ASSESSMENT OF SAFETY RISKS USING QUALIMETRIC METHODS

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DOI: 10.17973/MMSJ.2023_10_2023021

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Assessment of occupational safety risks at work is a requirement of the Occupational Health and Safety Management System, which is regulated by international standards. For quantitative risk assessment, it is proposed to use qualimetric methods. It is proposed to obtain estimates of hazardous factors on a dimensionless scale using the error function (erf). Knowing the density function of the law of distribution of random variables of quantitative values of negative factors, the density function of their estimates on a dimensionless scale was obtained. Functionally dependent statistics were obtained. The density function makes it possible to determine the risk of a hazardous factor score falling into the hazardous assessment interval.

KEYWORDS

Quality of life, risk assessment, occupational health and safety risk, risk of working conditions, occupational safety and health, error function, functionally dependent statistics

1 INTRODUCTION

The quality of human life is characterised by a large number of indicators, including the quality of education and healthcare; social security; unemployment; freedom of speech; safety for life; labour safety; environmental safety and many others. There are a number of methods for assessing the quality of life, but none of them is definitive and benchmark. Therefore, the development of such methods continues and is an urgent scientific task [Balara 2018, Duplakova 2018, Flegner 2019 & 2020, Monkova 2013, Murcinkova 2017, Baron 2016, Mrkvica 2012, Zaborowski 2007, Chaus 2018, Vagaska 2017 & 2021, Straka 2018a,b, Michalik 2014, Olejarova 2017 & 2021, Rimar 2022, Panda 2013a, Sedlackova 2019, Kurdel 2014 & 2022, Labun 2017 & 2019, Pollak 2019 & 2020, Svetlik 2014].

In this article, we will consider one of the most important indicators of quality of life - occupational safety. It is especially important to assess occupational safety at work or when performing work that is harmful to health and life. Since most people spend a significant part of their lives in the workplace, performing their duties, there is a risk that working conditions may affect their health. International organisations focus on continuous monitoring of the impact of harmful factors on human health, namely the UN, in its concept of "sustainable human development", considers occupational safety an important indicator of quality of life, and the International Organisation for Standardisation (ISO) has developed a number of standards related to risk assessment (ISO 31000:2018; ISO 31010:2013), quality management systems (ISO 9001:2015) and occupational health and safety management systems (ISO 45001:2018).

2 MATERIALS AND METHODS

The concepts of "risk", "quality" and "safety" are complex, as the quality of life is closely related to the risks of occupational diseases. Therefore, to ensure successful development, companies or organisations implement international standards that regulate the requirements for quality management systems, occupational health and safety management systems and risk management. Comprehensive implementation of the requirements of such standards improves the quality of products and services, the level of attractiveness of enterprises or organisations, allowing them to be efficient and competitive [Panda 2011a, Valicek 2016].

The International Standard [ISO 45001:2019] sets out the requirements for an occupational health and safety management system (OHSMS) and provides guidance on their application to enable an organisation to create safe working conditions in the workplace, preventing injuries and deterioration in the health of employees. In order to effectively address occupational safety issues at an enterprise, it is necessary to develop scientifically based methods and procedures for assessing occupational safety, which should be unified and have the status of regulatory documents. Sections of the standard [ISO 45001:2019] state that:

- the methodology and criteria for assessing occupational health and safety risks should be determined by the organisation, taking into account their scope, nature and timeliness. Documented information related to these methods and criteria should be managed and retained;
- To ensure that the expected results of the HS&E management system are achieved, the processes involved should be monitored, measured and analysed. In doing so, the organisation should evaluate safety performance and determine the effectiveness of the management system. The organisation should also determine the methods for monitoring, measuring, analysing and evaluating the relevant indicators to ensure occupational safety and health [Dyadyura 2017, Sukhodub 2018, Khosravi 2022].

Monitoring is defined as the supervision of working conditions. Measurement is a key part of monitoring. Analysis refers to the process of examining and processing the data obtained through measurement to determine management actions [Jurko 2011].

Effective management requires efficient methods of collecting and processing the information obtained. However, assessment methods are not regulated in international standards, so each company must develop them independently. This often causes difficulties, as it involves obtaining complex multi-criteria assessments of occupational safety in quantitative terms.

One of the principles of the development and implementation of the international standard [ISO 9001:2015] is the principle of risk assessment, which requires enterprises and organisations to develop methods for analysing, forecasting and managing risks. The requirements of this standard state that an organisation must identify and assess risks that may affect occupational safety. In addition, the organisation must create a risk response plan and make decisions based on the results of the assessment [Krenicky 2022].

At manufacturing enterprises, the sources of risks are not only production activities, but also related activities. To successfully manage risks, it is necessary to be able to analyse and predict them, which will increase the efficiency of management processes [Dyadyura 2021]. The purpose of the risk assessment process is to determine the magnitude and probability of adverse consequences.

An international standard has been developed for risk assessment [ISO 31000:2018]. This document provides general recommendations for risk management. The procedure for applying these recommendations can be adapted for any organisation, but it does not regulate the assessment methodology. To develop Standard [ISO 31000:2018], Standard [ISO 31010:2013] was developed, which provides recommendations for the selection and application of systematic methods for general risk assessment. Standard [ISO 31010:2013] is advisory in nature, so it can serve as a guide for different types of HSE management systems.

Today, there are no universal methods of risk assessment for different enterprises or processes, so the enterprise must independently determine the method of analysis, depending on the hazardousness of the processes at work, their number and methods of assessment. To solve this problem, it is necessary to develop a standard universal risk assessment methodology, regardless of the type and hazard of production.

The effectiveness of enterprise quality management largely depends on the effectiveness of enterprise safety risk management, which in turn is related to employee awareness. The authors of [Ramos 2020; Jurko 2012] conducted a study of occupational safety in a company operating in the field of solid waste management and assessed the negative impact of hazardous exposure on occupational health and safety. The results of the study showed that the implementation of SHWM at the company reduced the number of accidents due to the involvement of employees in risk management. The need to involve employees in risk management training is also noted in works [Kim 2019, Zadorozhna 2021, Kucheruk 2022, Jurko 2013 , Osuka 2023], where the introduction of incentives and responsibility is proposed. It has also been proven to have an effective impact on safety performance. At the same time, the authors note that in order to achieve the desired level of risk minimisation, it is necessary to develop integrated risk management approaches based on qualimetric methods of their assessment.

With the growth of globalisation in the industrial sphere, the issue of qualitative assessment of risks associated with industrial safety arises. To manage the industrial risk process, several studies and methods have been developed and are currently in use. For example, research [Jain 2017] considers two types of hazardous factors that interact with each other: technical (equipment failure, variation of process parameters) and social (policy, human and organisational factors). For effective risk management, it is proposed to use a holistic and integrated system that would take into account the dynamics of development of socio-technical aspects. The author proposes the Process Resilience Analysis Framework (PRAF) to include both technical and social factors in the complex. This is based on four principles: early detection (ED), error tolerance detection (ETD), plasticity (P) and recoverability (R). The resilience methodology emphasises the dynamics, unpredictability and even unknown types of threats, uncertainty, degradation of systems and complex interactions.

The authors of [8] analysed various administrative methods of occupational safety management. The paper presents a comparison of deterministic, probabilistic and combined methods in quantitative and qualitative terms. The authors also describe in detail the method of critical failure and consequence analysis (AMDEC) and SWOT (strength, weakness, opportunity and threat) analysis. The methods proposed by the authors can be useful in identifying hazards but provide limited information on its quantitative assessment (severity, severity of consequences, etc.).

The authors of [Li 2018] propose that a large safety management system should be divided into several subsystems that can comply with standard management systems. It is assumed that there are two standard models of the safety management system: accident-related models and organisational models. Comparison of elements of different systems makes it possible to investigate the degree of their compliance.

In publications [Zaloga 2019, Zaloga 2020, Panda 2013a, Zadorozhna 2021, Topchiyiv 2023], the authors considered risk assessment at the organisational level through the implementation of an integrated management system to align organisational culture with everyday practice.

Qualimetric methods have occupied an important niche in the processes of assessing the quality of objects of various nature, including occupational safety at work [Ginevicius 2021, Hrinchenko 2022, Cherniak 2020a, Kim 2021, Panda 2013b]. For example, [Ginevicius 2021] uses functionally dependent statistics to assess the development of the country's regions. As a result of obtaining such statistics, a multi-criteria indicator of regional development was determined. The results of the research resulted in a step-by-step methodology.

In [Ginevicius 2022, Panda 2011b], the authors used functional dependencies to assess the mental health of people affected by the COVID-19 pandemic. They developed a methodology that allowed them to process large arrays of psychological tests.

Research work [Trishch 2016] is related to the use of qualimetric methods to evaluate the processes of the quality management system in accordance with the ISO 9001 standard. The developed methodology allows to evaluate heterogeneous processes with different units and ranges of measurement and to obtain a comprehensive indicator, which allows to further determine the quality indicator of the entire system.

The application of qualimetrics to the assessment of occupational safety at work is presented in [Cherniak 2020b, Stefanovica 2019, Muhammet 2018], which used the hierarchy analysis method to determine the importance index of negative factors, as well as multicriteria decision-making (MCDM) based on fuzzy approaches to assess risks in the field of occupational health and safety.

Approaches to assessing different types of risks aimed at ensuring effective enterprise quality management are disclosed in [Trishch 2021, Tworek 2016, Arrfelt 2018, Hogarth 2018, Lagunova 2018]. The authors assess the risk from the point of view of making managerial decisions, ensuring the competitiveness of the enterprise and the quality of functioning of technological systems. The authors propose various approaches to risk assessment using qualitative and quantitative methods, including obtaining a dimensionless scale of product quality indicators and the impact of this approach on the risk of operation and competitiveness of an enterprise. The efficiency of implementation of such approaches and risk management in various areas of activity is analysed: technological, managerial, administrative, etc.

Based on the results of the analysis of scientific literature, it can be concluded that qualimetric methods are an important tool for assessing the quality and safety of labour at work and allow developing effective risk assessment methods.

The purpose of the article is to develop a methodology for assessing occupational risks at work. Such methods should be based on the effective use of the theory of qualimetry and be universal, so that they can be used by any enterprise.

3 QUALIMETRIC METHOD FOR ASSESSING OCCUPATIONAL SAFETY RISKS

3.1 *Developing mathematical dependencies for assessing hazards*

Any production is characterised by a set of hazards that can affect the health of workers. Examples include air temperature; relative humidity; air velocity; intensity of thermal radiation; noise; and vibration. Each of these factors has its own permissible standards, which may be limited by an upper limit. For example, vibration in the workplace is limited to an upper limit (Xmax). Others may have both upper and lower limits (Xmax; Xmin).

Each of the factors has a different range of permissible norms and different units of measurement, which makes it difficult to determine a comprehensive indicator of occupational safety. Therefore, it is necessary to bring all multidimensional factors to a dimensionless value. To do this, it is proposed to use a nonlinear function (mathematical dependence) that will transform the measured factors into dimensionless values in the range (0; 1).

As a mathematical dependence, it is proposed to use the error function, which is non-elementary and is used in mathematical statistics and mathematical physics to solve some practical problems. The error function is standardised in applications, so there are great opportunities for its practical application. The error function has the form:

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \tag{1}$$

For non-negative values of x, the error function has the following interpretation: for a random variable *Y* that has a normal distribution with a mathematical expectation of 0 and variance of $1/\sqrt{2}$, $erf(x)$ it is the probability that *Y* falls in the interval [*-x; x*].

Figure 1 shows a graphical representation of the error function (1).

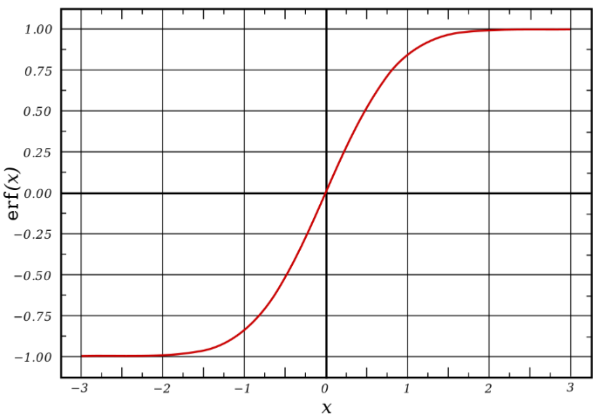

Figure 1. Graphical representation of the error function (1)

Since the evaluation of factors should be on a single evaluation scale, this fact makes the evaluation process more efficient, as it allows to increase the amount of statistical information for making management decisions.

Figure 1 shows that the rate of change of the dependence is not uniform from left to right, namely, the dependence graph is flat at the edges of the assessment range, but in the middle it increases rapidly. This fact is in line with the principles of qualimetry, because it is clear that the measured indicators and their estimates are not linearly related. Therefore, it can be concluded that the mathematical dependence (1) is reasonable and can be considered universal for obtaining estimates of any hazardous factors.

Since we need to obtain estimates in the estimation range: $0 \le y(x) \prec 1$, we transform dependence (1) into the following form:

$$y(x) = \frac{1}{2} + \frac{1}{2} erf\left(-2 + 4\frac{x-a}{b-a}\right), \tag{2}$$

where $erf(x)$ is the error function, *a* is the lowest possible permissible value of the hazardous factor, *b* is the highest possible permissible value of the hazardous factor; *x* is the actual value of the hazardous factor.

Note that the function $y(x)$ at point *a* takes a value close to zero, and at point *b* - close to one. The graphical form of dependence (2) is shown in Figure 2 at *a* = 25, *b* = 30.

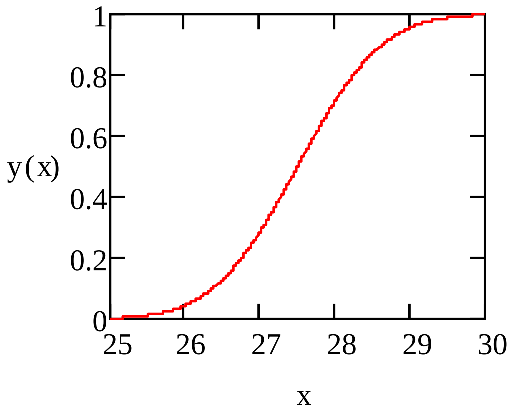

Figure 2. Graph of the function *y(x)* at *a* = 25, *b* = 30

Dependence (2) is characterised by the fact that the result is a quality indicator score from zero to one, and the (*x*) axis is limited to the maximum permissible values of the hazardous factor defined by regulatory documents. There are cases when the assessment is inverse, i.e., the highest value of the measured hazard corresponds to the lowest value of the assessment on a dimensionless scale. In this case, a type of dependence can be used:

$$y^*(x) = 1 - \left(\frac{1}{2} + \frac{1}{2} erf\left(-2 + 4\frac{x-a}{b-a}\right)\right) \tag{3}$$

The proposed dependencies (2) and (3) can be considered capable and effective, as they have an advantage over the existing ones used in qualimetry. Unlike the existing dependencies, which require complex calculations and the use of expert methods, the proposed ones use the error function that is built into Microsoft Excel. That is, there is no need to create special software, which allows automating the assessment process and, thus, expands the scope of application for the assessment of any hazardous factors.

The proposed mathematical dependencies can become a practical tool for its application and can also be implemented in regulatory documents at the level of an organisation or enterprise to introduce a hazard assessment procedure.

3.2 *Risk assessment*

Since the international standard [ISO 45001:2018] requires an assessment of safety risks at work, it is necessary to develop an appropriate universal methodology regardless of the type of production and hazard. To do this, let's define the concept of risk. Risk is the probability of an unfavourable situation occurring

[ISO 45001:2018]. The concept of probability is related to statistics, so it is necessary to apply statistical methods.
Suppose that the random scatter value of any hazardous factor X follows a normal distribution law with a density function:

$$f(x)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(x-\bar{X})^2}{2\sigma^2}},$$

and is related to the score on the dimensionless scale Y by dependence (2), then the probability density function $q(y)$ of the random variable y will be as follows:

$$q(y)=\frac{1}{\sigma\sqrt{2\pi}}\cdot\left|q_1(y)\right|\cdot e^{\frac{-1}{2\sigma^2}\left(q_2(y)-\bar{X}\right)^2} \tag{4}$$

where:

$$q_1(y)=\frac{1}{2}\cdot\left(\frac{1}{4}x_{\max}-\frac{1}{4}x_{\min}\right)\pi^{\frac{1}{2}}\cdot$$

$$\left[\begin{array}{l}2+\frac{1}{2}\pi\cdot(2y-1)^2+\frac{7}{48}\pi^2(2y-1)^4+\\+\frac{127}{2880}\pi^3(2y-1)^6\end{array}\right]$$

$$q_2(y)=\frac{x_{\max}-x_{\min}}{4}\left[\frac{\sqrt{\pi}}{2}\left[\begin{array}{l}(2y-1)+\frac{\pi(2y-1)^3}{12}+\\+\frac{7\pi^2(2y-1)^5}{480}+\\+\frac{127\pi^3(2y-1)^7}{40320}\end{array}\right]+2\right]+x_{\min}$$

Function (4) has two parameters:

$$\bar{X}=\frac{1}{n}\sum_{i=1}^{n}x_i \tag{5}$$

where x_i is the measured value of the hazardous factor, n is the number of measurements.

$$\sigma=\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_1-\bar{X}\right)^2} \tag{6}$$

The graphical form of function (4) is shown in Figure 3.

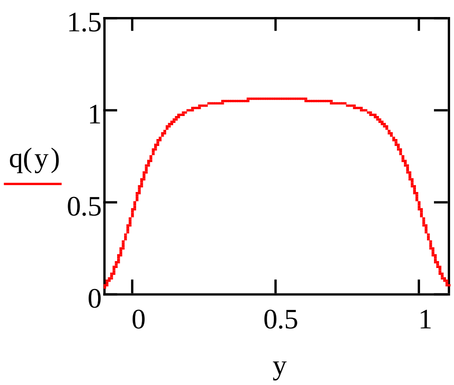

Figure 3. Graphical representation of density function

If the probability density function is known for a random variable Y, you can solve a number of practical problems, including finding the probability that the value of Y falls within a certain interval *(c, d)*:

$$P(c\prec y\prec d)=\int_c^d q(y)dy=F(d)-F(c),$$

where *q(y)* is the distribution function of the random variable *Y*.
Let's consider a practical problem - find the probability that the values of a random variable *Y* fall in the interval *(c, d)*. To do this, you need to calculate the integral:

$$P(c\prec y\prec d)=\int_c^d q(y)dy.$$

The results of the calculations are presented in Table 1.

Interval (c, d)	0-1	1-2	2-3	3-4	4-5
Probability P(c<y<d)	0.069	0.095	0.1	0.1	0.1
Interval (c, d)	5-6	6-7	7-8	8-9	9-1
Probability P(c<y<d)	0.1	0.1	0.1	0.095	0.069

Table 1. Probability of finding the value of a random variable *Y* in the interval (c, d)

An example of calculating the risk of a hot mechanical shop at a machine-building enterprise.
Regulatory documents set requirements for air temperature in the range: t_{min} = 13°C; t_{max} = 29°C. 25 measurements were made during a month, n=25.
Using formulas (5) and (6), we obtained the results of parameter estimates: $\bar{X}=19^\circ C$; σ = 6.8.
Substituting the values into formula (4), we obtained the result q(y) = 0.93.
Thus, the risk that the air temperature will exceed the established limits is 0.07, which is an acceptable value.

4 CONCLUSIONS

The article proposes to apply a qualimetric approach to assessing the risk of exposure to negative factors of production to humans. The mathematical apparatus used is the theory of mathematical statistics, which requires knowledge of the law of distribution of random values of measured factors affecting human health.
To obtain estimates of the influencing factors on a dimensionless scale, it is proposed to use the error function, which is standard and built into Microsoft Excel. To modernise it, coefficients were introduced that allowed it to be used for evaluation and to obtain estimates in the range (0, 1).
The density function on a dimensionless scale was determined, which is the probability of the measured value of a factor falling into the poor interval from 0 to 1. We tested this approach on the example of a machine-building enterprise.

ACKNOWLEDGMENTS

This work was supported by the project VEGA 1/0226/21 of Scientific Grant Agency of the Ministry of Education, science, research and sport of the Slovak Republic and the Slovak Academy of Sciences.

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