technical literature, so there is no need to dwell on the main principles; we describe its practical use in relation to our brought up problems.

The method of pairwise comparisons involves a phased calculation. Starting to assess the influence degree of ergonomic indicators on the generalized ergonomic indicator (ergonomics), it is necessary to
solve 2 problems: form a group of experts and develop a system of criteria (ergonomic indicators) by which the analysis will be performed.

The number of experts is taken equal to 7 people. These are independent qualified specialists with experience in this field of activity. Assessment will be performed according to the following indicators [1]:

- **Manageability** (the distribution of functions between a person and a machine, the algorithm complexity of the operator’s activity, the layout of the operator’s workplace, information display tools and controls, the severity of labor, the adequacy of the operator’s response in an emergency).
- **Occupancy in the operator’s cabin** (dustiness, noise level, vibration level on the operator’s seat, microclimate parameters, illumination of the face, sanitary facilities, protection against vandalism, ease of access to the cabin and seat).
- **Maintenance** (distribution of functions in the EMM during maintenance and repair, completeness, structure, quality of illustrations, style, format, color, retention of operational technical documentation, convenience and safety of access to main units and areas, lack of sliding surfaces, convenience of platforms, walkways and ladders for maintenance and repair, ergonomics of tools and devices for maintenance and repair, the availability of diagnostic tools).
- **Utilization** (selection, training, including in emergency operation, of the operator and maintenance personnel; provision of documentation for the study and operation; unification of the layout of the operator's workplace; unification of information encoding in the cabin and service areas).
- **Technology** (the ergonomics requirements of the mining machine, the level of noise and vibration in the manufacture of individual parts, the availability of technical documentation for the installation and transportation of individual components, ease of installation, transportation, dismantling and disposal).

It should be noted that each of these indicators has a different degree of significance. Accordingly, at the first stage, it is necessary to assess the significance of each from the point of view of the expert group members. Each expert should, firstly, make a pairwise comparison of the importance of the used assessment indicators (table 5), and then perform a pairwise comparison of the available alternatives from the point of view of each of the indicators. The total number of comparison matrices for the problem under consideration: \(1 + m(1 + 4) = 1 + 5m\), where \(m\) is the number of participating experts (\(m = 7\)).

**Table 3. Matrix of paired comparisons of the ergonomic indicator significance - expert 1.**

|            | Controllability | Habitability | Serviceability | Masterability | Manufacturability | \(\psi\) (Vector) | \(w\) (weight) |
|------------|----------------|--------------|----------------|---------------|------------------|------------------|---------------|
| Controllability | 1.000          | 1.000        | 7.000          | 9.000         | 9.000            | 3.554            | 0.4261        |
| Habitability   | 1.000          | 1.000        | 5.000          | 9.000         | 9.000            | 3.323            | 0.3984        |
| Serviceability  | 0.143          | 0.200        | 1.000          | 3.000         | 3.000            | 0.762            | 0.0914        |
| Masterability   | 0.111          | 0.111        | 0.333          | 1.000         | 5.000            | 0.450            | 0.0551        |
| Manufacturability | 0.111         | 0.111        | 0.333          | 0.200         | 1.000            | 0.241            | 0.0290        |
| Amount            | 2.365          | 2.422        | 13.667         | 22.200        | 27.000           | 8.340            | 1.000         |
Similarly, a survey of other experts is conducted and the consistency of their opinions is assessed. Then the results of the polls are averaged, and a collective opinion of the expert group members is formed (figure 1).

**Figure 1.** Influence of ergonomic indicators on a generalized ergonomic indicator by paired comparisons method according to T. Saati.

### 4. Conclusions
In the new economic conditions, requirements are increasing not only for the technical level of mining engineering products, but also for a qualitative change in its consumer properties, the most important of which are ergonomic properties that determine safety and ease of use.

Summing up the carried out study, it should be noted that the results will allow us to develop a methodology for assessing the compliance of excavation equipment with the ergonomic requirements of regulatory documents. The development is possible owing to obtaining numerical characteristics of the mismatch level in specific models of mining excavators by the ergonomics criterion.

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