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# Assessment of the occupational health and safety management system by qualimetric methods

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ABSTRACT

Requirements of the international standard ISO 45001:2018 were analysed to identify the need for monitoring, measuring and analysing the functioning of the occupational health and safety management system. This analysis has made it clear that the effectiveness of the development and implementation of the occupational health and safety management system depends on the assessment methodology. The study focused on existing studies and publications on the assessment of processes, including those related to occupational safety, assessment methods or qualitative methods, and statistical methods used for assessment. As a result, the topic has been proven relevant, and the goal of the article was determined: to study the possibility of using qualimetric methods for evaluating the labour safety management system. A survey was conducted among workers at a machine-building enterprise to evaluate the occupational health and safety management system. Verbal scales were proposed to process the study results as they allow quantitative ratings to be obtained on the coded scale of the desirability function. The study result is a technique for obtaining a quantitative assessment of the occupational health and safety management system. This technique is universal and can be applied to any enterprise. It can also be used to make managerial decisions regarding the improvement of the occupational health and safety management system.

KEY WORDS

**management system, assessment of the system, occupational health and safety, risk, qualimetric methods**

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## Introduction

Despite the growth of technology and industrial development that has led to increased productivity and economic prosperity, new challenges have arisen in occupational safety. Various accidents are possible in production that can lead to the death, injury or illness of workers, and production and financial losses.

To avoid accidents, occupational safety management systems that consider the processes of identification, control, assessment and management are

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implemented. In accordance with international standards, effective management becomes a key prerequisite for the successful functioning of any organisation.

An effective occupational safety management system is the implementation of occupational safety policies, procedures and practical measures aimed at preventing accidents and protecting employee health. This includes identification of the existing risks, assessment of risks, development of preventive measures, training of workers in safety, and the systematic monitoring and evaluation of the occupational safety system's effectiveness.

The availability of an effective occupational safety management system not only ensures the safety and health of employees but also has a positive impact on the organisation as a whole. It will help avoid possible costs related to accidents, lost work time and lawsuits. In addition, it can increase employee motivation and productivity, reduce employee attrition, and improve the organisation's reputation in the eyes of customers and the public.

Therefore, it is necessary to have a scientifically based methodology for quantitative assessment of the occupational safety management system. Qualimetry methods are used to obtain quantitative indicators of the quality of various objects, including the occupational safety management system. Qualimetry science studies the quantitative assessment methodology of the quality of various objects and processes. The occupational health and safety management system was considered an object of qualimetry.

Thus, the purpose of the article is to develop a methodology for assessing the occupational health and safety management system by qualimetric methods considering health risk factors.

The theoretical value of the article is the possibility of using qualimetric methods to assess the labour safety management system. The practical value is the developed technique for assessing the labour safety management system that can be applied at various enterprises.

The article presents the literature review results related to the justification of the need to assess the labour safety management system considering health risk factors and the assessment technique. It describes the study's methodology and presents and discusses its results. Also, the results are generalised, study limitations are explained, and directions for further research are indicated. The last section presents conclusions and directions for future research.

## 1. Literature review

The standard ISO 45001:2018 "Occupational Health and Safety Management Systems. Requirements with Guidance for Use" establishes requirements for the occupational health and safety (OH&S) management system and contains guidelines for their use to enable organisations to create safe and healthy conditions at the workplace, preventing injuries and deterioration of health related to production and actively improving its performance indicators in the field of occupational health and safety.

To effectively solve labour safety issues at an enterprise, it is necessary to develop and scientifically substantiate methods and procedures for assessing labour safety. They should be unified and have the status of a regulatory document. The analysis of ISO 45001:2018 requirements confirmed the need for assessing the state of occupational safety, for example:

6.1.2.2. Methods and criteria for OH&S risk assessment should be determined by the organisation considering their scope, nature and timeliness. Documented information related to these methods and criteria should be managed and maintained;

9.1.1. To ensure the achievement of the expected results of the OSH management system, processes should be monitored, measured and analysed. The organisation should evaluate OH&S indicators and determine the effectiveness of the OH&S management system. The organisation should determine the methods of monitoring, measurement, analysis and evaluation of indicators, as far as applicable, to ensure suitable results and criteria, according to which the organisation will evaluate indicators in the field of OH&S (ISO 45001, 2018).

Monitoring, measurement and analysis can relate to either production events or the effectiveness of supervisory measures. Monitoring can be defined as supervision of working conditions. Measurements are a key part of quantifying data (e.g., measurement of indoor air temperature). In turn, the analysis refers to the study of data for identifying relationships.

More advanced and economical methods of collecting and processing information are needed for effective management. However, the assessment methods are not regulated in the standard, and each enterprise independently faces the problem of determining the mechanism for assessing the occupational health and safety management system.

The methodology for assessing processes of the quality management system following the requirements of the ISO 9001 standard is sufficiently fundamentally, completely and reasonably presented in the scientific work (Ginevičius et al., 2015), which regulates methods and techniques of quantitative quality assessment of technological, assurance and management processes.

In qualimetry, mathematical dependence is an integral part of many processes of assessment and comparison of various indicators. For example, Trishch et al. (2023) used mathematical dependencies to assess the quality of investments, considering the real values of investments and their assessments on a dimensionless scale. Similarly, Ginevičius et al. (2022a) underlined that mathematical dependencies are needed to compare the economic development of the European Union countries. In another work, Ginevicius et al. (2021) stressed the need to study the economic indicators of the country's development. Cherniak et al. (2020) used various functional dependencies between the measured indicators of dangerous factors and their assessment on a dimensionless scale to evaluate indicators of occupational health and safety. Therefore, techniques that apply mathematical dependencies are useful tools for evaluating, comparing, and solving complex problems in various science and research fields. They have a more accurate application of the values of various indicators and ensure objectivity and scientific accuracy in the conducted studies.

Tazim et al. (2023) applied a fuzzy analytical hierarchy approach to identify and rank occupational safety risk factors and a fuzzy inference system (FIS) to develop a risk assessment model. Yazdi et al. (2020) improved the DEMATEL method for effective decision-making in occupational safety management by introducing the best-worst method (BWM) and the Bayesian network (BN).

Yazdani et al. (2020), Stefanovića et al. (2019), and Stojčić et al. (2019) used multi-criteria decision-making (MCDM) methods. The most common of them is TOPSIS, a method of multi-criteria decision analysis that is used to determine the optimal option among alternatives (Divya et al., 2020; Chakraborty, 2022). EDAS is popular in various fuzzy cases. The best solution is selected by calculating the distance of each alternative from the optimal value. In calculations, attributes are independent, and all qualitative attributes are converted into quantitative ones (Ozgur et al., 2020). To evaluate the processes of social and economic systems, the following methods are used: PROMETHEE (a method for organising the preference ranking that is used to rank alternatives based on their independent importance against a set of criteria), MOORA (a method of multi-objective optimisation that uses ratio analysis to arrange alternatives), WASPAS (a method used for weighted assessment of quality indicators) (Abdullah et al., 2019; Manurung et al., 2019; Mishra & Rani, 2021).

## 2. Research methods

To achieve this goal, it is proposed that function-dependent statistics from the theory of extreme statistics be used as a mathematical apparatus. Mathematician Gnedenko proved that the class of limit distributions for the largest sample value contains only three types of laws, where the first type for the largest sample term x(n) is:

$$F_1(x) = exp(-exp(-x)) \quad (- < x < ) \tag{1}$$

where x — numerical value of a variable; $F_1(x)$ — estimate of a variable on a dimensionless scale.

To obtain the asymptotic distribution of the smallest value, it is sufficient to use the symmetry principle and the asymptotic distribution of the largest values (1). Hence, the asymptotic distribution of the smallest value of the first type has the form:

$$F_2(x) = 1 - exp(-exp(x)) \tag{2}$$

Notice that the same distribution function in the region of the smallest values can belong to one type of asymptotic distributions, and in the region of the largest values — to another type. But, nevertheless, there is a class of functions that have extreme values whose asymptotic distribution is of the first type.

The important fact is that the first limiting distribution of extreme values can be linearly transformed into an expression containing no parameters. Since the normalised asymptotic distribution of the first type (1) has no parameters, it can be applied to the evaluation of any objects of qualimetry.

Taking the fact that the estimation of any object obeys such a distribution law that has the asymptotic distribution of the largest and smallest values of the first type, overestimated and underestimated values will be obtain, i.e., the estimation interval. The mean distribution is suggested to obtain a point estimate.

Thus, the lower and upper interval estimator is calculated by formulas (1) and (2), respectively, and

the point estimator, F(x), is of the form (Ginevičius et al., 2022b):

$$F_3(x) = \frac{\left(exp\left(-exp\left(-x\right)\right)+\left(1-exp\left(-exp\left(x\right)\right)\right)\right)}{2} \qquad (3)$$

Note that the function F(x) is the distribution function of the random variable x.

Fig. 1 presents functions $F_1(x)$, $F_2(x)$, and $F_3(x)$ in graphic form.

Based on Fig. 1, the OX scale should vary from -3 to 3 to obtain indicator estimates for qualimetry objects when using dependencies (1), (2), and (3). In the case when indicators are measurable and have different scales of measurement, the known method of dividing a segment in given proportion is applied. In the case when indicators of qualimetry objects are evaluated by experts or participants of survey or testing, then it is suggested to apply verbal scales.

The studied case used a quantitative-verbal matrix that allows for translating various options of verbal assessments into a coded scale to perform one of the assessment stages on the state of the system, i.e., the selection of the scale and measurement limits. The matrix involves the use of verbal scales with the number of assessment options (from 2 to 7). The coded scale varies from -3 to 3 in 0.5 steps and is functionally dependent on a score on a dimensionless scale due to nonlinear dependence (Fig. 2).

The experts choose the necessary dependence (1), (2), and (3) to assess the indicator and the value within the defined ranges on the coded scale. On the scale, there are "2 assessment options": "Bad" corresponds to the range from "-3" to "0"; "Good" corresponds to the range from "0" to "3". On the scale, there are "3 assessment options": "Bad" corresponds to the range from "-3" to "-0.5"; "Satisfactory" — from "-0.5" to "0.5"; "Good" — from "0.5" to "3". On the scale, there are "4 assessment options": "Very bad" corresponds to a range from "-3" to "-1"; "Bad" — from "-1" to "0"; "Good" — from "0" to "1"; "Very good" — from "1" to "3". On the scale, there are "5 assessment options": "Very bad" corresponds to a range from "-3" to "-1.5"; "Bad" — from "-1.5" to "-0.5"; "Satisfactory" — from "-0.5" to "0.5"; "Good" — from "0.5" to "1.5"; "Very good" — from "1.5" to "3". On the scale, there are "6 assessment options": "Very bad" corresponds to a range from "-3" to "-1.5"; "Bad" — from "-1.5" to "-0.5"; "More bad than good" — from "-0.5" to "0"; "More good than bad" — from "0" to "0.5"; "Good" — from "0.5" to "1.5"; "Very good" — from "1.5" to "3". On the scale, there are "7 assessment options": "Very bad" corresponds to the range from "-3" to "-1.5"; "Bad" – from "-1.5" to "-1"; "More bad than good" — from "-1" to "-0.5"; "Satisfactory" — from "-0.5" to "0.5"; "More good than bad" — from "0.5" to "1"; "Good" — from "1" to "1,5", "Very good" — from "1.5" to "3".

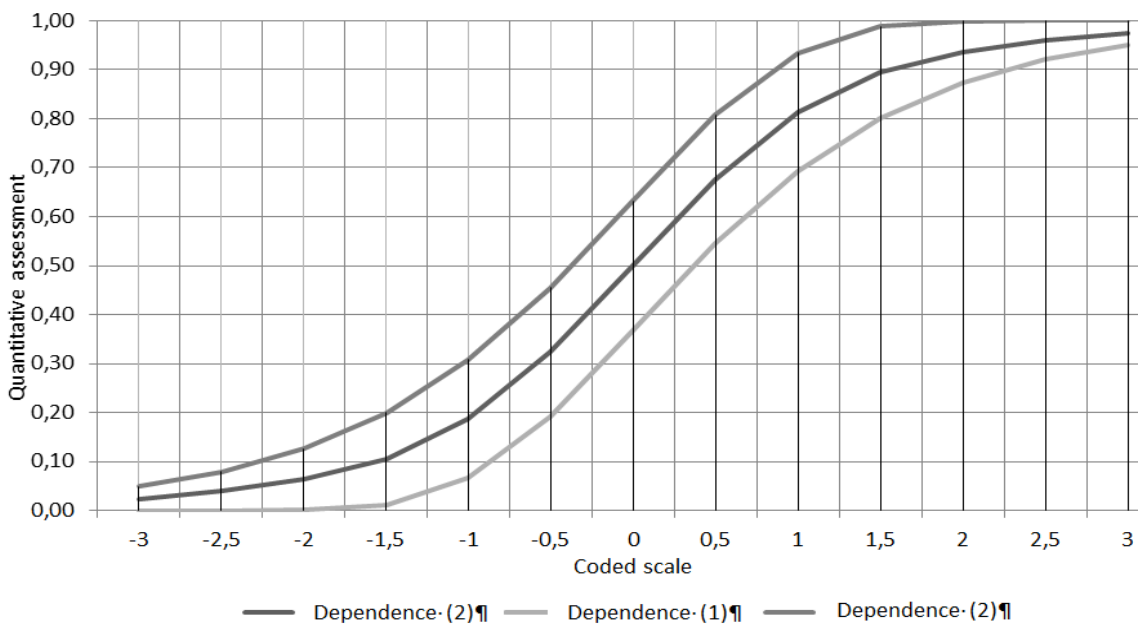


Fig. 1. Dependencies (1), (2), and (3) and their estimates on a dimensionless scale

Source: Ginevičius et al., 2022b.

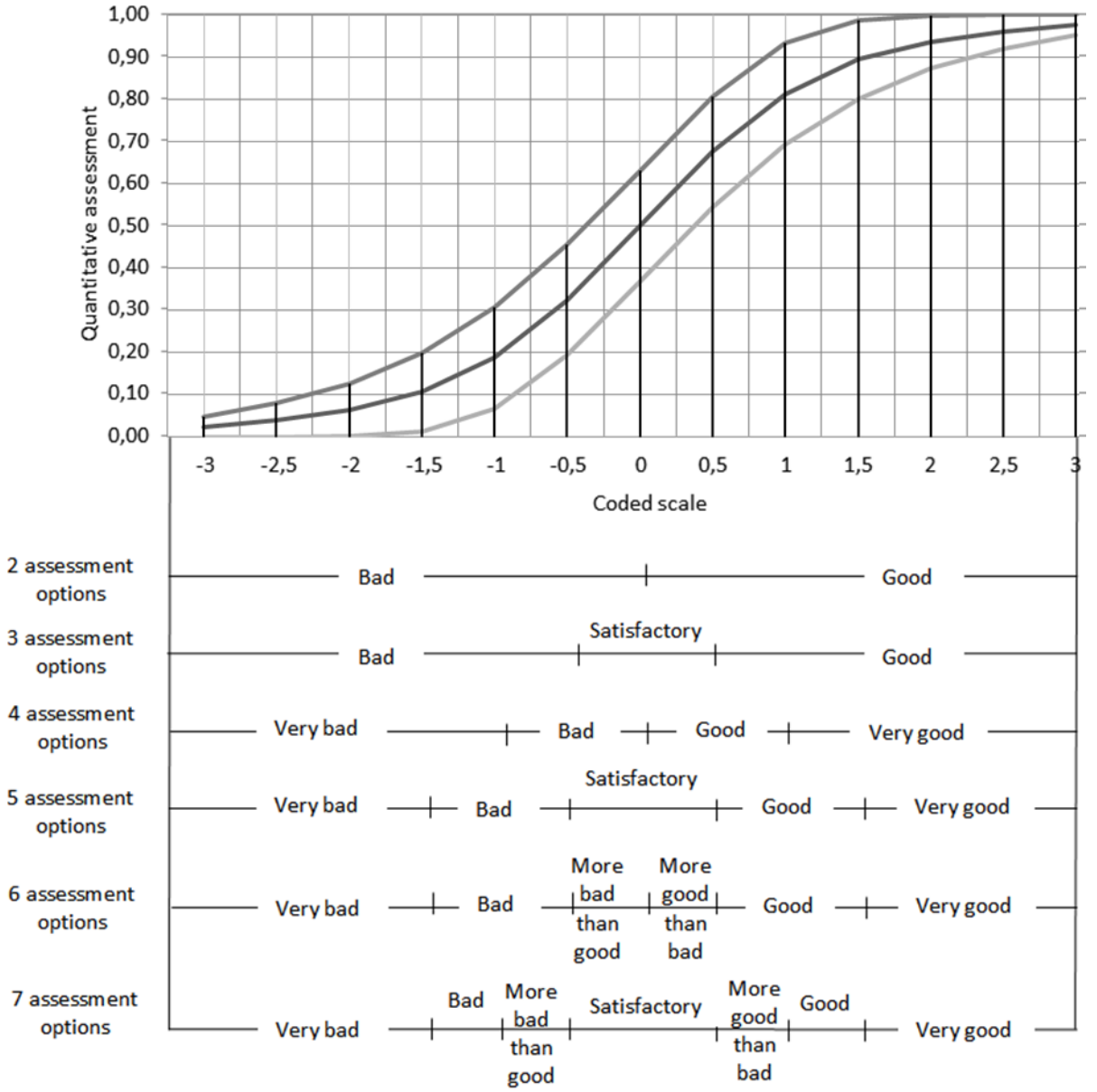


Fig. 2. Functional dependence of the verbal-numerical scale

Since the assessments of unit indicators have the same measurement scale (0 — 1), it is possible to find a comprehensive assessment by applying one of the average values. In this case, the arithmetic mean is used.

$$Q = \frac{1}{n}\sum_{i=1}^{n} F_i \qquad (4)$$

where n — is the number of unit indicators; $F_i$ — is the value of the i-th unit indicator on the dimensionless scale.

A step-by-step methodology for assessing the occupational safety management system consists of the following stages:

Step 1. Determining the list of questions for assessing the occupational health and safety management system.

Step 2. Choosing scales and limits of measurement using the quantitative-verbal matrix (Fig. 2). This matrix is not the only possible option, but it is quite universal and practical. It is necessary to select the number of assessment options and determine the numerical values that correspond to them on the coded scale.

Step 3. Determining the scores of the indicators on a dimensionless scale. With the help of experts, select the necessary dependence (1), (2), and (3) to estimate the indicator.

Step 4. Using the coded value x in formula (1) if the indicator is not very important, in formula (2) if the indicator is important, and in formula (3) if the indicator is very important.

Step 5. Determining with the use of formula (4) of the comprehensive assessment of the labour safety system, considering all individual indicators.

## 3. Results and discussion

Studies were conducted at a machine-building enterprise to confirm the efficiency of the developed technique for assessing occupational health and safety management systems. A questionnaire with tests was developed for the assessment, and a survey of the enterprise's employees was conducted.

The results of the tests that are presented in a qualitative format allow for assessing the dimensions of a particular problem, but this is usually not sufficient for making management decisions. The resulting data contain a limited amount of information and, in addition, are subjected to a grouping process that further reduces their value.

A questionnaire was drawn up, and interviews were conducted with 83 employees of the machine-building enterprise. Test questions in the questionnaire were divided into three test groups.

The first group of tests concerned working conditions at the workplace and their impact on workers' health. They were divided into four questions: (1.1) health status of employees in relation to existing labour safety requirements, (1.2) impact of working conditions on future employment at the enterprise, (1.3) assessment of labour conditions at the workplace, and (1.4) whether the employees of the company are provided with special clothing, footwear and other personal protective equipment. The results are presented in Table 1.

Tab. 1. Results of the survey on working conditions and their impact on workers' health

| Test No. | Answers | Quantity of responses |
|---|---|---|
| 1.1 | Significantly deteriorated | 9 |
| | Somewhat deteriorated | 10 |
| | Depends on the season | 20 |
| | Remained unchanged | 24 |
| | Improved | 7 |
| | Significantly improved | 13 |
| 1.2 | Had to quit | 62 |
| | Did not have to quit | 21 |
| 1.3 | Satisfies | 43 |
| | Hard to say | 31 |
| | Not satisfied | 9 |
| 1.4 | Yes, I am provided with | 32 |
| | No, I am not provided with | 3 |
| | I am provided with, but it could be better | 46 |
| | I am not sufficiently provided with | 2 |

Tab. 2. Results of the assessment of the occupational health and safety management system at the enterprise

| Test No. | Answers | Quantity of responses |
|---|---|---|
| 2.1 | Excellent | 21 |
| | Good | 20 |
| | Satisfactory | 8 |
| | Unsatisfactorily | 7 |
| 2.2 | All issues are resolved | 37 |
| | Some issues are resolved | 21 |
| | No issues unresolved | 25 |
| 2.3 | Familiarised | 67 |
| | Not familiarised | 16 |
| 2.4 | Not satisfactory at all | 3 |
| | Rather unsatisfactory than not | 4 |
| | Satisfactory | 15 |
| | Rather satisfactory than not | 17 |
| | Quite satisfactory | 44 |

Tab. 3. Ability of employees to protect their rights in the field of occupational health and safety

| Test No. | Answers | Quantity of responses |
|---|---|---|
| 3.1 | Yes, I know | 41 |
| | No, I do not know | 25 |
| | I think it is useless to do so | 17 |
| 3.2 | Yes, I have enough information about it | 19 |
| | Yes, I have information about it, but I would like to have more of it | 26 |
| | Yes, I have information about it, but it is not enough | 27 |
| | No, I do not have any information about it | 11 |
| 3.3 | Yes, it provides | 71 |
| | No, it does not provide | 12 |

Tab. 4. Quantitative and verbal assessments

| TEST NO. | EVALUATION SCALES | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -3 | -2,5 | -2 | -1,5 | -1 | -0,5 | 0 | 0,5 | 1 | 1,5 | 2 | 2,5 | 3 |
| 1.1 | Significantly deteriorated | | Somewhat deteriorated | | Depends on the season | | | | Remained unchanged | | Improved | | Significantly improved |
| 1.2 | | Had to quit | | | | | | | | | | Did not have to quit | |
| 1.3 | Not satisfies | | | | | | Hard to say | | | | | | Satisfies |
| 1.4 | No, I am not provided with | | | | I am not sufficiently provided with | | | | I am provided with, but it could be better | | | | Yes, I am provided with |
| 2.1 | Unsatisfactorily | | | | Satisfactory | | | | Good | | | | Excellent |
| 2.2 | No issues unresolved | | | | | | Some issues are resolved | | | | | | All issues are resolved |
| 2.3 | | Not familiarised | | | | | | | | | | Familiarised | |
| 2.4 | Not satisfactory at all | | | Rather unsatisfactory than not | | | Satisfactory | | | Rather satisfactory than not | | | Quite satisfactory |
| 3.1 | No, I do not know | | | | | | I think it is useless to do so | | | | | | Yes, I know |
| 3.2 | No, I do not have any information about it | | | | Yes, I have information about it, but it is not enough | | | | Yes, I have information about it, but I would like to have more of it | | | | Yes, I have enough information about it |
| 3.3 | | No, it does not provide | | | | | | | | | | Yes, it provides | |

The second group of tests referred to the assessment of the occupational health and safety management system and compliance with safety standards.

It also had four questions: (2.1) assessment by employees of the state of labour safety at the enterprise, (2.2) readiness of the company to improve working conditions, (2.3) procedures familiarising employees with enforced internal acts on labour safety, etc., (2.4) effectiveness of in-service information on occupational safety at the enterprise (informative content of labour safety posters, ensuring awareness of employees by showing a series of videos on labour safety, effectiveness of visual study of safe methods and techniques of work performance (posters), and introduction of labour safety instructions). The results are presented in Table 2.

The third group of tests referred to questions regarding employee satisfaction with the legal system of occupational safety. The group was subdivided into three questions: (3.1) the possibility of recourse in case of violation of your rights in the field of occupational safety, (3.2) sufficient information about their rights in the field of occupational health and safety, (3.3 ) the extent to which the legislation provides for the possibility of defending the interests of employees in relation to occupational safety. The results are presented in Table 3.

In the second stage of the research, a quantitative-verbal matrix was used to transform the qualitative assessment of the state of the enterprise's occupational safety and health management system into a quantitative one. The results are presented in Table 4.

By equating the test results in a qualitative form to the scale of normalised numerical values of the factors (from -3 to 3 with a step of 0.5), numerical values of the test results were obtained. An assessment of the factor on the dimensionless scale is achieved by using the values in the formula of functional dependence.

Thus, all indicators were assessed using a single (dimensionless) assessment scale. After that, a generalised multi-criteria assessment of the occupational safety management system can be obtained using the arithmetic mean formula (4).

The results of applying the proposed methodology in quantitative terms will be presented using the example of a machine-building enterprise when 83 employees were interviewed. Tables 1–3 present 11 questions and the number of answers to each of them. Using the proposed methodology and Table 4, the answers to questions presented in (Table 1–3) were converted into a verbal scale with a range of (-3;3). In this way, we convert the answers to the questions into numerical values.

Having the values on the verbal scale (OX) and applying dependencies (1–3), we obtain numerical values on the dimensionless scale for each answer to the question. Knowing the number of answers and their numerical values on a dimensionless scale, we obtain a complex indicator using the formula:

$$q_i = \frac{1}{n}\sum_{i=1}^{n} F_i k_i \qquad (5)$$

where $q_i$ — is the value of the complex indicator on a dimensionless scale; $F_i$ — is the assessment of the i-th question on a scale without dimensions, $k_i$ — is the number of answers to the i-th question; $n$ — is the number of indicators, in our example n=11.

Thus, we obtain complex indicators for all (11) questions. The results are presented in Table 5.

A comprehensive assessment of the occupational safety management system at a machine-building enterprise using the arithmetic mean of all $q_i$ can be found using the results of the surveys.

The complex indicators presented in Table 5 provide information for making management decisions within the enterprise. The company's management can make decisions on preventive and corrective actions in relation to a particular indicator.

The obtained value of the complex indicator of the occupational safety and health management system shows its level, which can serve as a criterion for assessing the enterprise at the state level and taking appropriate measures to improve the state of occupational safety at this enterprise.

Thus, the entire occupational safety management system in production can be assessed with the help of functional dependence and experts. The proposed technique can make management decisions that lead to the minimisation of risks and accidents. The technique is universal and can be applied to assessment of

$$Q = \frac{0{,}61 + 0{,}31 + 0{,}76 + 0{,}91 + 0{,}51 + 0{,}62 + 0{,}82 + 0{,}87 + 0{,}64 + 0{,}63 + 0{,}87}{11} = 0{,}69 \qquad (6)$$

Tab. 5. Complex indicators for 11 questions

| Test No | questions | complex indicator $q_i$ |
|---|---|---|
| **1.1** | Health status of employees in relation to existing labour safety requirements | 0.61 |
| **1.2** | Impact of working conditions on future employment at the enterprise | 0.31 |
| **1.3** | Assessment of labour conditions at the workplace | 0.76 |
| **1.4** | Whether the employees of the company are provided with special clothing, footwear and other personal protective equipment | 0.91 |
| **2.1** | Assessment by employees of the state of labour safety at the enterprise | 0.51 |
| **2.2** | Whether the company addresses the issue of improving working conditions | 0.62 |
| **2.3** | Whether employees are familiarised with internal acts on labour safety | 0.82 |
| **2.4** | Effectiveness of in-service information on occupational safety at the enterprise | 0.87 |
| **3.1** | The possibility of recourse in case of violation of your rights in the field of occupational safety | 0.64 |
| **3.2** | Sufficient information about their rights in the field of occupational health and safety | 0.63 |
| **3.3** | The extent to which the legislation provides for the possibility of defending the interests of employees in relation to occupational safety | 0.87 |

the occupational health and safety management system in various organisations.

## Discussion

The results obtained in the article open up a new direction for research in terms of quantitative assessment of the labour safety management system using qualimetric methods. The proposed methodology allows for obtaining quantitative values of occupational safety indicators using survey results. In this case, mathematical statistics methods were used, making the methodology universal. In addition, this methodology can be applied to management decisions at the enterprise and higher levels.

In the existing scientific literature (Trishch et al., 2023; Ginevičius et al., 2022a), nonlinear functional dependencies are used to assess socio-economic systems, but unlike the proposed methodology, it is not clear why the scales are divided into three groups. There is also no justification for the choice of such an uneven scale.

In contrast to the methodology (Ginevičius et al., 2022b) that also uses qualimetric methods, the proposed methodology proposes to use the functional dependence of the verbal-numerical scale. This allows it to be universally applicable.

For the further development of scientific research, it is possible to apply other mathematical dependencies between the measured indicators of working conditions and their assessment on the dimensionless scale that would consider various features of the qualimetry object. Based on the proposed technique, it is desirable to develop a computer program that will allow the assessment process to be automated.

## Conclusions

The result of the article is a technique of obtaining quantitative assessments of the occupational health and safety management system with a large number of indicators. This technique allows using a wide range of mathematical tools for assessment and management decision-making.

At the same time, several scientific tasks were solved:

- a quantitative-verbal matrix that allows converting various options of verbal assessments into the coded numerical scale has been developed. The matrix involves the use of verbal scales with several assessment options (from 2 to 7) that make it universal;
- the numerical values of the generalised multicriteria assessments of the tests of the employees of the machine-building enterprise and the system of ensuring safe working conditions at the enterprise within the limits of a representative sample (83 persons) have been obtained;
- a comprehensive assessment of the occupational health and safety management system at the machine-building enterprise has been found.

The scientific value of the proposed technique lies in its universality. It can be used to assess working conditions at production facilities of various industries with a different number of harmful factors and

with a different range of measurements. In addition, the indicators may have different measurement scales, which may be determined by legal or corporate requirements. They can also be reviewed and changed to manage the occupational safety system effectively.

The limitation of this methodology is that it does not use quantitative indicators. It refers to the impact of physical, chemical and biological factors on health. In addition, it uses verbal scales with a limited number of answers, namely seven options. Also, questions that use scoring are not used in the employee survey.

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