EMPIRICAL VALIDATION OF A NEW OCCUPATIONAL RISK ASSESSMENT TOOL BASED ON A RISK MATRIX FOR SMALL AND MEDIUM-SIZED ENTERPRISES
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VALIDAREA EMPIRICĂ A UNUI NOU INSTRUMENT DE EVALUARE A RISCURILOR OCUPAȚIONALE BAZAT PE O MATRICE DE RISC ÎN ÎNTREPRINDERILE MICI ȘI MIJLOCII

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ABSTRACT
This study scientifically validates a tool for identifying and assessing occupational risks in the agricultural and food industry, aiming to enhance worker health and safety. Developed through a systematic literature review, the tool integrates theoretical and operational perspectives, addressing both traditional and emerging risks from digitalization - such as ergonomic, psychosocial, and managerial factors linked to technology use and automation. Validation, via comparative and statistical analyses (e.g., Gaussian distributions, Cronbach α coefficient), confirmed its reliability and applicability. The tool proves effective in supporting risk prevention strategies adapted to evolving, digitally influenced organizational environments.

ABSTRACT
Acest studiu validează științific un instrument pentru identificarea și evaluarea riscurilor ocupaționale în industria agricolă și alimentară, cu scopul de a îmbunătăți sănătatea și securitatea lucrătorilor. Dezvoltat printr-o analiză sistematică a literaturii de specialitate, instrumentul integrează perspective teoretice și operaționale, abordând atât riscurile tradiționale, cât și pe cele emergente generate de digitalizare - cum ar fi factorii ergonomici, psihosociali și manageriali legați de utilizarea tehnologiei și automatizare. Validarea, prin analize comparative și statistice (de exemplu, distribuții Gaussiene, coeficient Cronbach α), a confirmat fiabilitatea și aplicabilitatea sa. Instrumentul se dovedește eficient în susținerea strategiilor de prevenire a riscurilor adaptate la medii organizaționale în evoluție, influențate digital.

INTRODUCTION
This study aims to make a significant contribution to the existing knowledge in the field of occupational risk assessment (*Gul, 2018*), by formulating and pursuing two objectives:

1. Brief presentation of the stages of the tool developed for the identification and assessment of occupational risks, with an emphasis on defining its essential components. This is an essential stage for understanding the scientific validation of the instrument, carried out within this study (stage 2).
2. Scientific validation of the developed instrument, carried out by applying specific statistical methods, including distribution analysis (normal and interval), estimation of internal consistency through Cronbach α coefficients, as well as SWOT analysis, used to identify strengths, limitations, opportunities for improvement and potential methodological risks associated with the instrument code.

This study is structured in a logical and progressive manner, starting with a brief, structured presentation of the stages of the tool intended for the identification and assessment of occupational risks. This stage is followed by the presentation of the results obtained from the scientific validation process of the developed instrument, including the methods used to assess the consistency and validity of the instrument. In the final part of the paper, the conclusions derived from the research are formulated, while highlighting the identified limitations, which may constitute starting points for future research in this direction.

Adequate risk assessment is a central element in ensuring organizational resilience, especially in the context of the accelerating transition to a digitalized work environment (*Badea et al, 2024*). A comprehensive and effective risk assessment involves not only identifying technical and operational threats, but also integrating human and organizational dimensions. It is essential to correlate cybersecurity risks with those regarding data protection and workforce adaptability. It is also necessary to take into account the interdependencies between the technologies used, the level of employee training and the organizational culture in relation to digital innovation (*Iordache et al, 2025*). Such an approach allows the development of proactive mechanisms for risk prevention and mitigation, thus contributing to a sustainable and secure digital transition (*Baumgart et al., 2017; Inam et al., 2018*).

This article is part of a broader research, carried out in two complementary stages: the first stage aimed at developing an original tool for identifying and assessing occupational risks, adapted to the specifics of the paper and corrugated cardboard manufacturing industry and paper and cardboard packaging, and the next stage aimed at developing a digital solution aimed at facilitating the efficient application of this tool in risk prevention and control processes, thus contributing to increasing the level of safety and sustainability within the analyzed sector. Thus, the main objective of the article is to validate the developed instrument by conducting a comparative analysis with a well-established and widely used evaluation method in Romania, an approach based on the application of relevant statistical indicators, capable of highlighting both the robustness and the added value of the proposed solution.

MATERIALS AND METHODS

Considering the central objective of this study, it is necessary to briefly present the defining elements of the developed tool – Figure 1:

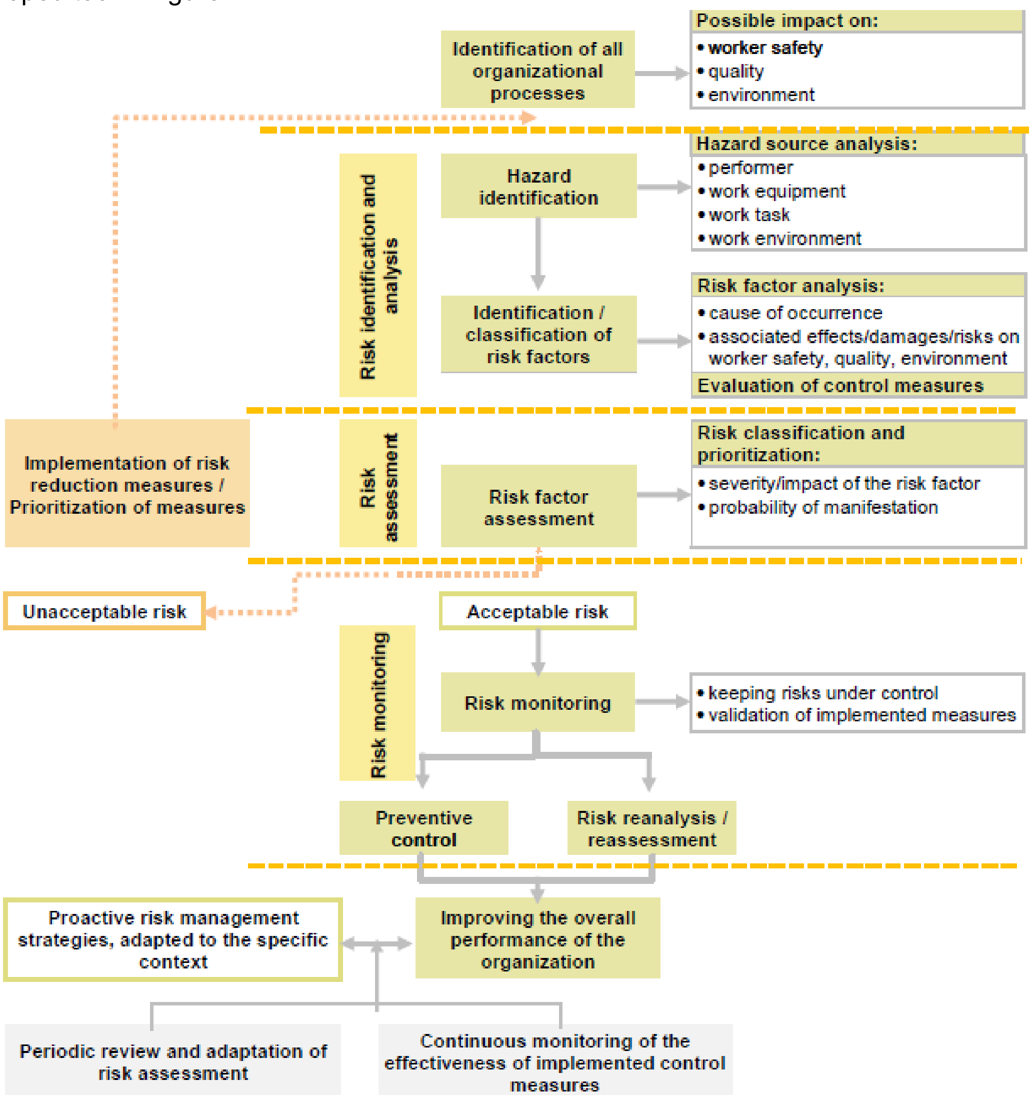


Fig. 1 - Methodological diagram of the process of identifying and assessing occupational risks
(*Milea (Pârvu) & Cioca, 2025*)

The proposed method stands out for its novelty at the national level, being an original concept that makes a distinct contribution to the practice of occupational risk assessment. It is specifically designed to meet the needs of small and medium-sized enterprises, where resources dedicated to prevention and protection activities are often limited, but where the impact of uncontrolled risks can be significant. In addition, the method explicitly integrates emerging risks associated with technological evolution and the digitalization of production processes, which gives it increased relevance in the current context of accelerated changes in the industry. Through this approach, it is aimed not only at compliance with legal requirements, but also at creating a practical and adapted framework for proactive risk management at the organizational level.

The development process of the occupational risk identification and assessment tool was carried out between January and August 2024. This stage included a systematic and critical analysis of the specialized literature, with the aim of theoretically substantiating the structure and content of the tool. Based on the conclusions drawn from the literature and the best practices identified internationally, a preliminary version of the tool was developed. The results obtained, respectively the stages of the developed tool, are briefly presented below, with an emphasis on defining its essential components:

Stage 1 – Identification of all organizational processes

This stage consists of identifying all processes carried out within the organization, with the aim of substantiating the assessment of occupational risks (*Drăghici A., Căruțașu N., 2020; WordHealthOrganisation, 2010*). This stage involves identifying activities, identifying and analyzing all processes, organizational sub-processes, the resources involved and how these resources interact (*Gholamizadeh et al., 2023; Giménez et al., 2024; Kirsten, 2024*). This stage of identifying and analyzing organizational processes constitutes the foundation for identifying hazards and the detailed assessment of the risks associated with each individual process (*Milea (Pârvu) et al., 2025*).

Stage 2 – Establishment of the working group for analysis and evaluation

This stage involves the establishment of a working group with a multidisciplinary profile, bringing together expertise in technical fields, occupational health and safety, psychosociology and data protection. The diversity of skills involved allows for a comprehensive risk assessment, facilitating an integrated understanding of the factors involved and the promotion of innovative and efficient solutions, appropriate to the challenges of a work environment undergoing accelerated digitalization (*Cazan, 2020*).

Stage 3 – Hazard identification

This stage consists of analyzing the dependencies and interactions between the components of the work system: performer, equipment used, workload, work environment, materials involved and organizational factors (management) (*Milea (Pârvu) & Cioca, 2024*). The result of the process is the development of a list of identified hazards, together with their classification into relevant categories (physical, chemical, biological, ergonomic, psychosocial, etc.) (*Adattila et al., 2024; Bejinariu et al., 2023; Cioca et al., 2011; Costantino et al., 2021; Lindholm et al., 2020; Neal & Griffin, 2006; Yuan et al., 2024*), as well as the location of critical areas or situations with a high probability of undesirable events occurring. The identified hazards provide the foundation for the subsequent stages of risk analysis, evaluation, and management.

Stage 4 – Identification / classification of risk factors

This stage involves the systematic analysis of a relevant set of information and resources, in order to identify risk factors associated with organizational processes (*Moraru, 2023; Safety and Health at Work: A Vision for Sustainable Prevention*, *n.d.*). Risk factors are identified and analyzed not only in correlation with the potential effects on the health and safety of workers but also taking into account the potential effects on the quality of products/services and environmental protection, thus reflecting the interdependencies within the organization's integrated management system (*Abeje, 2024; Gholamizadeh et al., 2023; Jiang et al., 2024; SR EN ISO 45001:2023*, n.d.).

Stage 5 – Assessment of risk factors

The assessment of risk factors is carried out based on the analysis of previously collected information, namely the identification of hazards and the preliminary classification of the identified risks (*Schulte et al., 2022; Xu et al., 2021*). At this stage, a quantitative assessment model is applied, through which risks are classified according to the level of associated risk. To ensure a balance between simplicity and relevance, a five-level rating scale (1–5) is used for each of the two fundamental dimensions: severity (S) and probability (P) – Figure 2:

Severity class	
1	Insignificant
2	Minor
3	Moderate
4	Serious
5	Catastrophic

Probability class	
1	Very rare
2	Rare
3	Possible
4	Probable
5	Very likely

Fig. 2 - Classification of risk factors according to potential severity/impact and probability of occurrence (*Milea (Pârvu) & Cioca, 2025*).

The risk level (*Taibi et al., 2022*) is determined by the relationship: *Risk level = S × P*, resulting in a score between 1 (minimum risk) and 25 (maximum risk) – Figure 3:

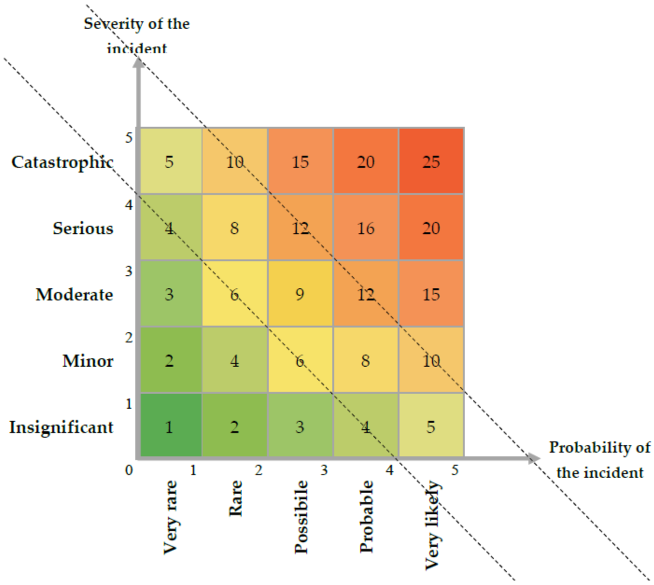


Fig. 3 - Risk classification matrix (based on severity and probability of incident) (*Milea (Pârvu) & Cioca, 2025*).

The score obtained allows both the classification and prioritization of risks – Figure 4, facilitating the decision-making process regarding the control and prevention measures to be implemented:

UNACCEPTABLE RISK

Risk classification	Risk level
Extreme risk	21-25
High risk	16-20
Significant risk	11-15
Moderate risk	6-10
Low risk	1-5

ACCEPTABLE RISK

Fig. 4 - Risk classification according to risk level (*Milea (Pârvu) & Cioca, 2025*).

Stage 6 – Risk management

This stage aims to formulate and implement effective solutions to control, reduce or, where possible, eliminate the risks identified in the previous stages (*Fernández-Muñiz et al., 2007*). The main results of the stage consist of developing an action plan for risk management, which includes technical, organizational, procedural and individual measures, aimed at eliminating hazards or reducing them to an acceptable risk level (*Dragano & Lunau, 2020*). Also, at this stage, control measures are prioritized, depending on the level of risk associated with each factor. Although all identified risks are addressed to prevent their amplification over time, priority is given to those with a high probability of manifestation and severe consequences for worker safety.

Stage 7 – Risk monitoring

This stage ensures ongoing risk assessment and the effectiveness of prevention measures. Monitoring focuses on detecting changes or new risks arising from technological, operational, or organizational shifts, and identifying residual risks that persist after initial actions.

Based on this overview of the developed tool, the premises for evaluating its validity and applicability in occupational risk management are established. The next phase involves testing it in real work conditions to assess its relevance and efficiency in supporting decision-making in occupational health and safety.

RESULTS

To validate the tool developed for the identification and assessment of occupational risks, it was applied within a company in the paper and corrugated cardboard and paper and cardboard packaging manufacturing industry, with the aim of identifying hazards and assessing occupational risks (*Ávila-Gutiérrez et al., 2022; Koessler & Schuett, 2023*). To verify the accuracy and effectiveness of the tool, a comparative analysis was carried out between its results and those obtained through an independent evaluation, using the method developed by the National Institute for Research and Development for Labor Protection "Alexandru Darabonț" in Bucharest (the I.N.C.D.P.M. method, hereinafter referred to as the "reference method"), a method that is widely used in Romania (*Băbuţ, 2009; Băbuț, G.B., 2017; Mariken H.C. Everdij (NLR), 2022; Milea (Pârvu) & Cioca, 2024; Pece, Şt., Dăscălescu, 1998*). Both methods were applied simultaneously on the same workstation, under identical operating conditions and within the same time interval, to ensure direct comparability of results and the elimination of external influences.

a) Preparation of collected data

Table 1

Summary of the results obtained following the application of the developed method and the "reference method"

Source of danger (developed method)	Source of danger (reference method)	Risk factors (developed method)	Risk factors (reference method)	Risk factors - coding	Severity (S) (developed method)	Probability (P) (proposed method)	Risk level (SxP) (developed method)	Risk level (SxP) (reference method)
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F1	4	3	12	3
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F2	4	2	8	3
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F3	3	3	9	3
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F4	4	3	12	2
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F5	5	1	5	3
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F6	3	3	9	3
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F7	5	1	5	3
PERFORMER	PERFORMER	Wrong actions	-	F8	3	3	9	-
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F9	4	3	12	3
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F10	3	3	9	3
PERFORMER	PERFORMER	Wrong actions	Wrong actions	F11	4	2	8	3
PERFORMER	PERFORMER	Wrong actions	-	F12	3	4	12	-
PERFORMER	PERFORMER	Ergonomic risk factors	Ergonomic risk factors	F13	4	4	16	3
PERFORMER	PERFORMER	Ergonomic risk factors	-	F14	2	5	10	-
PERFORMER	PERFORMER	Psychosocial risk factors	-	F15	3	3	9	-
PERFORMER	PERFORMER	Psychosocial risk factors	Ergonomic risk factors	F16	2	1	2	2
PERFORMER	PERFORMER	Psychosocial risk factors	-	F17	1	1	1	-
WORK EQUIPMENT	WORK EQUIPMENT	Mechanical risk factors	-	F18	3	2	6	-
WORK EQUIPMENT	WORK EQUIPMENT	Mechanical risk factors	Mechanical risk factors	F19	3	2	6	3
WORK EQUIPMENT	WORK EQUIPMENT	Mechanical risk factors	-	F20	2	1	2	-
WORK EQUIPMENT	WORK EQUIPMENT	Mechanical risk factors	-	F21	1	3	3	-
WORK EQUIPMENT	WORK EQUIPMENT	Mechanical risk factors	-	F22	1	3	3	-
WORK EQUIPMENT	WORK EQUIPMENT	Mechanical risk factors	-	F23	1	3	3	-
WORK EQUIPMENT	WORK EQUIPMENT	Thermal risk factors	Thermal risk factors	F24	5	1	5	3
WORK EQUIPMENT	WORK EQUIPMENT	Electrical risk factors	Electrical risk factors	F25	4	1	4	3
WORK EQUIPMENT	WORK EQUIPMENT	Chemical risk factors	Chemical risk factors	F26	4	4	16	2
WORK EQUIPMENT	WORK EQUIPMENT	Ergonomic risk factors	-	F27	1	1	1	-
WORKLOAD	WORKLOAD	Ergonomic risk factors	-	F28	2	3	6	-
WORKLOAD	WORKLOAD	Ergonomic risk factors	Ergonomic risk factors	F29	3	5	15	2
WORKLOAD	WORKLOAD	Ergonomic risk factors	-	F30	3	5	15	-
WORKLOAD	WORKLOAD	Psychosocial risk factors	-	F31	1	2	2	-
WORKLOAD	WORKLOAD	Psychosocial risk factors	-	F32	1	2	2	-
WORKLOAD	WORKLOAD	Psychosocial risk factors	-	F33	2	4	8	-
WORKLOAD	WORKLOAD	Psychosocial risk factors	-	F34	2	4	8	-
WORKLOAD	WORKLOAD	Psychosocial risk factors	-	F35	2	3	6	-
WORKLOAD	WORKLOAD	Psychosocial risk factors	-	F36	1	2	2	-
WORKLOAD	WORKLOAD	Psychosocial risk factors	-	F37	1	1	1	-
WORKLOAD	WORKLOAD	Psychosocial risk factors	-	F38	2	3	6	-
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Physical risk factors	Physical risk factors	F39	1	2	2	2
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Physical risk factors	-	F40	2	2	4	-
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Physical risk factors	-	F41	1	5	5	-
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Physical risk factors	Physical risk factors	F42	1	1	1	2
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Physical risk factors	-	F43	2	4	8	-
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Physical risk factors	-	F44	5	1	5	-
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Physical risk factors	Physical risk factors	F45	5	1	5	3
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Chemical risk factors	Chemical risk factors	F46	2	5	10	2
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Biological risk factors	-	F47	2	1	2	-
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Psychosocial risk factors	-	F48	1	2	2	-
WORKING ENVIRONMENT	WORKING ENVIRONMENT	Psychosocial risk factors	-	F49	1	1	1	-
MATERIALS	-	Physical risk factors	Physical risk factors	F50	4	3	12	2
MATERIALS	-	Physical risk factors	Physical risk factors	F51	4	2	8	2
MATERIALS	-	Chemical risk factors	-	F52	3	3	9	-
MANAGEMENT	-	Management	-	F53	1	1	1	-
MANAGEMENT	-	Management	-	F54	2	3	6	-

Table 1 includes a comparative synthesis of the results obtained by applying the developed method and those generated by applying the I.N.C.D.P.M. method (called the "reference method").

To support the analysis and correlation of risk factors within the study, they were assigned unique codes, numbered sequentially from F1 to F54. Also, the color coding used facilitates data identification: green – values associated with the developed method; white – values obtained by the reference method; gray – unique identification codes assigned to risk factors.

In this analysis, severity and probability classes were not compared, as the two methods use distinct classification scales (5×5 in the case of the developed method, and 7×6 for the reference method). Also, risk level values were not included, given the differences in calculation algorithms and formulas between the two methods, which would have affected direct comparability and accuracy of interpretation.

b) Formulation of hypotheses

To validate the developed risk assessment method, the following statistical hypotheses were formulated, aimed at evaluating its efficiency and relevance in comparison with the reference method:

- ⇨ Hypothesis 1: The developed method is effective in identifying emerging risks associated with new processes and technologies used (ergonomic, psychosocial, management risks, etc.), which may be underestimated or omitted by conventional methods.
- ⇨ Hypothesis 2: The total number of risk factors identified by the developed method is higher than that identified by the reference method.
- ⇨ Hypothesis 3: The developed method allows a more specific classification of risks, causes and conditions that may generate effects/damages/associated risks on worker safety, quality or the environment (on the organization's integrated management system).

c) Method quality analysis

To ensure the methodological rigor of the analysis and to justify the use of the Gaussian distribution in the assessment of risk levels, it was necessary to test the normality of the distribution of the raw data. For this purpose, the Shapiro-Wilk test was applied both to the data resulting from the developed method and to those obtained by the reference method.

The results were as follows:

- developed method: $W = 0{,}956$; $p = 0{,}394 \Rightarrow p > 0{,}05$ → the distribution can be considered normal;
- reference method: $W = 0{,}622$; $p \approx 0{,}0000016 \Rightarrow p < 0{,}05$ → the distribution deviates significantly from normality.

These results indicate that only the data related to the developed method respect the normality assumption, supporting the choice of the Gaussian distribution for modeling risk levels.

Figure 5 presents the histograms and Q-Q plots for the two methods, visually confirming the approximately symmetrical nature of the distribution for the developed method. Thus, the estimation of the normal distribution is justified both statistically and graphically, in the context of the structure and dispersion of the analyzed data.

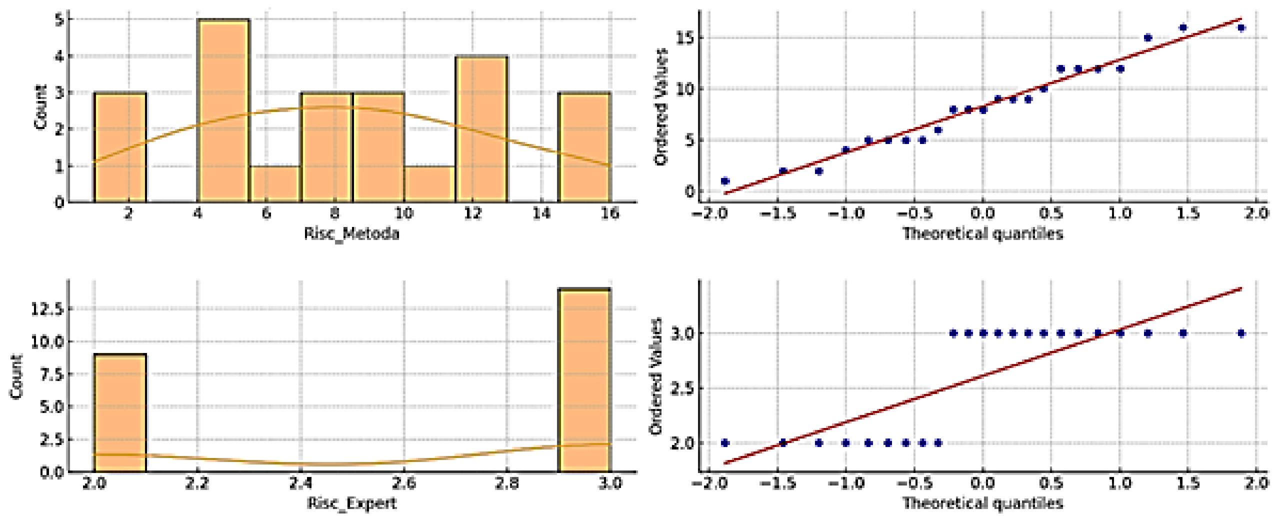


Fig. 5 - Graphical representations (histograms and Q-Q plots) generated for the risk levels related to the developed method and the reference method

To validate the developed method, a comparative analysis was performed between it and a reference method, using the distribution of risk values by intervals and the estimation of the Gaussian distribution. The aim of this approach was to quantitatively assess the variability of the identified risks, thus providing a solid basis for comparing the two methods.

The distribution by intervals allowed a clear classification of risks by level, thus facilitating their prioritization. In parallel, the estimation of the Gaussian distribution contributed to the understanding of the central structure and dispersion of the values, allowing the identification of significant deviations.

For each source of hazard, distinct graphs were generated for both methods, using specific segmentations of the value range. The intervals had fixed widths, established empirically: 3,3 units for the developed method and 2,2 units for the reference method. The analysis domain was delimited by the minimum and maximum values of the risk level, and the following formulas were applied for segmentation:

- For the developed method: $3.3*k$, $3.3*k + 3.3$, cu $k \in \{0, ..., N-1\}$ and $3.3*N + 3.3$
- For the reference method: $2.2*k$, $2.2*k + 2.2$, cu $k \in \{0, ..., N-1\}$ and $2.2*N + 2.2 \leq Max$

The absolute frequencies of the values in each interval were then normalized so that the total area under the distribution equaled 1 – according to the fundamental principle of a continuous Gaussian distribution. For example, for a discrete distribution with frequencies 8, 12 and 5 in three intervals of 3,3 units, the total area is A = 3,3*(8+12+5) = 82,5, and the normalized values become 8/82,5, 12/82,5 and 5/82,5.

Based on these data, graphs with discrete (bars) and continuous (Gaussian curve) distributions were generated, for each hazard source separately, as well as in aggregate, for all sources. The continuous distribution was constructed using the Gaussian density function:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \tag{1}$$

where:

$\mu = \frac{\sum_{i=0}^{N-1} x_i}{N}$, is the arithmetic mean

$\sigma = \sqrt{\frac{\sum_{i=0}^{N-1}(x_i-\mu)^2}{N}}$, is the standard deviation.

These graphs are presented in Figures 6–9 and serve as a basis for validating the developed method, by demonstrating the coherence and comparability of the obtained distributions with the reference method.

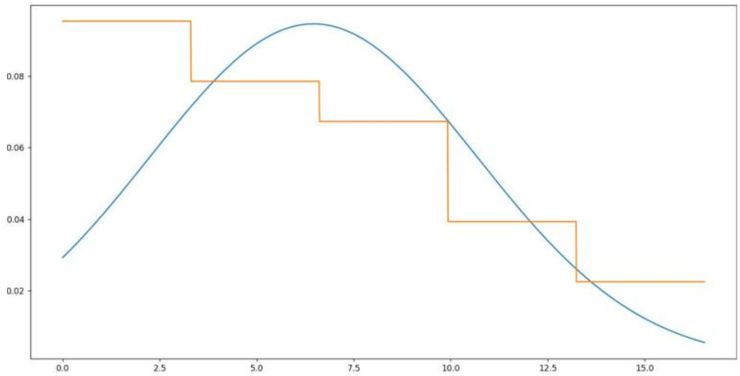
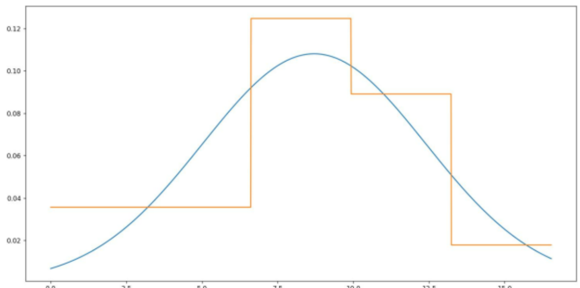
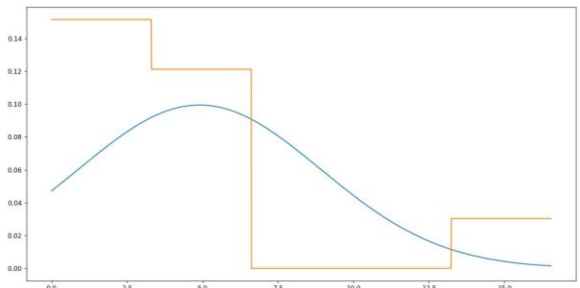
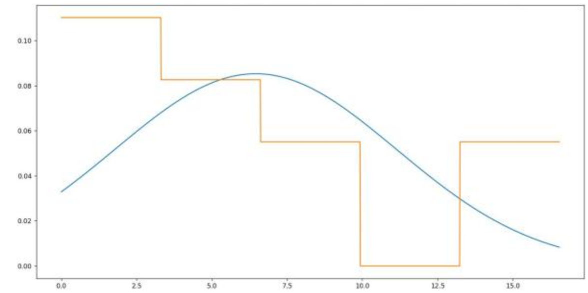
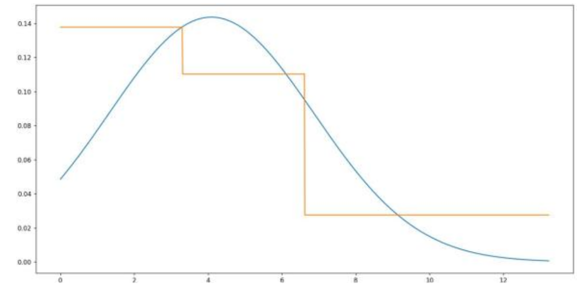


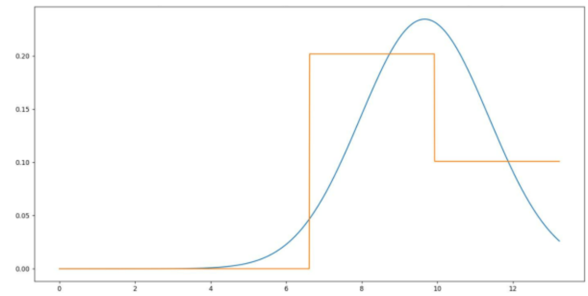
Fig. 6 - Interval distribution of risk values for all hazard sources and estimated Gaussian distribution (developed method)

Source of hazard: performer	Source of hazard: work equipment
	
Source of hazard: work load	Source of hazard: work environment





Source of hazard: materials | Source of hazard: management



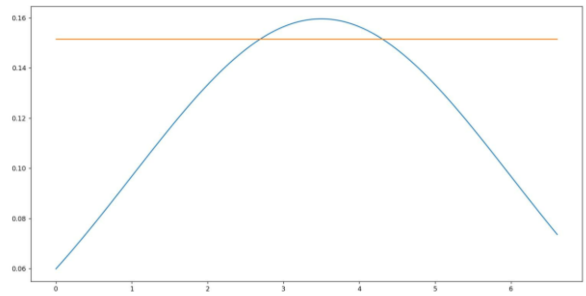


Fig. 7 - Distribution by intervals of risk values for each source of hazard (performer / work equipment / work task / working environment / materials) and estimated Gauss distribution (developed method)

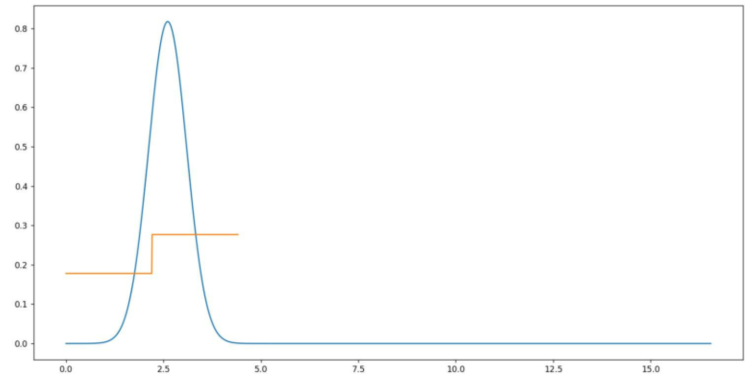
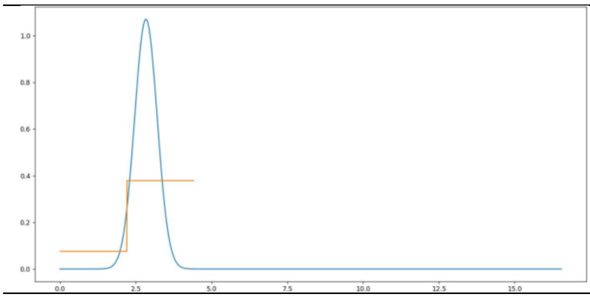
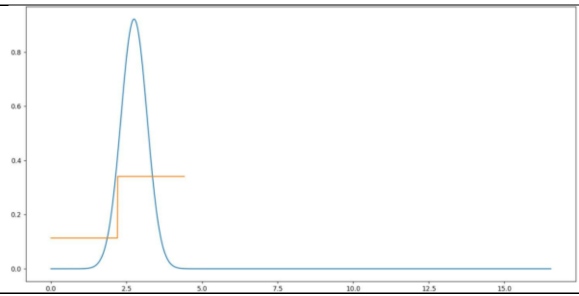


Fig. 8 - Distribution by intervals of risk values for all hazard sources and estimated Gauss (reference method)

Source of hazard: performer | Source of hazard: work equipment





Source of hazard: work load | Source of hazard: work environment

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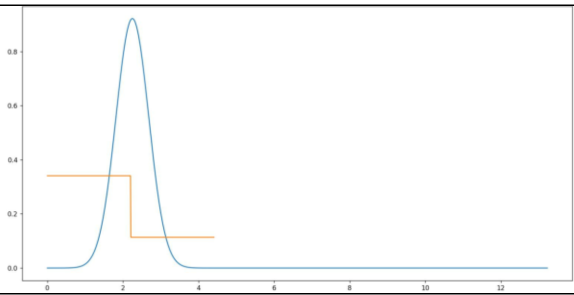

Source of hazard: materials | Source of hazard: management

Fig. 9 - Distribution by intervals of risk values for each hazard source (performer / work equipment / workload / work environment) and estimated Gauss distribution (reference method)

Analysis of discrete variables and correlation between risk assessment methods:

For each source of hazard, discrete random variables that describe the distribution of risk levels have been defined in relation to the two identification methods analyzed. Each variable was represented in the form of a matrix with two lines and n columns, where the first line contains the possible values of the risk levels (corresponding to the center of each interval), and the second line indicates the probabilities of appearance associated:

$$X = \begin{pmatrix} x_0 & x_1 & \dots & x_{N-1} \\ p_0 & p_1 & \dots & p_{N-1} \end{pmatrix} \quad (2)$$

The x_i values represent the arithmetic mean of the extremities of each range (the middle of the interval), and the probabilities P_i have been calculated as a ratio between the number of risk values in the respective range and the total number of values observed:

$$p_i = \frac{Number\ of\ values\ in\ range\ i}{Total\ number\ of\ risk\ values} \quad (3)$$

Based on these discrete variables, the Pearson correlation coefficient was determined for each pair of distributions associated with the same source of hazard, but obtained by different methods.

The formula used is:

$$Cor(X,Y) = \frac{Cov(X,Y)}{\sigma_x \sigma_y}, where\ Cov(X,Y) = M(XY) - M(X) * M(Y) \quad (4)$$

The average of a discrete variable X is given by:

$$M(X) = \sum_{i=0}^{N-1} p_i * x_i \quad (5)$$

The results obtained - Table 2 indicate a low global correlation between the distributions generated by the two methods, with an aggregate value of the Pearson coefficient equal to 0.

Table 2

Correlation coefficients between hazard sources for the two risk identification methods

Source of hazard	Coefficient correlation
Performer	0
Work equipment	$4,84 * 10^{-16}$
Work load	-
Work environment	$-3,01 * 10^{-16}$
Materials	-
Management	-

This lack of correlation highlights the fundamental differences between the evaluation methods used, caused by divergences in calculation algorithms, input parameters and risk classification criteria. Thus, a critical analysis of how each method interprets and prioritizes the risks is justified.

Calculation of Pearson correlation coefficient (*Https://En.Wikipedia.Org/Wiki/Pearson_correlation_coefficient*):

For a detailed assessment of the relationship between the estimated risk levels by the two analyzed methods, the Pearson correlation coefficient has been calculated for each source of hazard. This coefficient quantifies the degree of linear association between the two data sets, and the statistical significance was determined on the basis of the appropriate p-value values.

The analysis was performed using the gross values of risk levels without turning them into discrete distributions. The Pearson coefficient was applied directly to the pairs of values corresponding to each source of hazard, faithfully reflecting the degree of linear association between the results obtained by the two methods for each source of hazard – Table 3:

Table 3

Correlation coefficients between hazard sources for the two risk identification methods

Source of hazard	Pearson correlation coefficient	p-value	Interpretation of significance
Performer	0,236	0,416	Weak, insignificant correlation
Work equipment	-0,989	0,011	Strong, statistically significant correlation
Work load	-	-	Insufficient data
Work environment	0,082	0,918	Without correlation, insignificant
Materials	-	-	Insufficient data
Management	-	-	Insufficient data

The results, presented in table 3, indicate a statistically significant correlation only in the case of the source "work equipment" ($p < 0,05$), but this is negative. For the other sources, the high values of the p-value suggest the lack of significant linear correlation. Also, the "materials" and "management" sources could not be included in the analysis due to an insufficient volume of data.

These findings argue that the differences between the two methods are mainly determined by the distinct algorithmic approaches used in the risk assessment. The lack of significant correlation between the obtained results underlines the different fundamental character of the two methods and suggests the need for additional validation according to the specific context of application.

Calculating the Cronbach Alpha coefficient (*Https://En.Wikipedia.Org/Wiki/Cronbach%27s_alpha*):

To assess the internal consistency of the estimated risk levels, Cronbach Alpha coefficients were calculated for each hazard source, separately for the developed method and for the reference method. This coefficient measures the homogeneity of risk factors (items) within a source, assuming that they reflect a common construct – the general level of risk associated with that source.

The formula used is:

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=0}^{K-1} \sigma_i{}^2}{\sigma_{tot}{}^2}\right) \quad (6)$$

where: K is the number of items (risk factors),

σ_i^2 represents the variance of risk values for each risk factor,

σ_{tot}^2 is the total variance of the total scores (cumulative risk levels).

An α coefficient between 0,7 and 1 is generally considered indicative of acceptable internal consistency. Negative or super-unit values may occur in the case of a small number of items, negative correlations between items, or in situations where the total variance is very low.

Because risk factors may reflect distinct dimensions of the hazard being analyzed, the application of the Cronbach coefficient must be interpreted with caution. It is designed to assess consistency between items measuring the same construct, not for heterogeneous items.

Table 4 presents the results obtained, namely the Cronbach coefficients calculated for each source of hazard, within the two methods of risk identification:

Table 4

Cronbach coefficients calculated for each source of hazard, within the two methods of risk identification

Proposed method		Reference method	
Source of hazard	**Cronbach coefficient**	**Source of hazard**	**Cronbach coefficient**
Performer	-1,52	Performer	-2,89
Work equipment	1,05	Work equipment	1,33
Work load	-0,32	Work load	-
Work environment	0,51	Work environment	-0,37
Materials	-0,76	Materials	-
Management	-	Management	0
Total Cronbach coefficient	**-3,45**	**Total Cronbach coefficient**	**-1,14**

It is noted that the developed method allowed the calculation of the Cronbach coefficient for a larger number of sources, due to the wider coverage and the increased volume of data generated (number of risk factors identified). In contrast, in the case of the reference method, the coefficient could not be calculated for some sources ("materials", "management"), due to insufficient data.

In conclusion, the obtained coefficients must be interpreted in the context of the data structure and the purpose of the analysis. Negative or non-computable values do not invalidate the method, but reflect the internal diversity of the risk factors analyzed. These results also highlight the ability of the developed method to cover risk assessment more completely and in detail, providing a more solid basis for internal analysis and validation.

d) Validation of research hypotheses

⇨ Hypothesis 1: *The developed method is effective in identifying emerging risks associated with new processes and technologies used (ergonomic, psychosocial, management risks, etc.), which may be underestimated or omitted by conventional methods*.

The results obtained confirm this hypothesis. The application of the developed method led to the identification of 54 risk factors, compared to only 23 identified by the reference method. Among the additional factors identified are ergonomic risks (incorrect positions, repetitive operations), psychosocial (exhaustion, stress, job insecurity, complex or varied tasks), management risks (organizational climate, poor communication), as well as physical or chemical risks generated by materials specific to the work environment. This expanded capacity to identify risk factors highlights the method's adaptability to changing organizational and technological contexts, allowing the integration of emerging, often subtle and interdependent risks into the analysis.

⇨ Hypothesis 2: *The total number of risk factors identified by the developed method is higher than that identified by the reference method*.

The comparative analysis shows a significant difference between the two methods: 54 risk factors were identified by the developed method, compared to 23 by the reference method, which corresponds to a percentage increase of 134,78%. This difference validates the hypothesis and suggests a superior capacity of the developed method in identifying a wider and more diversified range of risks, which can be attributed to the higher level of detail in the analysis of hazard sources. Consequently, the developed method contributes to improving the risk management process and strengthening worker protection measures.

⇨ Hypothesis 3: *The developed method allows a more specific classification of risks, causes and conditions that may generate effects/damages/associated risks on worker safety, quality or the environment (on the organization's integrated management system)*.

The results support this hypothesis, demonstrating that the developed method provides a more detailed and specific structuring of risks and causative factors. Thus, the developed method contributes to the more precise identification of conditions that may generate effects/damages/ associated risks on occupational health and safety, on the quality of products and services, as well as on the environment. This more specific classification capability supports the efficient integration of results into the organization's integrated management system, improving strategic decisions related to risk prevention and control.

e) SWOT analysis

To systematically evaluate the tool developed for the identification and assessment of occupational risks, SWOT analysis was applied – a strategic tool recognized for its ability to highlight strengths, weaknesses, opportunities and threats associated with a methodological approach. The application of this analysis aimed to provide insight into the effectiveness and relevance of the developed tool, as well as its potential limitations in different occupational contexts. This approach allowed for a critical examination of the applicability of the method, both from a practical and conceptual point of view. The results generated by the SWOT analysis reflect the added values of using this tool in the organizational environment, as well as the aspects that require adjustment or further development.

The data synthesized following the application of this analysis were presented in a structured manner in Table 5, providing an overview of the main conclusions drawn from this analysis stage:

Table 5

SWOT analysis

Strengths	Weaknesses
• integrates the requirements of EN ISO 45001:2023, which contributes to increasing the credibility and efficiency of the method; • allows a systematic and documented approach to risks; • extends the analysis to multiple sources of hazard, ensuring a more comprehensive assessment; • ensures the analysis of dependencies and interactions between all component elements of the work system, thus improving risk identification; • allows the identification of all risk factors, including new, emerging risks, in the context of the integration of digital technologies by organizations; • adopts a proactive approach to managing occupational risks (treating all identified risks); • supports the development and implementation of coordinated measures to ensure continuous improvement in worker safety, quality or the environment; • allows the integration of digital technologies into the risk assessment process;	• alignment with EN ISO 45001:2023 requirements and the assessment of emerging risks (ergonomic, psychosocial, etc.) requires a high level of competence from the assessors (specialized knowledge), which may increase the costs associated with this process; • extending the method to include more sources of hazard and emerging risks may increase the workload and complexity of the analysis process; • requires more time and resources to implement, which can be an obstacle in small or resource-limited organizations; • for some organizations, assessing and treating all risks (including small risks) may be considered a waste of resources, especially if there are no significant events associated with them; • analyzing multiple sources of hazard and all risks can lead to the accumulation of a large volume of information, complicating the prioritization and implementation of measures.

Strengths	Weaknesses
• the method can be used in a wide range of industries and processes, being scalable and flexible depending on the specifics of the workplace.	
Opportunities	**Threats**
• integrating the method can contribute to organizations obtaining EN ISO 45001:2023 certification, which can represent a competitive advantage; • using a software tool for risk analysis can simplify and accelerate the process of assessment and data management; • by including emerging risks in the analysis, the method becomes a proactive tool, capable of responding quickly to technological and social changes; • the method can be used to develop long-term policies and strategies regarding occupational health and safety; • a detailed approach to all risks can help raise awareness and promote a strong safety culture.	• implementing the method may require considerable investment in human and technological resources, which may discourage small organizations or those with limited budgets; • employees and managers may resist new requirements and standards, especially if they require significant changes in the way they work; • emerging risks are, by definition, constantly changing, which can make the method quickly become outdated if not reviewed periodically; • methods based on artificial intelligence, big data or advanced simulations could become more attractive to organizations, reducing interest in this method.

CONCLUSIONS

The present study highlighted the potential of the developed method to improve the process of identifying and assessing occupational risks, through a more comprehensive, structured and adaptable approach to emerging risks in modern organizational environments. The results obtained through the application and validation of the tool demonstrate both its efficiency and practical relevance, compared to conventional methods.

The main contributions made by this study are the following:

- Rigorous validation of the developed tool, through the use of statistical distributions (Gaussian and interval distributions), through the use of complementary statistical methods (Pearson correlation, Cronbach Alpha coefficient), to ensure an objective and comparable assessment of the risk levels established by applying the two assessment methods. This analysis confirmed the consistency and practical utility of the developed method;
- Applying SWOT analysis in the methodological validation process, to identify strengths, limitations, opportunities for improvement and potential risks associated with the implementation of the method. This approach provided a strategic perspective on the effectiveness and adaptability of the tool in various organizational environments;
- Providing a replicable methodological framework, which can be adapted and applied in various sectors of activity, offering concrete support in the development of proactive strategies for the prevention and control of occupational risks.

Through these elements, the study contributes to improving the decision-making process regarding occupational health and safety and offers a scientifically validated tool, with extensive applicability in the field of occupational health and safety, relevant for strengthening integrated management systems in modern organizations.

Although the results obtained validate the efficiency of the method developed for identifying and assessing occupational risks, limitations were identified, which may influence the degree of generalization and applicability of the conclusions. These limitations include:

- The method was applied and tested in a specific organizational setting, which may limit the generalizability of the results to other fields or industries. To ensure the transferability and adaptability of the tool, additional validations are needed in varied work contexts, characterized by different organizational structures, operational processes and technologies;
- Although the proposed method is based on a structured approach, the process of identifying and classifying risks remains, to a certain extent, dependent on the individual perception and experience of the evaluators. This human component can introduce a degree of subjectivity into the results obtained, influencing the consistency and comparability of the assessments;
- In some cases, Pearson correlation coefficients indicated low or insignificant values, and the Cronbach Alpha coefficient was impossible to calculate for data sets with few items or low variability. These limitations reflect the sensitivity of statistical methods to data structure and not necessarily shortcomings of the proposed method;

- The study focused mainly on the risk identification and assessment stage, without addressing in depth the subsequent stages of the risk management process, such as the selection and implementation of control measures.

Despite these limitations, the results obtained provide a solid basis for expanding the research, and the proposed method proves to be a valuable tool in the assessment of occupational risks, requiring only additional adjustments depending on the context of application.

In order to expand the applicability of the method, further research is needed in various organizational contexts, as well as the development of digital solutions that facilitate its large-scale implementation:

- It is recommended to test the developed tool in different activity sectors (industry, services, health, construction, etc.), to evaluate its robustness, flexibility and degree of adaptability to the specifics of each field;
- To reduce the subjective influence in the evaluation process, it is recommended to develop a detailed guide for applying the method, which should include examples, interpretation criteria and instructions for users with different levels of expertise;
- Given its ability to classify risks on multiple dimensions (security, quality, environment) *(Abdrakhmanov et al., 2022*), it is recommended to integrate the proposed method within integrated management systems, for a unitary and coherent approach to organizational risks;
- To facilitate large-scale application, it is recommended to develop a software tool that implements the calculation algorithms, graph generation and reporting, thus reducing the time required for manual data processing;
- It is recommended to conduct long-term research to evaluate the impact of the proposed method on the actual reduction of risks and on the effectiveness of the preventive measures adopted following the assessment.

Thus, the contribution of this study is part of a broader approach to modernizing risk management tools and supporting a safe work environment, adapted to current and future requirements.

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