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Assessment of product quality risks by qualimetric methods using functionally dependent statistics

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ABSTRACT
In modern production systems, ensuring high product quality while minimising risk is a critical challenge. Traditional quality assessment methods often rely on expert judgment or complex models, which may introduce subjectivity or require large datasets. This study aims to develop a universal methodology for assessing product quality risks using a mathematically grounded approach that eliminates the need for expert-based evaluations and can be easily implemented in various industrial contexts. A qualimetric method based on nonlinear mathematical dependence using the error function "erf" is proposed. The method transforms measured quality indicators into a dimensionless scale and derives functionally dependent statistics under the assumption of a uniform distribution. The model is validated through analytical derivations and numerical experiments on piston components in precision mechanical engineering. A new mathematical model was established to calculate the probability density function of transformed quality indicators. The methodology enables the estimation of the probability that a quality indicator will fall within a risky range near tolerance limits. Numerical experiments confirmed the validity of the model, demonstrating its applicability to real-world production scenarios and its alignment with known principles of qualimetry. The proposed method provides a universal, objective, and practical tool for risk-based quality assessment. It can be applied across different industries, integrated into existing quality management systems, and used to support decision-making in production control. Future research should expand the model to accommodate non-uniform distributions and explore its integration with real-time quality monitoring systems.

KEY WORDS
qualimetry, quality of life, risk, risk assessment, quality risk, sustainability criteria, error function, functionally dependent statistics, multicriteria quality assessment

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Introduction

The development of the public production of any country, its position in the global trade market, as well as the growth of national prosperity and living standards, are all closely connected to maintaining a high level of quality in products, services, and the functioning of socio-economic systems such as education, healthcare, environmental protection, and labour safety. Since the beginning of social production, mankind has been managing product quality. The quality of products and services offered by a national producer significantly influences foreign

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policy, national security, and the overall stability of the national currency. It also plays a key role in determining the standard of living and quality of life within the country.

Risk is a critical factor in decision-making and is essential for making effective management choices. In a market economy, businesses achieve competitiveness through innovation, which inherently carries risks. Risk-based decisions lead to more efficient production processes, benefiting entrepreneurs, consumers, and society at large (Crawford & Jabbour, 2023).

Risk is both a cause of possible losses and a source of possible profit. The primary objective of risk management is not to avoid risk altogether, but to make risk-related decisions based on objective criteria. Risk reduction is possible by improving the reliability of goods and systems, reducing the possible intensity of undesirable factors (for example, limiting the stock of hazardous substances), and increasing the protection of facilities from their impact. Risk reduction is possible (Settembre-Blundo et al., 2021):

- at the stage of planning an operation (project) or designing samples - by introducing additional reliability elements and other necessary measures;
- at the decision-making stage - by using appropriate criteria for evaluating the effectiveness of a decision, such as the Wald or Savage criteria ("expect the worst");
- at the stage of technical systems operation - by observing operating modes and their control.

Within each of the areas, the measures taken will have different effectiveness. These measures are costly and need to increase as the complexity of the systems increases. Therefore, under certain conditions, it may be more economically feasible to spend money not on preventing or reducing the degree of risk, but on compensating for possible losses, using the insurance mechanism.

Production risks include, in particular, the risks of defective products. In the context of mass production, enterprises have technical control departments, quality bureaus and other units that control product quality. In the machine building industry, the average cost of control operations is approx. 10 % of the cost of production. Part of the risk losses can be compensated for by maintenance services for products that are already in the hands of consumers (Ha et al., 2022).

Another group of production risks is related to the performance of existing technological processes - accidents of varying severity, which lead to production reduction and stoppage. Production reduction and stoppage are the consequences of an accident or equipment breakdown, leading to direct losses of profit due to a decrease in production output and indirect losses due to the non-delivery of products to customers (Raian et al., 2023).

The production of high-quality products is linked to the quality of technological processes at all stages of the production life cycle. Any technological process is associated with the risk that standardised product quality indicators will deviate from the ideal values provided in regulatory documents and technical regulations (Pirbalouti et al., 2023).

Many scientific fields, such as game theory, probability, mathematical statistics, decision-making, psychology, military sciences, economics, demography, medicine, biology, law, and others, study the concept of risk. Modern scientific achievements allow for considering risk at two levels: theoretical, where it is studied as a social phenomenon with its own essence and patterns of development and management under conditions of uncertainty, and applied, which arises from specific research in various scientific fields (Fleurbaey & Zuber, 2022).

In the field of qualimetrics, a crucial aspect when evaluating the quality of objects is understanding the type of relationship between the measured quality indicators and their corresponding scores on a dimensionless scale. This is significant because the relationship between quality indicators and their scores may not always be linear. Statistical methods are often employed to effectively manage and assess the quality of qualimetric objects. In this context, it is important not only to have information on the distribution of the quality indicators in their original measurement units but also to understand how these indicators are distributed on a dimensionless scale. This article presents research focused on identifying the patterns and regularities of the distribution of quality indicator scores when mapped onto a dimensionless scale.

The purpose of the article is to develop and validate the effectiveness of a universal methodology for assessing the risks associated with products of a specified quality using nonlinear mathematical dependencies.

The article presents the results of a literature review on existing approaches to product quality risk assessment and the justification for developing a universal methodology based on nonlinear mathematical dependencies. The research methodology is described in detail, including the transformation of quality indicators into a dimensionless scale and the determination of probability density functions. The results of applying the proposed method to the evaluation of high-precision mechanical parts are presented and discussed, highlighting its advantages over traditional expert-based approaches. Generalisations of the findings are provided, along with an explanation of the study's limitations and potential applications in various industries. The conclusion and recommendations for future research directions are outlined in the final section.

1. Literature review

1.1. Risk essence and methods of risk assessment

As outlined in EN IEC 31010:2019, IDT Risk Management - Risk Assessment Techniques (ISO 31010, 2019), and the ISO Guide 73:2009 Risk Management - Terminology - Guidelines for Use in Standards (ISO Guide 73, 2009), risk is defined as the likelihood and frequency of adverse impacts within areas of human activity. It serves as a crucial factor in decision-making, forming the foundation for effective management strategies. In a competitive market economy, innovation plays a pivotal role in driving business success; however, it inherently involves taking risks. Businesses can achieve more efficient production processes by embracing risk-oriented approaches, benefiting entrepreneurs and consumers, and positively contributing to society as a whole.

Risk refers to the probability of losses or a shortfall in income compared to anticipated outcomes. It serves as a tool for addressing uncertainty - essentially, the absence of reliable information or assurance. In practice, risk often involves decision-making in situations where choices are unavoidable. In such cases, it becomes possible to quantitatively and qualitatively assess the likelihood of achieving desired outcomes, encountering failures, or deviating from established goals.

Globally and locally, over 30 methods for general risk assessment are employed, as outlined in the standard ISO 31010 (2019). These methods enable decision-makers and stakeholders to gain a clearer understanding of potential risks that could impact goal achievement, as well as to evaluate the adequacy and effectiveness of existing controls.

This standard expands on the principles outlined in ISO 31000:2018, IDT "Risk Management - Guidelines" (ISO 31000, 2018), offering practical guidance on selecting and applying systematic methods for comprehensive risk assessment. It supports broader risk management activities by providing insights into various methodologies and references to international standards that detail their concepts and applications. Notably, this standard is not intended for certification, regulatory compliance, or contractual use.

This standard does not define specific criteria for determining when risk analysis is necessary, nor does it mandate the use of any particular method for a given application. Additionally, it does not cover all possible risk analysis methods; the absence of a method in the standard does not imply its invalidity. The applicability of a method to a specific situation does not automatically make it the optimal choice for use.

A comprehensive risk assessment empowers decision-makers and stakeholders to gain deeper insights into risks that could impact the achievement of objectives and the effectiveness of existing controls. This understanding serves as a foundation for choosing the most suitable risk management strategies. The results of the assessment become integral to the organisation's decision-making processes, ensuring informed and strategic actions (Ismail et al., 2024; Glette-Iversen et al., 2023).

Comprehensive risk assessment involves a collaborative approach to identifying, analysing, and evaluating risks. The application of this process varies based on the context of the risk management framework, as well as the specific methods and techniques employed. Given the diverse nature of risks and their potential causes and impacts, this process often necessitates a multidisciplinary approach to ensure all relevant factors are thoroughly addressed (Fraume et al., 2020; Hu et al., 2023).

Risk analysis is a critical step in gaining a deeper understanding of potential risks. It supports the overall risk assessment process and informs decisions about whether action is required and which strategies or methods are best suited for addressing the risks. This process involves identifying potential outcomes of risk events and their probabilities, considering the presence and effectiveness of existing controls. By combining these outcomes and probabilities, the analysis determines the overall level of risk, serving as a foundation for effective risk management (Aven, 2023).

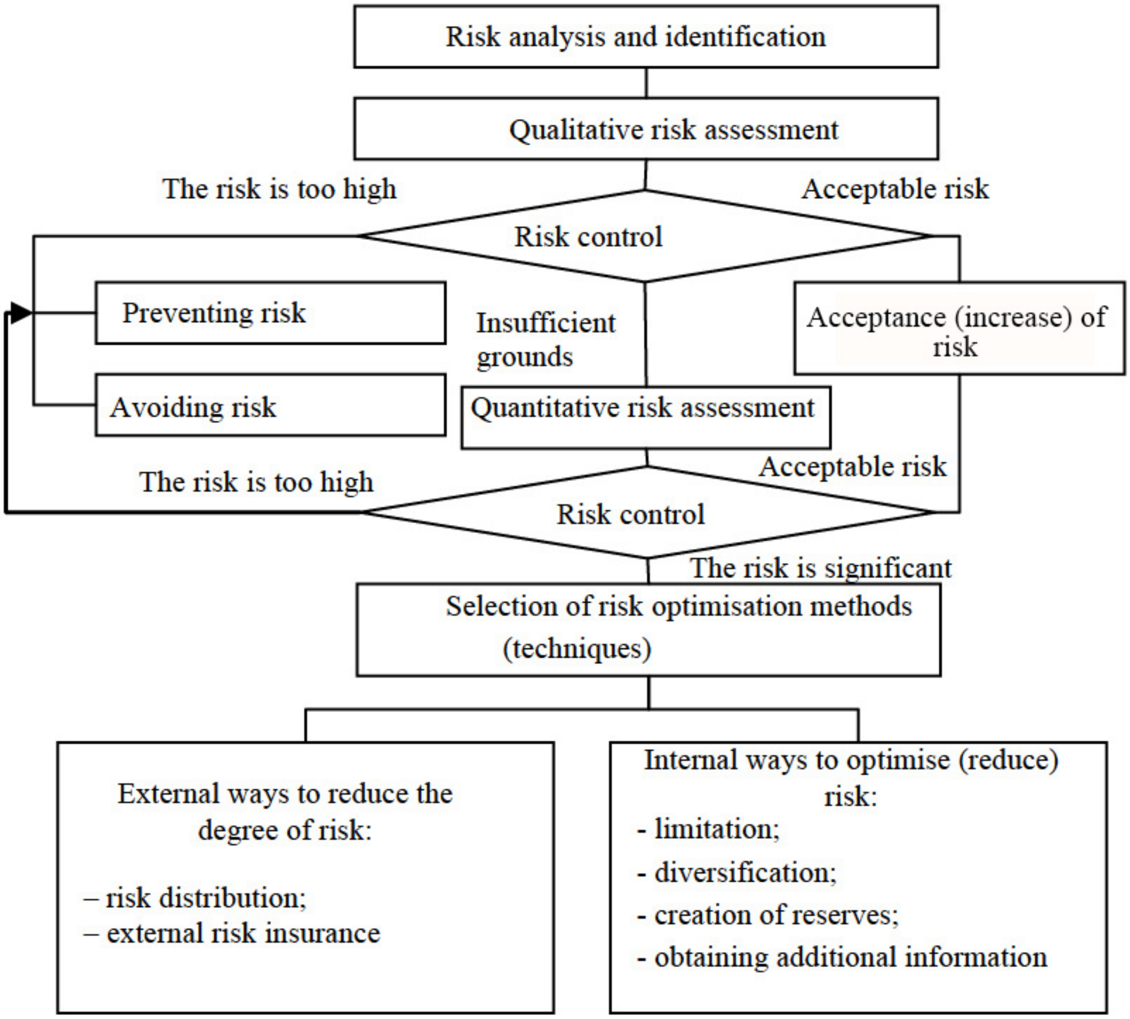

Fig. 1. Generalised risk management process flowchart

Risk analysis involves examining the causes and sources of risks, their potential consequences, and the likelihood of these consequences. It is essential to identify the factors that influence these outcomes and probabilities. A single event may have multiple consequences, impacting various objectives. The analysis should also consider the available controls and their effectiveness. In more complex cases, it may be necessary to use multiple methods to fully assess the risk. Risk analysis often involves quantifying a range of possible outcomes resulting from an event, situation, or circumstance, along with their associated probabilities, to assess the level of risk. However, in certain cases - such as when the consequences are minimal or the likelihood of occurrence is extremely low - it may be sufficient to evaluate just one parameter in order to decide (Simpson, 2024; Nateghi & Aven, 2021).

In certain situations, a consequence may arise from multiple events or conditions, or a specific event might remain unidentified. In such cases, the overall risk assessment concentrates on evaluating the importance and vulnerability of system elements to determine the appropriate risk management approaches, which may involve protection levels or recovery strategies (Li, 2020).

Risk analysis methods can be qualitative, semi-quantitative, or quantitative, depending on the specific needs of the application, the availability of reliable data, and the organisation's decision-making requirements. In some cases, certain methods and levels of analysis may be mandated by law. A qualitative assessment categorises consequences, likelihood, and risk levels using descriptive terms such as high, medium, or low. The consequence and likelihood are then combined to determine the resulting risk level according to qualitative criteria. Semi-quantitative methods use numerical scales to assess consequences and probabilities, which are then combined using a formula to calculate the overall risk level. These scales may follow linear, logarithmic, or other types of relationships, and the formulas may differ based on the method used (Tzanakakis, 2021).

Quantitative analysis evaluates the practical significance of consequences and their probabilities, calculating risk levels in specific units identified during the environmental assessment. However, a full quantitative analysis may not always be feasible or appropriate due to factors such as insufficient information, lack of data, human factors, or because the costs associated with quantitative analysis may not be justified or required. In such cases, a comparative semi-quantitative or qualitative risk ranking, involving specialists with expertise in the relevant fields, can be an effective alternative (Elhammady & Fischmeister, 2023; Urbano et al., 2023).

A risk object refers to an economic system whose efficiency and operational conditions are not predetermined. A risk subject is an individual or entity with an interest in the outcomes of managing the risk object and the competence to make decisions regarding it (Lee, 2021). A risk source is any factor (such as a phenomenon or process) that introduces uncertainty into the expected outcomes or creates conflict. In economics, the classical theory of entrepreneurial risk equates risk to the mathematical expectation of losses resulting from the selection of a particular decision, meaning that risk represents the cost associated with implementing that decision (Kilström & Roth, 2024).

The term "risk" is applied differently across various social and natural sciences, each with its own focus and research methods. In the context of sustainable development, the concept of "risk" gives rise to different types, such as economic, social, psychological, political, biomedical, legal, natural, man-made, environmental, and more. The international standard ISO 31010 (2019) provides a comprehensive list of risk assessment methods that can be applied in different fields of sustainable development. It also outlines the advantages, disadvantages, and application principles of each method. By using this standard (ISO 31010, 2019), one can select the most appropriate method for risk assessment in any area of sustainable development or combine methods to create custom approaches tailored to specific applied risk assessment challenges.

The concept of risk is utilised across a wide range of social and natural sciences, each with its own focus, subject matter, and research methods. This enables the identification of various aspects of risk, including economic, social, psychological, political, biomedical, legal, natural, man-made, environmental, and others.

Risk assessment methodology is heavily influenced by the industry in question, as it is shaped by several key factors, such as the specifics of technological and product sales cycles, the nature of business entities' assets, the dynamics of scientific and technological advancements, economic development models, and information and communication support, among others. To effectively analyse risk, it is essential to first understand it. Risk analysis provides the necessary inputs for evaluating the degree of risk and guides discussions on whether risk management is needed, as well as the appropriate strategies and methods for managing those risks.

1.2. Modern approaches to assessing industrial risks

Production risks encompass the risk of defective products. In mass production settings, companies typically have dedicated departments, such as technical control departments, quality bureaus, and other units, to oversee product quality. In the machine-building industry, the average cost of control operations is about 10 % of production costs. Some of the risk losses can be offset through maintenance services for products already in the hands of consumers.

Another category of production risks is associated with the execution of existing technological processes, including various severity accidents, from minor disruptions to catastrophic events with human casualties. Such incidents can occur at industrial facilities due to various factors: natural causes (earthquakes, floods, and lightning), man-made factors (wear and tear of buildings, equipment, design errors, human mistakes, or equipment damage during repairs), or mixed causes (such as disruptions to the natural balance due to human activity, like the emergence of an oil and gas fountain during well drilling). In such cases, environmental risks may arise, such as accidental discharges of process fluids into rivers or gas emissions into the atmosphere. For these incidents, companies may face fines imposed by environmental authorities. Accidents or equipment breakdowns lead to reduced production or even shutdowns, resulting in direct profit losses due to decreased output and indirect losses from product delivery delays and lawsuits from consumers.

"Failure Mode and Effects Analysis (FMEA)" is a widely recognised and effective method used to assess risks in the operation of technological processes across various industries (Ouyang et al., 2020). This method is effective in reducing the number of potential risks in production; however, it has its limitations. The primary drawback of FMEA is that it focuses on the results rather than the causes that lead to an unfavourable situation. Moreover, FMEA relies heavily on expert assessments, which can introduce subjectivity into the process.

Ouyang et al. (2020) introduced an alternative approach to the FMEA method by applying fuzzy set theory, enabling the estimation of risk probabilities within specified intervals. This method reduces the influence of expert opinion on subjective risk assessments and allows for the comparison of probabilities across different risks, offering more nuanced information for improved risk management. The authors also compared various methods for analysing the causes and consequences of failures, providing insights into their effectiveness in selecting the most appropriate risk assessment method for specific applications.

Stødle et al. (2024) examined the use of artificial intelligence in risk analysis, emphasising the importance of combining automated algorithms with human oversight. They demonstrated that modern AI approaches enhance the description of consequences, management of uncertainties, and knowledge handling, thereby opening new possibilities in the field. At the same time, the authors highlighted the limitations of full automation, noting that critical risk management decisions cannot be entirely delegated to algorithms. They thus presented AI as a tool that strengthens analytical capabilities and improves decision-making efficiency rather than replacing human expertise.

Gul et al. (2024) proposed an innovative SBBWM model that combines stratification, the Bayesian approach, and TOPSIS sorting, which significantly improves the accuracy and adaptability of professional risk assessment. However, the study is limited to the case of flour production, which calls into question the universality of the results for other industries. Although the method considers the uncertainty and conflict of expert assessments, it requires significant resources to collect and process data from several experts. Thus, the model is promising but needs further testing and optimisation for practical use in different production environments.

Arroyo-Montaño et al. (2025) used a mixed methodology, combining quantitative data (surveys) and documentary analysis, and found a positive attitude towards the use of monitoring for risk identification, strategic alignment and quality, although they identified challenges related to staff training, policy updates and the effectiveness of alerts.

Tetelepta et al. (2025) demonstrated the practical application of the HIRARC methodology in the logistics company PT XYZ, covering 12 typical operations with injury potential and proposing realistic control measures such as training, PPE, and technical instructions. Cheng et al. (2024) developed a fall-risk assessment model that accounts for both geographical location and physiological factors to improve prediction accuracy. They created a real-time algorithm enabling rapid identification of high-risk situations and immediate warnings, which has strong potential in occupational safety, healthcare, and public safety.

Different economic sectors employ distinct methods for assessing product quality and associated risks, which depend on several factors. Riabchykov et al. (2022) investigated the probabilities associated with actual cavity sizes of porous materials when converted into foam, using them as quality indicators. Elmadhoun et al. (2025) devoted their work to the implementation of quality risk management at the final operational stage of sterile drug production (at the stages of sterilisation, packaging, labelling, inspection, and storage), using the ICH Q9 methodology and FMEA analysis for the systematic identification and mitigation of risks in a pharmaceutical context. Articles by other authors (Riabchykov et al., 2023a; Riabchykov et al., 2023b) demonstrated that the efficiency of medical materials is influenced by the size of the scattering field of actual quality indicators.

Several scientific studies (Wang et al., 2025; Burduk et al., 2025) explored methods for assessing production risks, specifically the probability of unexpected results. This approach is applied across various sectors of the national economy, including energy and nuclear facilities (Hovorov et al., 2025; Khomiak et al., 2025; Khomiak et al., 2024), the oil industry (Tang et al., 2024), the chemical industry (He et al., 2025), and construction (Cai et al., 2024; Zhao, 2024).

In assessing complex indicators as combined values of individual quality indicators, various methods are used. Wickramaratne (2024) described the use of weighted average values for combining individual quality indicators into complex metrics.

Bubela et al. (2025) assessed the risks of cyber-physical systems, in particular, researching potential vulnerabilities in the integration of physical devices and digital components. The authors analyse how factors related to security, reliability and data management can affect the smooth operation of such systems, emphasising the need for proactive risk management to ensure stable functioning.

Guliyeva (2021) developed a system of indicators for measuring quality of life, integrating both objective and subjective factors to capture the well-being of the population. The author argued for a multidimensional approach, which proved more effective than traditional one-dimensional assessments, and provided practical guidance for policy and management improvement.

Dyadyura et al. (2023), Cherniak et al. (2024), and Rudyk et al. (2024) examined statistical methods for relating the actual values of individual quality indicators for various qualimetry objects to their dimensionless assessments, facilitating integration into a comprehensive quality measure. Hovorov et al. (2025), Hrinchenko et al. (2019), and Panda et al. (2024) proposed a nonlinear mathematical relationship for assessing energy efficiency in the energy sector, demonstrating the universality of such an approach across different measurement units and indicator ranges.

An alternative mathematical model is proposed for a comprehensive evaluation of quality indicators for manufacturing parts, such as bodies of revolution, in the machine-building industry. This model is flexible, allowing its shape to vary based on the chosen shape parameter, which is determined by an expert.

When assessing sustainable development indices, mathematical dependencies are employed that do not rely on expert methods but instead focus solely on the maximum permissible values of the quality indicator (Fedorovich et al., 2023; Fedorovich et al., 2024; Komari et al., 2023). It is recommended to follow the requirements outlined in the international standard ISO 9001 (2015) to ensure the quality of measurements for individual indicators. A methodological analysis of the requirements of this standard is provided in publications (Trishch et al., 2024).

Risk assessment is mandatory when implementing international standards for quality management systems of testing and calibration laboratories. One of the requirements of this standard is the development and maintenance of a procedure for estimating measurement uncertainty. Recent scientific papers consider the extended measurement uncertainty in product quality assurance (Vasilevskyi, 2021; Vasilevskyi et al., 2021; Vasilevskyi et al., 2022; Vasilevskyi et al., 2023; Vasilevskyi et al., 2024). The fundamental requirements of this standard are presented by Trishch et al. (2019).

AI-driven risk assessment tools can predict the probability of manufacturing low-quality products by continuously monitoring process parameters and identifying deviations from optimal conditions. These systems leverage machine learning algorithms to provide rapid, detailed insights into process health, supporting proactive interventions to prevent quality issues. The integration of AI in risk management frameworks has demonstrated significant improvements in the accuracy and speed of risk detection compared to traditional methods (Canon et al., 2023; Sureshkumar et al., 2024; Palakurti, 2025; Yazdi et al., 2024).

An analysis of several publications related to quality assessment of various qualimetry objects and quality risk assessment demonstrates that most existing methodologies rely on the involvement of experts. Based on the findings from these scientific publications, the development of a universal methodology for assessing quality risks in any qualimetry objects without expert involvement appears to be a pressing challenge. Moreover, determining the probabilities of product quality risks in the production process using objective methods is an urgent task. This can be addressed through the application of mathematical statistics methods.

2. Research methods

2.1. Mathematical nonlinear functional dependence

Any product manufactured through a technological process is characterised by a set of quality indicators, which are governed by regulatory documents or customer requirements outlined in agreements. Product quality is defined as the set of characteristics that meet consumer expectations. It is essential to know the values of individual quality indicators in quantitative terms, or as measured values, to manage technological processes effectively. This information is crucial for controlling a technological operation.

To provide a comprehensive assessment of the quality of a technological system, it is necessary to determine a composite quality indicator, which combines all individual quality indicators into a single value. For this combination to be meaningful, the quality indicators must share a common scale and evaluation range. This is achieved using nonlinear mathematical dependencies, which convert individual quality indicators into dimensionless terms. By applying mathematical statistics methods, these quality indicator values are transformed into functionally dependent values or statistics.

Based on an analysis of existing mathematical dependencies used in qualimetry to assess the quality of various objects, it is evident that these methods have limitations. Therefore, the authors propose an alternative mathematical relationship, grounded in the error function. The error function, denoted as erf(x) in mathematical statistics, is commonly used in statistical processing methods. It has the following form:

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

The error function (1) is defined in scientific literature as follows: "If a random variable x has a mean of 0 and a variance of 1/(√2), and it follows a normal distribution, then applying the mathematical dependence (1) to it yields the probability that Y will fall within the interval [-x, x]" (Cherniak et al., 2024). The graphical representation of this mathematical relationship is shown in Fig. 2.

The mathematical dependence (1) takes an exponential form and has an inflexion point at x = 0. This aligns with established principles in qualimetry. According to the qualimetry theory, quality indicators at the edges of the tolerance field have a lower probability density compared to those in the middle. The tolerance field represents the range between the smallest and largest acceptable values for a quality indicator. These limits and the tolerance field are typically defined by regulatory documents that govern product quality requirements.

Therefore, mathematical dependence (1) is reasonable and can be considered a universal tool for assessing single quality indicators of any qualimetry object with established permissible limits and a tolerance field. However, since the tolerance field and permissible limits vary for each qualimetry object, the mathematical dependence (1) cannot be universally applicable as the evaluation range (-6, 6) is predefined on the (X) axis.

To address this, it is proposed to apply mathematical transformations that allow for the creation of a universally applicable mathematical dependence. This is achieved by using the principle of dividing a segment into specified proportions. The transformations result in a new mathematical dependence that can be universally applied to any qualimetry object.

$$y(x) = \frac{1}{2} + \frac{1}{2} erf\left(-2 + 4\frac{X - X_{min}}{X_{max} - X_{min}}\right) \qquad (2)$$

where erf(x) - the error function, X_{min} and X_{max} - allowable values of single quality indicators; and X - the measured value of the quality indicator.

The graphical form of the mathematical dependence (2) is shown in Fig. 3, provided that the unit quality indicator has the following boundary constraints: X_{min} = 10, X_{max} = 20.

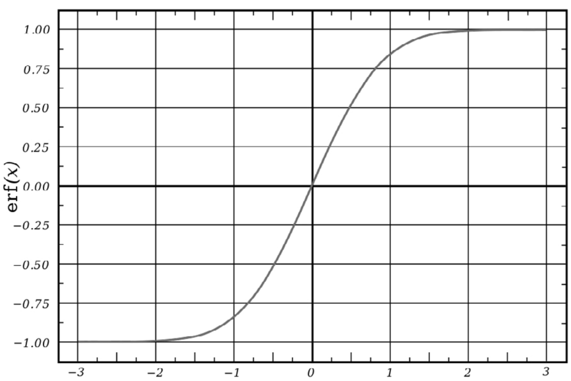

Fig. 2. Graphical view of mathematical dependence (1)

Source: (Cherniak et al., 2024).

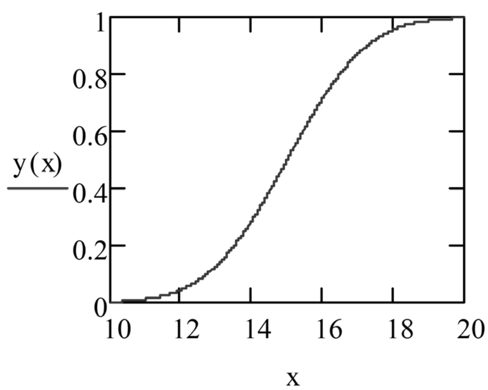

Fig. 3. Graphical view of the mathematical dependence (1) at X_{min} = 10, X_{max} = 20

The proposed mathematical dependence (2) presents several advantages over existing methods used in qualimetry:

1. Nonlinear Nature. The nonlinear character of dependence (2) aligns with the theoretical principles of qualimetry. It is supported by the fact that quality indicator estimates change minimally at the edges of the evaluation scale. This property makes the method particularly suitable for assessing quality indicators that exhibit such behaviour.

2. Ease of Use. Unlike existing methods that require complex calculations and expert assessments, the proposed dependence utilises the error function, which is already built into Microsoft Excel. This eliminates the need for specialised software, making it easier to automate the assessment process. As a result, the method can be applied to a wider range of objects, including processes, products, and knowledge across various sectors of the economy.

3. Practical Application. The proposed mathematical dependencies offer a practical tool for evaluating the quality of diverse objects. They can also be incorporated into regulatory documents at the organisational or enterprise level to standardise and streamline the quality assessment process. This enhances the flexibility and accessibility of the method in different industries and applications.

2.2. Assessing the probability of product quality risks

Modern technological systems must incorporate risk assessment procedures, as understanding the risk of producing low-quality products allows for influence over process control and the implementation of corrective actions. This enables ongoing monitoring of individual quality indicators and corrective measures to ensure their actual values remain within the established permissible limits. As existing international regulations do not provide specific methods for risk assessment, each company is required to develop its own approach based on the quality indicators, production volume, and the availability of skilled personnel.

The development of methods for assessing the risks associated with low-quality products should be grounded in the concept of "risk". The risk of producing low-quality products is understood as the probability that the quality indicators of the products will approach the permissible limits within the tolerance field. Since the calculation of probabilities is a key aspect of mathematical statistics, suitable mathematical tools must be utilised for risk evaluation.

Assume that the distribution of random values for any quality indicator follows a uniform distribution law with the corresponding density function.

$$f(x) = \begin{cases} 0 & at \quad x < a \\ \frac{1}{b-a} & at \quad a \le x \le b \\ 0 & at \quad x > b \end{cases} \qquad (3)$$

where a and b are the parameters of the distribution law.

In this case, the area under the surface of the distribution law takes the value 1.

$$\int_{-\infty}^{+\infty} f(x)dx = \int_a^b \frac{1}{b-a}dx = 1$$

The substitution of the actual value of a single quality indicator of any product (qualimetry object) and the permissible values in the mathematical dependence (2) results in an estimate of this quality indicator on the dimensionless scale OY. Many such values provide statistics of quality indicator estimates in the form of random variables. The use of the mathematical apparatus of mathematical statistics obtains the probability density function of random variables of quality indicator estimates q(y):

$$q(y) = f(C_2(y)) \cdot |C_1(y)| \qquad (4)$$

where:

$$C_1(y) = \frac{1}{2} \cdot (\frac{1}{4}X_{max} - \frac{1}{4}X_{min})\pi^{\frac{1}{2}} \begin{bmatrix} 2 + \frac{1}{2}\pi \cdot (2y-1)^2 + \frac{7}{48}\pi^2 \cdot (2y-1)^4 + \\ + \frac{127}{2880}\pi^3 \cdot (2y-1)^6 \end{bmatrix}$$

$$C_2(y) = \frac{X_{\max} - X_{\min}}{4}\left[\frac{\sqrt{\pi}}{2}\begin{bmatrix} (2y-1) + \frac{\pi(2y-1)^3}{12} + \frac{7\pi^2(2y-1)^5}{480} + \\ + \frac{127\pi^3(2y-1)^7}{40320} \end{bmatrix} + 2\right],$$

Fig. 4 shows a graph of the probability density function (4).

The determined probability density function of random variables pertaining to numerical values of single quality indicator assessments on a dimensionless scale makes it possible to find the probability that the value of a random variable Y can be in a certain range (c, d):

$$P(c < y < d) = \int_c^d q(y)dy, \qquad (7)$$

where q(y) - probability density function of the distribution of a random variable Y.

If the tolerance field of a quality indicator is divided into zones, it is evident from the principles of

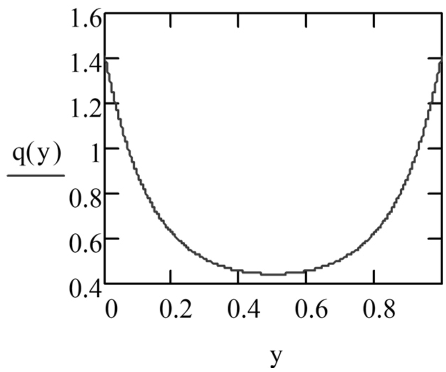

Fig. 4. Graph of the probability density function of random variables (4)

qualimetrics that manufacturers aim for the actual values of the quality indicator to be centrally positioned within the tolerance field. Values at the edges of the tolerance field are considered risky, as random factors affecting the technological system may cause the actual quality indicator to fall outside the tolerance field, leading to a product defect. Therefore, it is crucial for decision-makers to understand the probability of the actual value of the quality indicator falling within a certain range, which equates to the probability of producing low-quality products.

The likelihood that a random value of quality indicator estimates falls within a specified interval is calculated to determine this probability. This is done by determining the integral based on the formula (7).

Table 1 is constructed based on the results of the calculations.

The integration results demonstrate that the sum of the areas of the intervals from 0 to 1 equals one, which validates the accuracy of the scientific research. For further development of the methodology for assessing the quality risks of qualimetry objects, it is essential to determine the distribution law of the random variables Y. This means selecting an appropriate distribution law with which the random variables will align. Understanding the distribution law will enhance the efficiency of solving practical risk assessment tasks.

3. Research results

To validate the effectiveness of the proposed risk assessment method, it is suggested to apply it to evaluate the quality of industrial production, specifically in the manufacture of high-precision parts in mechanical engineering. Internal combustion engines are critical components of vehicles, and the parts of the piston group (piston and cylinder liner) are among the most precise components in these engines. Thus, the proposed method was tested by using it to assess the risks associated with producing a low-quality piston part.

In mechanical engineering, high-quality parts are those whose dimensions are as close as possible to the centre of the tolerance field. The tolerance field is defined by the difference between the minimum and maximum acceptable values for the part, as outlined

$$\int_0^{0.1} q(y)\,dy = 0.111; \quad \int_{0.1}^{0.2} q(y)\,dy = 0.073; \quad \int_{0.2}^{0.3} q(y)\,dy = 0.056;$$
$$\int_{0.3}^{0.4} q(y)\,dy = 0.048; \quad \int_{0.4}^{0.5} q(y)\,dy = 0.045; \quad \int_{0.5}^{0.6} q(y)\,dy = 0.045;$$
$$\int_{0.6}^{0.7} q(y)\,dy = 0.048; \quad \int_{0.7}^{0.8} q(y)\,dy = 0.056; \quad \int_{0.8}^{0.9} q(y)\,dy = 0.073;$$
$$\int_{0.9}^{1} q(y)\,dy = 0.111;$$

Tab. 1. Probability of a random variable Y falling into the interval (c, d)

Range (c, d)	**0-0.1**	**0.11-0.2**	**0.2-0.3**	**0.3-0.4**	**0.4-0.5**	**0.5-0.6**	**0.6-0.7**	**0.7-0.8**	**0.8-0.9**	**0.9-1**	**Σ**
Probability P(c<Y<d)	0.111	0.073	0.056	0.048	0.045	0.045	0.048	0.056	0.073	0.111	0.666

$$\int_{-\infty}^{0} q(y)dy = 0.168; \qquad \int_{1}^{\infty} q(y)dy = 0.168.$$

$$\sum P(c < y < d) = 0.168 + 0.666 + 0.168 = 1$$

Tab. 2. Experimental data for assessing the quality indicators of the "piston" parts in the order of their manufacture

No.	d_1 = 82.867 ± 0.005 mm	d_2 = 82.238 ± 0.005 mm	d_3 = 81.704 ± 0.005 mm	d_4 = 21.979 ± 0.005 mm
	x_{min}=82.862 mm	x_{min}=82.233 mm	x_{min}=81.699 mm	x_{min}=21.974 mm
	x_{max}=82.872 mm	x_{max}=82.243 mm	x_{max}=81.709 mm	x_{max}=21.984 mm
	Evaluation y(x) of a quality indicator on a dimensionless scale			
1	0.213	0.170	0.935	0.893
2	0.480	0.813	0.002	0.976
3	0.997	0.436	0.037	0.993
4	0.009	0.138	0.036	0.004
5	0.040	0.254	0.969	0.217
6	0.026	0.460	0.503	0.018
7	0.133	0.970	0.777	0.984
8	0.210	0.145	0.995	0.106
9	0.824	0.108	0.995	0.993
10	0.011	0.976	0.039	0.989
11	0.026	0.060	0.996	0.953
12	0.474	0.875	0.314	0.080
13	0.361	0.023	0.092	0.063
14	0.053	0.998	0.320	0.570
15	0.363	0.293	0.346	0.950
16	0.617	0.286	0.003	0.400
17	0.394	0.081	0.067	0.706
18	0.984	0.975	0.072	0.961
19	0.004	0.995	0.110	0.004
20	0.950	0.169	0.073	0.828
21	0.938	0.082	0.983	0.698
22	0.992	0.481	0.008	0.098
23	0.891	0.006	0.970	0.992
24	0.998	0.474	0.535	0.009
25	0.739	0.621	0.668	0.988
26	0.046	0.113	0.655	0.055
27	0.014	0.305	0.563	0.974
28	0.005	0.649	0.979	0.167
29	0.963	0.993	0.013	0.859
30	0.171	0.797	0.978	0.297

in the technical documentation. Therefore, if the dimensions of a part approach the edges of the tolerance field, this signals that the manufacturing process may need correction or adjustment.

When manufacturing high-precision parts, statistical methods and mathematical statistics are used for quality control. The law governing the distribution of part dimensions, treated as random variables, is typically a uniform distribution, based on the principles of mechanical engineering technology.

A numerical experiment will be conducted to apply the proposed risk assessment method for evaluating the production of a low-quality piston part, specifically focusing on the risk that the dimensions of the part may fall at the edges of the tolerance field.

The quality of the "piston" part is largely characterised by the accuracy of the diameter dimensions: d_1 = 82.867 ± 0.005 mm; d_2 = 82.238 ± 0.005mm; d_3 = 81.704 ± 0.005 mm; and d_4 = 21.979 ± 0.005 mm. A measurement experiment is carried out, which consists of measuring the listed quality indicators of parts in the order of their manufacture in the form of deviations from the middle of the tolerance field. According to formula (2), the assessment of the qual-

Tab. 3. Probability of finding the value of estimates of a random variable Y in the range (c, d)

Range (c, d)	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0	Σ
Probability P(c<Y<d)	0.17	0.11	0.1	0.07	0.05	0.05	0.07	0.1	0.11	0.17	1

ity indicator is determined by y(x) on a dimensionless scale. The results of the assessment are summarised in Table 2.

Substituting the results of the measurement experiment from Table 1 into formulas (4), (5) and (6) provides the experimental (empirical) probability density function q(y).

Applying formula (7) obtains the probabilities of falling into the assessment range (c, d). The results of the calculations are presented in Table 3.

The integration results demonstrated that the sum of the probabilities for the estimates of the random variable Y equals one, providing experimental confirmation of the reliability of the scientific research.

The next stage in advancing the proposed qualimetric method involves determining the distribution law of functionally dependent statistics along the OY axis and deriving effective estimates for its parameters. This will necessitate further scientific investigation to ensure accuracy and applicability.

4. Discussion of the results

The proposed method of assessing product quality risks using functionally dependent statistics based on the error function complements and enhances existing risk assessment methodologies. In contrast to traditional approaches such as FMEA (Ouyang et al., 2020), which rely heavily on expert judgment and often focus on the consequences rather than the causes of defects, the presented approach enables the calculation of quality risks based on mathematical formalism. This reduces subjectivity and enhances reproducibility.

The use of a nonlinear error function aligns with the theoretical principles of qualimetry, as supported by studies by Khomiak et al. (2025; 2024), which propose similar nonlinear transformations in the energy sector. Furthermore, the application of a dimensionless scale, as developed in this article, corresponds with the findings by Cherniak et al. (2024) and Trishch et al. (2024), where quality indicators are evaluated without reference to measurement units, making cross-comparison possible across various domains.

Unlike methods based on fuzzy logic (Gul et al., 2024; Irfan et al., 2022) or artificial neural networks (Canon et al., 2023; Palakurti, 2025; Yazdi et al., 2024), which require either expert-defined membership functions or large datasets for training, the proposed method is based purely on objective statistical distributions. This allows for its application even in data-scarce environments, such as in high-precision engineering or pilot-scale production, where real-time decision-making is crucial.

As such, the proposed method fills a significant methodological gap by offering a universal, mathematically rigorous, and easily implementable approach to quantifying quality risks. It can be integrated into existing quality management systems (e.g., ISO 9001 and ISO/IEC 17025) and used to enhance product quality monitoring, particularly in industries where standardisation and risk minimisation are critical.

Conclusions

This study presents and validates a universal methodology for assessing the risk of manufacturing products of a given quality by applying nonlinear mathematical dependencies derived from the error function. The proposed approach enables the transformation of measured quality indicators into a dimensionless scale and the construction of functionally dependent statistics. The key theoretical contribution lies in substantiating the applicability of the error function to qualimetric assessments under the assumption of uniform distribution of quality indicators.

From a theoretical standpoint, the developed model contributes to the field of qualimetry and statistical quality control by offering a mathematically grounded, non-subjective approach to evaluating quality risk. Unlike traditional expert-based methods (e.g., FMEA), this methodology allows for analytical determination of risk intervals without human bias. The application of nonlinear functional dependence provides a more accurate reflection of quality variation near tolerance boundaries, aligning with the core principles of qualimetry.

Practically, the model can be integrated into quality assurance procedures in high-precision industries such as mechanical engineering, metrology, and manufacturing of critical components. The implementation of the proposed method in spreadsheet tools (e.g., Excel) allows for easy adoption in real production environments without the need for complex software or AI systems. It also enables continuous monitoring of product quality and early detection of trends leading to defects.

One key limitation of the current study is the assumption of a uniform distribution of quality indicators. While this assumption is reasonable in certain manufacturing contexts, it may not hold universally, especially in processes characterised by systematic deviations or multimodal distributions. Another limitation is the use of synthetic data in testing, which, although illustrative, requires further validation on large-scale real production datasets across multiple industries.

Future research should focus on extending the methodology to account for other statistical distributions, such as normal or beta distributions, which may better represent quality variation in different sectors. Additionally, integrating this model with real-time data acquisition systems and developing automated software tools for dynamic risk visualisation could enhance its practical value. Comparative studies involving industry-standard methods (e.g., Six Sigma, AI-based prediction models) will help position this methodology more clearly within the landscape of quality management tools.

Literature

Arroyo-Montaño, M., Erazo-Álvarez, J. & Zapata-Sánchez, P. (2025). Optimizing operational efficiency in the footwear industry through continuous audit monitoring. *Revista Metropolitana de Ciencias Aplicadas*, *8*(2), 33-44. doi: 10.62452/09xyw841

Aven, T. (2023). On the gap between theory and practice in defining and understanding risk. *Safety Science*, *168*, 106325. doi: 10.1016/j.ssci.2023.106325

Bubela, T., Michalowska, J., Hots, N., Yatsuk, V., Seheda, O., Ivanyshyn, A., Sus, B. & Kozynets, A. (2025). Risk assessment of the functioning of cyber-physical monitoring systems. In Z. Hu et al. (eds), *Artificial Intelligence, Medical Engineering and Education*, *65*, 290-300. doi: 3233/ATDE250138

Burduk, A. & Pihnastyi, O. (2025). Risk assessment of a production system based on a technological description model. *Eksploatacja i Niezawodnosc - Maintenance and Reliability*, *28*(2). doi: 10.17531/ein/204577

Cai, B., Ye, Z., Chen, S. & Liang, X. (2024). Reducing safety risks in construction tower crane operations: A dynamic path planning model. *Applied Sciences*, *14*(22), 10599. doi: 10.3390/app142210599

Canon, J., Broussard, T., Johnson, A., Singletary, W. & Colmenares-Diaz, L. (2022). A knowledge-based artificial intelligence approach to risk management. *SPE Annual Technical Conference and Exhibition,* Houston, USA. doi: 10.2118/210303-ms

Cheng, M.-Y., Vu, Q.-T., & Teng, R.-K. (2024). Real-time risk assessment of multi-parameter induced fall accidents at construction sites. *Automation in Construction*, *162*, 105409. doi: 10.1016/j.autcon.2024.105409

Cherniak, O., Trishch, R., Ginevičius, R., Nechuiviter, O. & Burdeina, V. (2024). Methodology for assessing the processes of the occupational safety management system using functional dependencies. In *Integrated Computer Technologies in Mechanical Engineering – 2023*. Cham, Switzerland. doi: 10.1007/978-3-031-60549-9_1

Crawford, J., & Jabbour, M. (2023). The relationship between enterprise risk management and managerial judgement in decision-making: A systematic literature review. *International Journal of Management Reviews, 26*(1), 110-136. doi: 10.1111/ijmr.12337

Dyadyura, K., Slyuz, A., Vysotsky, I. Y., Bubela, T. & Cherniak, O. (2024). Decision support algorithm at the life cycle stages of medical devices based on the application of Markov process. In *Integrated Computer Technologies in Mechanical Engineering – 2023*. Cham, Switzerland. doi: 10.1007/978-3-031-60549-9_7

Elmadhoun, B., Alsaidalani, R. & Burczynski, F. (2025). Quality risk management in the final operational stage of sterile pharmaceutical manufacturing: A case study highlighting the management of sustainable related risks in product sterilization, inspection, labeling, packaging, and storage processes. *Sustainability*, *17*(4), 1670. doi: 10.3390/su17041670

Fedorovich, O., Lutai, L., Kompanets, V. & Bahaiev, I. (2024). The creation of an optimisation component-oriented model for the formation of the architecture of science-based products. In *Integrated Computer Technologies in Mechanical Engineering – 2023*. Cham, Switzerland. doi: 10.1007/978-3-031-60549-9_31

Fedorovich, O., Lutai, L., Trishch, R., Zabolotnyi, O., Khomiak, E. & Nikitin, A. (2024). Models for reducing the duration and cost of the aviation equipment diagnostics process using the decomposition of the component architecture of a complex product. In *Information Technology for Education, Science, and Technics*. ITEST 2024. Cham, Switzerland. doi: 10.1007/978-3-031-71801-4_9

Fleurbaey, M., & Zuber, S. (2022). A new puzzle in the social evaluation of risk. *Economics and Philosophy*, *38*, 450-465. doi: 10.1017/S0266267121000225

Fraume, M., Omar-Darío Cardona, A., Fraume, P., Martha-Liliana Carreño, T., & Barbat, A. (2020). Evaluating risk from a holistic perspective to improve resilience: The United Nations evaluation at global level. *Safety Science*, *127*, 104739. doi: 10.1016/j.ssci.2020.104739

Glette-Iversen, I., Flage, R., & Aven, T. (2023). Extending and improving current frameworks for risk management and decision-making: A new approach for incorporating dynamic aspects of risk and uncertainty. *Safety Science*, *168*, 106317. doi: 10.1016/j.ssci.2023.106317

Gul, M., Yucesan, M. & Karci, C. (2024). A stratified Bayesian decision-making model for occupational risk assessment of production facilities. *Engineering Applications of Artificial Intelligence*, *133*, 108283. doi: 10.1016/j.engappai.2024.108283

Guliyeva, A. (2021). Measuring quality of life: A system of indicators. *Economic and Political Studies*, *10*476-491. doi: 10.1080/20954816.2021.1996939

Ha, D., Park, J., & Lee, S. (2022). Risk Assessment of Reported Accident-causing Products Using Rapid Exchange of Information System Risk Assessment Guideline. *Journal of Applied Reliability*, *22*(1), 59-71. doi: 10.33162/jar.2022.3.22.1.059

He, Z., Shen, K., Lan, M. & Weng, W. (2024). An evacuation path planning method for multi-hazard accidents in chemical industries based on risk perception. *Reliability Engineering & System Safety*, *244*, 109912. doi: 10.1016/j.ress.2023.109912

Hovorov, P., Trishch, R., Ginevičius, R., Petraškevičius, V. & Šuhajda, K. (2025). Assessment of risks of voltage quality decline in load nodes of power systems. Energies, *18*, 1579. doi: 10.3390/en18071579

Hrinchenko, H., Trisch, R., Burdeina, V. & Chelysheva, S. (2019). Algorithm of technical diagnostics of the complicated damage to the continued resource of the circulation pipeline of the nuclear power plant. *Problems of Atomic Science And Technology (PAST)*, *2*(120), 104-110

Hu, S., Zhang, Y., Lin, Q., Wan, Z., & Liu, Y. (2023). Risk Assessment Method of Project Whole Process Based on Fuzzy Comprehensive Evaluation. *SHS Web of Conferences*, *170*, 02002. doi: 10.1051/shsconf/202317002002

International Organization for Standardization. (2009). *ISO Guide 73:2009 Risk management – Vocabulary - Guidelines for use in standards*. Retrieved from https://www.iso.org/standard/44651.html

International Organization for Standardization. (2015). *ISO 9001:2015 IDT Quality management systems - Requirement*. Retrieved from https://www.iso.org/standard/62085.html

International Organization for Standardization. (2018). *ISO 31000:2018 IDT Risk management - Guidelines*. Retrieved from https://www.iso.org/standard/65694.html

International Organization for Standardization. (2019). *ISO 31010:2019 IDT Risk management - Risk assessment techniques*. Retrieved from https://www.iso.org/standard/72140.html

Irfan, D., Tang, X., Narayan, V., Mall, P. K., Srivastava, S. & Saravanan, V. (2022). Prediction of quality food sale in mart using the AI-based TOR method. *Journal of Food Quality*, *2022*(1), 6877520. doi: 10.1155/2022/6877520

Ismail, M. N., Kallow, S. M., Gati, K. H., Al-Bayati, H. N. A., & Butsenko, Y. (2024). Quantitative Approaches in Decision Theory for Enhancing Risk Assessment Strategies. *Journal of Ecohumanism*, *3*(5), 308-321. doi: 10.62754/joe.v3i5.3908

Khomiak, E., Trishch, R., Nazarko, J., Novotný, M. & Petraškevičius, V. (2025). Method of quality control of nuclear reactor element tightness to improve environmental safety. *Energies*, *18*(9), 2172. doi: 10.3390/en18092172

Khomiak, E., Trishch, R., Zabolotnyi, O., Cherniak, O., Lutai, L. & Katrich, O. (2024). Automated mode of improvement of the quality control system for nuclear reactor fuel element shell tightness. In *International Scientific-Practical Conference "Information Technology for Education, Science and Technics"*. Cham, Switzerland. doi: 10.1007/978-3-031-71801-4_7

Kilström, M., & Roth, P. (2024). Risk-sharing and entrepreneurship. *Journal of Comparative Economics, 52*(1), 341-360. doi: 10.1016/j.jce.2023.12.002

Komari, I. E., Fedorenko, M., Kharchenko, V., Yehorova, Y., Bardis, N. & Lutai, L. (2020). The neural modules network with collective relearning for the recognition of diseases: Fault-tolerant structures and reliability assessment. *International Journal of Circuits, Systems and Signal Processing*, *14*, 792-800. doi: 10.46300/9106.2020.14.102.o

Lee, H. (2021). The Concept of Risk and Corporate Risk. In: *Risk Management. Risk Management: Fundamentals, Theory, and Practice in Asia* (pp. 3-12). Singapore, Asia: Springer.

Li, Y. (2020) A Vulnerability Risk Assessment Method for Industrial Control System. In *2020 International Conference on Computer Communication and Network Security (CCNS)*. Xi'an, China. doi: 10.1109/CCNS50731.2020.00040

Nateghi, R., & Aven, T. (2021). Risk Analysis in the Age of Big Data: The Promises and Pitfalls. *Risk Analysis*, *41*(10), 1751-1758. doi: 10.1111/risa.13682

Ouyang, L., Zheng, W., Zhu, Y. & Zhou, X. (2020). An interval probability-based FMEA model for risk assessment: A real-world case. *Quality and Reliability Engineering International, 36*, 125-143. doi: 10.1002/qre.2563

Palakurti, N. (2025). The role of artificial intelligence in risk assessment and mitigation in the financial sector. *International Journal of Advanced Research in Science, Communication and Technology, 5*(2), 633-641. doi: 10.48175/ijarsct-23392

Panda, A., Dyadyura, K., & Kokhan, O. (2024). Increase of technological indicators used in the energy industry. *MM Science Journal*, 7724-7730. doi: 10.17973/MMSJ.2024_11_2024025

Pirbalouti, R., Behnam, B., & Dehkordi, M. (2023). A risk-based approach to identify safety-critical equipment in process industries. *Results in Engineering, 20,* 101448. doi: 10.1016/j.rineng.2023.101448

Raian, S., Siddiqua, T., Moktadir, M., & Rahman, T. (2023). An empirical model for identifying and controlling operational and environmental risks in spinning industry in an emerging economy. *Computers & Industrial Engineering*, *180*, 109244. doi:10.1016/j.cie.2023.109244

Riabchykov, M., Alexandrov, A., Trishch, R., Nikulina, A. & Korolyova, N. (2022). Prospects for the development of smart clothing with the use of textile materials with magnetic properties. *Tekstilec*, *65*(1), 1-8. doi: 10.14502/tekstilec.65.2021050

Riabchykov, M., Nazarchuk, L. & Tkachuk, O. (2022). Basic parameters of medical textile materials for removal and retention of exudate from wounds. *Tekstilec*, *65*(4), 268-277. doi: 10.14502/tekstilec.65.2022064

Riabchykov, M., Tkachuk, O., Nazarchuk, L. & Alexandrov, A. (2023). Conditions for the open pores formation in medical textile materials for the treatment of wounds using iron oxide nanopowders. *Materials Research Express*, *10*(1), 015401. doi:10.1088/2053-1591/acadcf

Riabchykov, M., Tsykhanovska, I. & Alexandrov, A. (2023). Justification of technologies for the synthesis of mineral nanoparticles for the creation of magnetic smart textile. *Journal of Materials Science, 58*(16), 7244-7256. doi: 10.1007/s10853-023-08463-x

Rudyk, Y., Mykyichuk, M., & Menshykova, O. (2024). Criteria for the Use of Information Technology in Assessing the Quality of Critical Infrastructure by Safety Indexes. In: *International Scientific-Practical Conference" Information Technology for Education, Science and Technics"*. Cham, Switzerland. doi: 10.1007/978-3-031-71801-4_13

Settembre-Blundo, D., González-Sánchez, R., Medina-Salgado, S., & García-Muiña, F. (2021). Flexibility and Resilience in Corporate Decision Making: A New Sustainability-Based Risk Management System in Uncertain Times. *Global Journal of Flexible Systems Management, 22*, 107-132. doi: 10.1007/s40171-021-00277-7

Simpson, A. (2024). Into the unknown: the need to reframe risk analysis. *Journal of Cybersecurity*, *10*(1). doi: 10.1093/cybsec/tyae022

Stødle, K., Flage, R., Guikema, S. & Aven, T. (2024). Artificial intelligence for risk analysis - A risk characterization perspective on advances, opportunities, and limitations. *Risk Analysis*, *45*, 738-751. doi: 10.1111/risa.14307

Sureshkumar, N., Narayanan, P., Ghapar, F., Chew, L., Pandiyan, V., Sundram, K., Naidu, B. M., Zulfakar, M. & Daud, A. (2024). Artificial intelligence-powered risk assessment in supply chain safety. *Information Management and Business Review*, *16*(3), 107-114. doi: 10.22610/imbr.v16i3s(i)a.4124

Tang, K. H. D. (2024). Artificial intelligence in occupational health and safety risk management of construction, mining, and oil and gas sectors: Advances and prospects. *Journal of Engineering Research and Reports*, *26*(6). 241-253. doi: 10.9734/jerr/2024/v26i61177

Tetelepta, J. O. & De Carvalho Belo, G. B. (2025). Analysis of potential hazards of work accidents to workers using the Hazard Identification, Risk Assessment and Risk Control (HIRARC) method in freight forwarding companies. *Jurnal Ilmiah Manajemen Sumber Daya Manusia*, *8*(3), 329-340. doi: 10.32493/jjsdm.v8i3.46222

Trishch, R., Cherniak, O., Zdenek, D. & Petraskevicius, V. (2024). Assessment of the occupational health and safety management system by qualimetric methods. *Engineering Management in Production and Services*, *16*(2), 118-127. doi: 10.2478/emj-2024-0017

Trishch, R., Maletska, O., Hrinchenko, H., Artiukh, S., Burdeina, V. & Antonenko, N. (2019). Development and validation of measurement techniques according to ISO/IEC 17025:2017. In *2019 IEEE 8th International Conference on Advanced Optoelectronics and Lasers (CAOL)*. Sozopol, Bulgaria. doi: 10.1109/CAOL46282.2019.9019539

Tzanakakis, K. (2021). Risk Assessment Techniques. In *Managing Risks in the Railway System: A Practice-Oriented Guide* (pp. 113-146). Cham, Switzerland: Springer

Urbano, E., Martínez-Viol, V., Kampouropoulos, K., & Romeral, L. (2023). Quantitative and qualitative risk-informed energy investment for industrial companies. *Energy Reports*, *9*, 3290-3304. doi: 10.1016/j.egyr.2023.01.131.

Vasilevskyi, O. (2021). Assessing the level of confidence for expressing extended uncertainty through control errors on the example of a model of a means of measuring ion activity. *Acta IMEKO*, *10*(2), 199-203. doi: 10.21014/acta_imeko.v10i2.810

Vasilevskyi, O., Cullinan, M. & Allison, J. (2024). Theoretical approach for determining an emissivity of solid materials and its comparison with experimental studies on the example of 316l powder steel. *Informatyka, Automatyka, Pomiary W Gospodarce I Ochronie Środowiska*, *14*(3), 5-8. doi: 10.35784/iapgos.6289

Vasilevskyi, O., Koval, M. & Kravets, S. (2021). Indicators of reproducibility and suitability for assessing the quality of production services. *Acta IMEKO*, *10*(4), 54-61. doi: 10.21014/acta_imeko.v10i4.814

Vasilevskyi, O., Sevastianov, V., Ovchynnykov, K., Didych, V. & Burlaka, S. (2023). Accuracy of potentiometric methods for measuring ion activity in solutions. In *Proceedings of Seventh International Congress on Information and Communication Technology: ICICT 2022*. London, Unitek Kingdom. doi: 10.1007/978-981-19-1607-6_16

Vasilevskyi, O., Voznyak, O., Didych, V., Sevastianov, V., Ruchka, O. & Rykun, V. (2022). Methods for constructing high-precision potentiometric measuring instruments of ion activity. In *2022 IEEE 41st International Conference on Electronics and Nanotechnology (ELNANO)*. Kyiv, Ukraine. doi: 10.1109/ELNANO54667.2022.9927128

Wang, Q., Zhang, X., Wang, F., Dou, Z., Jiang, Y. & Yang, G. (2022). Human factors risk assessment for high-danger production processes based on SPA. In *12th International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering (QR2MSE 2022)*. Emeishan, China. doi: 10.1049/icp.2022.2901

Wickramaratne, K. A. C. (2023). Risk based quality management: the way forward to improve quality in medical laboratories. *The Sri Lanka Journal of Haematology*, *15*(1), 12-18. doi: 10.4038/tsljh.v15i1.10

Yazdi, M., Zarei, E., Adumene, S. & Beheshti, A. (2024). Navigating the power of artificial intelligence in risk management: A comparative analysis. *Safety*, *10*(2), 42. doi: 10.3390/safety10020042

Zhao, X. (2024). Research on high-rise building risk identification and safety risk factor analysis. *Theoretical and Natural Science*, *31*, 313-319. doi: 10.54254/2753-8818/31/20240997