Stochastic Environmental Research and Risk Assessment (2022) 36:629–642
https://doi.org/10.1007/s00477-021-02069-y

ORIGINAL PAPER

Occupational health, safety and environmental risk assessment in textile production industry through a Bayesian BWM-VIKOR approach

M. Fatih Ak[1] · Melih Yucesan[2] · Muhammet Gul[3]

Accepted: 24 July 2021 / Published online: 5 August 2021

Abstract

Occupational risk assessment (ORA) is a process that consists of evaluating, ranking, and classifying the hazards and associated risks arising in any workplace from the viewpoint of occupational health and safety. Many ORA methods have been proposed in the literature, from a single independent expert to participatory methodologies made by group decision and simple to complex ones. In this paper, a holistic ORA is presented, which uses two important multi-attribute decision methods named Bayesian Best-Worst Method (Bayesian BWM) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). Bayesian BWM is used to determine the importance weights of six different assessment criteria, which are the probability of hazardous event (P), frequency (F), severity (S), detectability (D), cost (C) and sensitivity not to use personal protective equipment (SNP). Since the classical BWM finds solution to the weights of a number of criteria from only one expert's judgment, Bayesian BWM is preferred in this paper (1) to enable participation of a group of experts, (2) to aggregate the preferences of these multiple experts into consensus without loss of information and (3) to follow a probabilistic way for solving the ORA problem. The hazards are then ranked by VIKOR. The approach is implemented in the ORA process of a textile production plant. Results of risk analysis showed that electricity hazard and associated risks constitute the highest risk ratings. These hazards arise from the product, process, human and working environment. The associated risks are evaluated, prioritized, and detailed control measures are proposed. This study made comparisons with the classical BWM-VIKOR approach to demonstrate the proposed approach's difference and practicality. Results can also help practitioners and risk analysts in formulating the improvement measures to increase the overall safety of the working environment further.

Keywords Risk assessment · BWM · Bayesian BWM · VIKOR · Textile industry

1 Introduction

The occupational risk assessment (ORA) covers evaluating, ranking, and classification of the hazards and associated risks in a workplace from the occupational health and safety (OHS) perspective. This systematic process determines whether the emerged possible hazards and associated risks are acceptable and foresees the necessary measures with a proactive approach. It aims to ensure that the employees are in a well-being business life (Kabakulak 2019). While this process's priority is to protect the employee, production and operational safety are also secondary targets within the scope of ORA. A well-managed ORA process is concerned with maximizing and maintaining employees' physical, mental, and social well-being, assigning employees to a job suitable for their

✉ Muhammet Gul
muhammetgul@munzur.edu.tr

M. Fatih Ak
fatih.ak@antalya.edu.tr

Melih Yucesan
melihyucesan@munzur.edu.tr

1 Department of Industrial Engineering, Antalya Bilim University, 07190 Antalya, Turkey

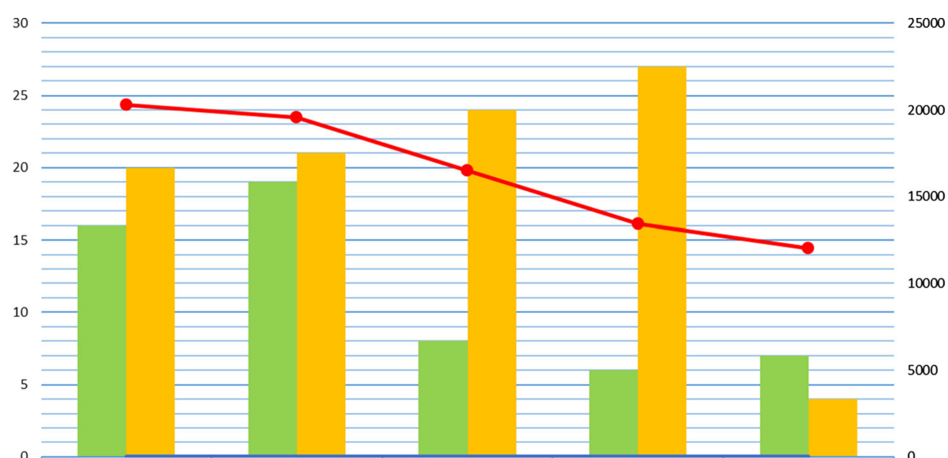
2 Department of Mechanical Engineering, Munzur University, 62000 Tunceli, Turkey

3 Department of Emergency Aid and Disaster Management, Munzur University, 62000 Tunceli, Turkey

characteristics, risk factors and protecting employees from risk factors working conditions (ÇSGB 2018). In the production industries, the harmony and well management of the workplace environment, production machines/tools, and workers are necessary for the production to be carried out by OHS principles. At this point, the government, employer, and employee triangle should work in coordination and ensure cooperation (Kabakulak 2019). The government is responsible for monitoring the elimination of the nonconformities detected within the framework of laws and regulations. The employer should minimize the workplace environment's unsafe conditions and production and the employees' unsafe movements by fulfilling the necessary OHS conditions. On the other hand, employees should notify the employer of any unsafe situations they notice, ensure that necessary measures are taken, and contribute to making the production process safe. ORA is therefore crucial for production-based industries as well as textile production.

Textile production is a risky sector in terms of both the high density of employees and the availability of serious hazards in its production phases in Turkey (ÇSGB 2018). It involves numerous hazards (e.g., physical factors, powders, chemical agents, biological factors, ergonomic factors, psychosocial factors) that lead to human casualties, environmental destruction and financial loss. According to the work accidents and occupational diseases statistics by the Social Security Institution of Turkey (SGK), for the recent five years, the number of workers (insured) who has a work accident by incapacity days in textile production has been increased from 2015 to 2019 (Fig. 1). In 2015, the value of this indicator was 12,041. It has almost a %41 increase in 2019 with a value of 20,274. Similarly, the number of insured people having an occupational disease has been increased from 2015 to 2019. On the other hand, as an optimistic indicator, the number of fatal accidents at work follows a decreasing trend after 2016. These figures are important in showing how risky the textile industry is. The ability of such a risky sector to implement the necessary activities in terms of OHS and prevent the hazards can be achieved by selecting and applying an appropriate ORA methodology considering all stakeholders' participation.

A significant number of ORA methods, either in quantitative or qualitative/hybrid structures, are in use in the academic and industry environment. An ISO standard of IEC 31,010: 2019 'Risk management' Risk assessment techniques' includes techniques for eliciting views from stakeholders and experts (brainstorming, Delphi, Nominal group, interviewing), identifying risks (checklist, FMEA, HAZOP, scenario analysis, what-if analysis), determining sources, causes and drivers of the risk (fishbone technique), analyzing controls (Bow-tie analysis, LOPA), understanding consequences and likelihood (Bayesian Network, ETA, FTA, Markov analysis, Monte-Carlo simulation), analyzing dependencies and interactions (causal mapping), including a measure of risk (Value at Risk), evaluating the significance of risk (Frequency-Number diagrams, Pareto charts), selecting between options (cost-benefit analysis, decision trees, Multi-criteria decision making, game theory), and recording and reporting (Consequence/Likelihood matrix, S-curve) (ISO 2019). From this ISO standard, it is easily inferred that multi-criteria (MCDM) has an important place among these ORA techniques (Ak 2020). The MCDM concept is merged with the fuzzy set (with different



	2019	2018	2017	2016	2015
Number of insured having occupational disease	16	19	8	6	7
Number of fatal accident at work	20	21	24	27	4
Number of fatal occupational diseases	0	0	0	0	0
Number of insured having work accident by incapacity days	20274	19573	16520	13446	12041

Fig. 1 The last five years of work accidents and occupational diseases figures of Turkey's textile production industry (SGK Statistics, 2015 to 2019)

versions) (Celik et al. 2015; Gul 2018), soft set (Khameneh and Kılıçman, 2019), neutrosophic set (Peng and Dai, 2020), computational intelligence (Doumpos and Grigoroudis, 2013) and probability theory (Zhang and Mohandes, 2020; Pelissari et al. 2018) in developing ORA methods which for various sectors. This need for merging arises from some of the deficiencies of the methods mentioned in the ISO standard. These have been highlighted in the literature several times (Gul 2018). Methods such as Consequence/Likelihood matrix, Fine-Kinney, FMEA, ETA, FTA, and HAZOP have problematic aspects such as the lack of importance weights of risk parameters, logical problems due to numerical scale defined for the parameters, and the insufficient number of parameters (Gul et al. 2021; Valipour et al. 2021; Gul et al. 2020; Bashan et al. 2020a; Nowak et al. 2020; Gul and Ak 2020; Bashan et al. 2020b). Most of the ORA studies developed with the aid of the MCDM concept follow a two-stage approach. While the first stage concerns the determination of risk parameter weights, the latter focuses on the risk priority values/ numbers of each emerged hazard of the system. In assigning weights to the risk parameters specific for each method (e.g., in Fine-Kinney, three parameters are available named probability, severity and frequency), pairwise comparison-based MCDM methods are frequently preferred by the scholars. One of the most widely applied and usable methods is the Analytic Hierarchy Process (AHP) (Kaya 2020; Yucesan and Kahraman, 2019; Gul and Ak, 2018). BWM (Gul et al. 2020; Tang et al. 2020; Gul and Ak 2020; Delice and Can, 2020; Ghoushchi et al. 2019; Tian et al. 2018), SWARA (Liu et al. 2020) and non-pair wise comparison based-MCDM tools (Yazdi et al. 2020) are also used to determine risk parameter weights in assessing the risk of occupational hazards. BWM has some superiorities compared to other pairwise comparison-based MCDM methods, including providing more consistent matrices in expert judgment and requiring a lower number of pairwise comparisons (Rezaei 2015; 2016; Mi et al. 2019; Liang et al. 2020). However, it seeks solutions to the weights of a number of criteria from only one expert's judgment. To overcome shortcomings of conventional arithmetic mean to integrate experts' opinions into consensus, Bayesian BWM is then developed by Mohammadi and Rezaei (2020a) using statistical estimation methods. It provides a group decision making without loss of knowledge. A criterion with a higher weight indicates that it is relatively more important in the assessment system. It has been applied to some areas following its initial proposal, but this area and problems are very limited since the method (Bayesian BWM) is still new (Mohammadi and Rezaei, 2020b; Guo et al. 2020). Mohammadi and Rezaei (2020a) also proposed in Bayesian BWM a new ranking method called "credal ranking" for the criteria. A reliability value is defined in this credal ranking method by a value between 0 and 1, where one criterion is more important than another criterion, unlike the traditional ranking. They constructed this probabilistic approach via both Monte Carlo simulation and some statistical distributions in its structure. This is not because the problem is probabilistic, but to make the interpretation of the ranking more robust for the criterion weights to be obtained by the application of the method. Therefore, ultimately, this method is also an MCDM method. As a matter of fact, it can be easily used and applied to assign criterion weights in a MCDM problem, as was done in previous literature via AHP, entropy and their fuzzy versions etc. Therefore, we used Bayesian BWM in an ORA problem to assign weights to risk parameters by aggregating the judgments of multiple experts. The idea of combining these two MCDM methods (one completely new and sound for the scientific community, other is very old and widely used) in an ORA problem is novel and original. It has benefits and contributions to the current ORA field. We believe that in addition to proposing a method from scratch, we believe that applying a hybrid approach to a field for the first time contributes to knowledge.

Following the initial proposal of Bayesian BWM, Mohammadi and Rezaei (2020b) evaluated and compared ontology alignment systems using the Bayesian BWM. Guo et al. (2020) proposed a risk assessment model for electricity retail companies using a combination of Bayesian BWM and the improved matter-element extension model. Yang et al. (2020) developed a Bayesian BWM-VIKOR approach to sustainable tourism evaluation for Taiwan. Li et al. (2020) introduced a new Bayesian BWM-based multi-attribute competence analysis and applied it for a Chinese takeaway delivery platform.

In addition to its narrow application domains, it has not yet integrated with other MCDM methods from either compromise or outranking categories. Therefore, in this paper, Bayesian BWM is incorporated with VIKOR, which is a touchstone compromise MCDM method for an ORA problem. Here, it is used to determine the importance weights of six different ORA parameters, which are occurrence probability of hazardous event (O), frequency (F), severity (S), detectability (D), cost (C) and sensitivity not to use personal protective equipment (SNP). The second step of the holistic approach is to rank hazards concerning each of the six decision criteria by VIKOR. Finally, the Bayesian BWM-VIKOR approach is implemented for the ORA process of a textile production plant.

The current paper aims at presenting a holistic ORA approach, which includes the integration of Bayesian BWM with VIKOR in determining risk parameters' importance and hazard rankings under a group of expert evaluations. The approach has contributions for the current literature by the following aspects:

- Bayesian BWM is applied to an ORA problem for the first time in the literature. It has strong features in aggregating the preferences of multiple ORA experts into consensus without loss of information.
- The credal ranking shows the degree of preference of one criterion over another. Thus, it provides extra information to decision-makers about the interrelationship between the risk parameters. In addition, it shows the degree of dominance graphically.
- In the approach, both ORA concept solved in a probabilistic way (methodologically by Bayesian BWM) and multi-criteria optimization and compromise solution (via VIKOR) are utilized.
- Six different ORA parameters are considered, none of which were used together in a problem before.
- The study results guide decision-makers and authorities of the textile production industry to pay attention to the prioritized hazards and their associated risks in the risk control step of the OHS risk management cycle.

The paper is organized as follows. Section 2 presents the literature review on the integration of BWM and VIKOR. Section 3 describes the material and method. Section 4 demonstrates a case study for the implementation of the approach in textile production. The final section presents the conclusion with limitations and future recommendations.

2 Applied methodology

2.1 Bayesian BWM

BWM is a fairly new MCDM method proposed by Rezaei (2015). This method requires 2n-3 comparisons instead of full comparison n(n-1)/2. First, the “best” (most important, most desirable) and “worst (least important, least desirable) criteria are determined. Then, these criteria are compared with other criteria. The numbers between 1 and 9 are used for comparison. Structure enables decision-makers to make more reliable comparisons. The most significant disadvantage of the original BWM is that it cannot aggregate more than one decision-maker’s evaluation. Although the arithmetic or geometric mean technique is used to combine the evaluation of more than one decision-maker, it causes information loss (Rezaei 2015, 2016; Mohammadi and Rezaei 2020a). To aggregate decision-makers’ evaluations, Hafezalkotob and Hafezalkotob (2017) proposed democratic and autocratic decision-making styles. Mou et al. (2016) used fuzzy multiplicative weighted geometric aggregation. Bayesian BWM was proposed by Mohammadi and Rezai (2020a) to aggregate decision-makers’ evaluations in the probabilistic environment, and it is an extension of the BWM proposed by Rezai (2015).

Bayesian BWM consists of three steps. In the first step, the criteria to be evaluated were determined. In the second step, a survey was prepared in accordance with the original BWM evaluation. In the third step, the problem was made applicable to Bayesian BWM with a probabilistic perspective after evaluating according to the original BWM. This step is divided into four sub-steps. Sub-steps 3.1-3.3 in Fig. 1 are done for all the experts, and then all the obtained vectors are given to the BBWM. The implementation steps are presented in the following with an acceptable level of detail and presented in Fig. 2.

2.2 VIKOR

The VIKOR method has been developed for multi-criteria optimization of complex systems by Opricovic and Tzeng (2004). It is a very effective method to solve Multiple Attribute Decision-making (MADM) problems. In recent years, its use has become widespread, especially in the economy, business, and management (Gao et al. 2020). It supports decision-making mechanisms by identifying cost and benefit criteria and a ranking procedure under these conditions (Rafieyan et al. 2020; Dong et al. 2017). It allows sorting and selecting among conflicting criteria by using pre-determined criteria weights. It further provides a ranking index using a measure of closeness (S, R and Q values) to the ideal solution (Opricovic 1998; Opricovic and Tzeng, 2004; Jahan et al. 2011). Solution steps of the VIKOR method can be found in Opricovic (1998) and Opricovic and Tzeng (2004).

2.3 Overview to the holistic ORA approach

In this section, an overview of the holistic ORA approach is introduced. First, as input to the first process of the approach, the ORA context is described, and selection criteria to organize the OHS expert team is determined. The output of this initial step is an organized expert team consisting of five experienced professionals. The second step concerns the implementation of Bayesian BWM. Inputs of this step include five filled questionnaire forms, which are prepared as suitable for BWM style. This step’s output is a weight matrix that contains the importance weight values of five risk parameters, which are “occurrence, frequency, severity, detectability, cost, and sensitivity to PPE non-utilization”. Third, the implementation of VIKOR is performed to prioritize hazards. In this step, the filled questionnaire forms are required as the second step to providing inputs for the process. At the output step, final VIKOR Q index values and ranking orders for each hazard

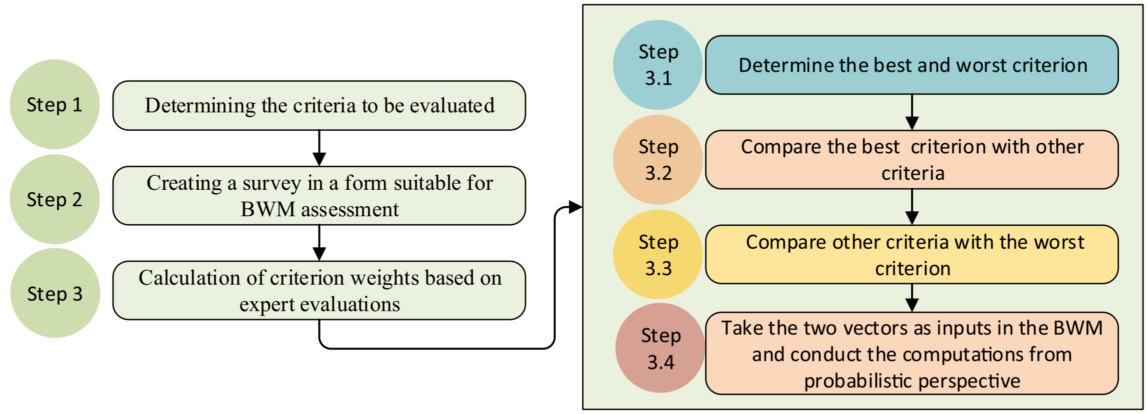


Fig. 2 Implementation steps in Bayesian BWM

are obtained. The final step is regarding a comparative analysis and sensitivity analysis. To provide the holistic approach's solidity, hazard ranking by VIKOR is carried out considering a different weight matrix obtained from the original BWM is used. Moreover, the maximum group utility "v" value in VIKOR has been changed from 0 to 1 in 0.1 intervals to make a sensitivity analysis. Figure 3 shows the procedural steps of the proposed holistic ORA approach in the form of a flowchart.

3 Case study: occupational risk assessment in textile production

3.1 Design of expert team

The selection of a suitable expert team is essential for an ORA problem in the industry. Similarly, it enables support in the determination of the risk parameters and hazard identification. In this case, five OHS experts were finally chosen to participate in the ORA process: four engineers from different disciplines and a production line manager, all well-experienced in occupational safety and have different certification levels in OHS management. The experts' profile is presented in Table 1. Experts with Certificate C are eligible to work in the less dangerous industries, Certificate B in less dangerous and dangerous classes, and Certificate A in all hazard classes (including the most serious and dangerous industries) (Demir et al. 2020).

The scientific literature regarding classical ORA methods such as decision matrix, Fine-Kinney, and FMEA has been served as a basis for defining our risk parameters for this study. In classical FMEA, three risk parameters of severity, occurrence, and detectability are used for failure ranking (Gul et al. 2020). Also, in the Fine-Kinney method,

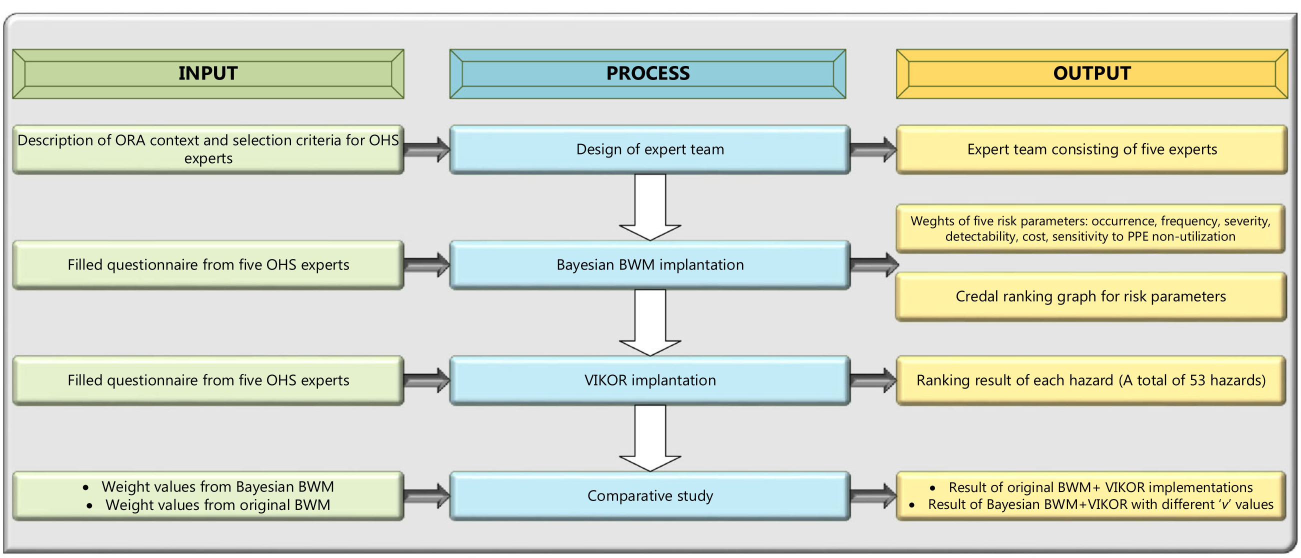


Fig. 3 INPUT-PROCESS-OUTPUT demonstration of the holistic approach

Table 1 Description of experts participating in the ORA team

#	Title	Educational Stage	Age
Expert-1	Mechanical Engineer (OHS expert, Certificate B)	Master of Science	40
Expert-2	Textile Engineer (OHS expert, Certificate B)	PhD	48
Expert-3	Mechatronic Engineer (OHS expert, Certificate B)	Master of Science	37
Expert-4	Production Engineer (Production Line Manager)	Master of Science	49
Expert-5	Mechanical Engineer (OHS expert, Certificate A)	PhD	51

a different parameter of "frequency" is available. Therefore, as highlighted before in this study, more and different risk parameters must be attached to reflect the real-world problem and assess the risk of hazards precisely and in a reliable way. In the current study, we consider three more risk parameters in addition to the current three of FMEA. They are frequency, cost, and sensitivity to PPE non-utilization. An explanation of each ORA parameters are presented in Table 2.

The other important argument in an ORA study is hazards and their associated risks. Due to the space limitations, the hazard list is demonstrated as an online supplementary file. In this file, hazard sources and associated risks, consequences of it are also presented.

3.2 Bayesian BWM implementation

The calculation steps in Bayesian BWM are presented in detail in Sect. 3.1. First of all, all experts determine "best" (most important) and "worst" (least important) one from six risk parameters. The 1–9 scale is used in pairwise comparison. "1" means equally important, while "9" means extremely important. In the following, A_B is the matrix in which the rows refer to the best-to-others vector of each decision-maker. Similarly, A_w has been given as well, which corresponds to the others-to-worst vector of each decision-maker.

$$A_B = \begin{bmatrix} 2 & 4 & 1 & 3 & 8 & 2 \\ 2 & 2 & 1 & 3 & 7 & 2 \\ 5 & 2 & 1 & 2 & 5 & 2 \\ 2 & 1 & 1 & 2 & 8 & 1 \\ 3 & 1 & 1 & 2 & 7 & 1 \end{bmatrix},$$

$$A_w = \begin{bmatrix} 6 & 4 & 8 & 5 & 1 & 6 \\ 5 & 5 & 7 & 4 & 1 & 5 \\ 1 & 4 & 5 & 4 & 1 & 4 \\ 6 & 8 & 7 & 6 & 1 & 7 \\ 4 & 7 & 6 & 5 & 1 & 6 \end{bmatrix}.$$

The Bayesian BWM handled and solved the ORA problem via a probabilistic perspective and estimated the weight of each risk parameter. By following the calculation steps in Fig. 2, the optimal weights of the risk parameters are determined. The calculation platform (Matlab, version 2018) used in this study to perform Bayesian BWM was the same as Mohammadi and Rezaei (2020a). The average weights of the six risk parameters are given in Table 3.

The factor of "Severity" was determined as the most important risk factor with an importance value of 0.248. It helps determine the magnitude of the impact of a potential risk factor in manufacturing processes (Sotoodeh 2020; Lipol and Haq, 2001). Therefore, improvements made in a production system can significantly contribute to reducing failures. The second most crucial factor was "Sensitivity to PPE non-utilization" with a value of 0.2038. This criterion means to what extent the use of personal protective

Table 2 Description of ORA parameters

Risk parameter	Parameter description	Reference
Occurrence (O)	The probability of the hazard	Gul et al. (2020); Bashan et al. (2020a), Bashan et al. (2020b)
Frequency (F)	Exposure factor	Gul et al. (2021)
Severity (S)	The seriousness (consequence) of the hazard	Gul et al. (2020); Bashan et al. (2020a), Bashan et al. (2020b)
Detectability (D)	The ability to detect the hazard before the impact of the effect is realized	Gul et al. (2020); Bashan et al. (2020a), Bashan et al. (2020b)
Cost (C)	Percentage of the total annual budget fixed by the company for OHS measures	Di Bona et al. (2018)
Sensitivity to PPE non-utilization (PPE)	To what extent the use of personal protective equipment can affect the severity of the risk	Grassi et al. (2009)

equipment can affect the severity of risk (Grassi et al. 2009). Therefore, the use of PPE in the enterprise should be given importance. The third most important risk factor was "Frequency" with 0.1917. Corrective actions need to be planned if the risks are higher than the threshold (Lee et al. 2019). The fourth most important risk factor was "Detectability" with 0.1638. Although detectability does not pose a direct risk, it is included in the final risk score calculation (Ahn et al. 2017). The fifth most important factor was "Occurrence" with 0.142. The occurrence factor indicates the likelihood of injury due to an accident (Gul et al. 2020; Grassi et al. 2009). The relative lowness of this value is an indication that the chemical, physical, biological, and ergonomic risks in the enterprise have little impact on human health. The least important factor is "Cost" with 0.0506. This shows the firm's annual budget (Di Bona et al. 2018). It indicates the firm's potential budget for risk prevention activities.

When determining the weights with MCDM, it is considered more important than the criterion calculated as high. However, there may be a slight difference between the two criteria when ranking. This becomes even more important for group decision-makers, especially when weighing. "*Credal ranking*", which determines the degree to which a criterion is superior to another criterion, was proposed by Mohammadi and Rezaei (2020a). Figure 4 shows the credal ranking results of our studied risk parameters. $A \rightarrow^{D} B$ shows that the A criterion is more important than the B criterion in D reliability. D takes a value between 0 and 1. For example, according to Credal ranking, "*Severity*" is definitely more important than the "*Cost*" parameter. ($Severity \rightarrow^{1} Cost$). Also, the "*Cost*" parameter to which all arrows point is the least important. Although the criterion importance threshold is 0.5, it shows variation from problem to problem (Mohammadi and Rezaei, 2020a).

3.3 VIKOR implementation

In the third stage of the proposed approach, VIKOR has been implemented to determine the final priority values of each hazard. By utilizing the weights of six risk parameters obtained from Bayesian BWM, the expert evaluations of each hazard concerning the observed textile production facility's risk parameters are aggregated. In the paper, the OHS experts made their subjective judgments against each hazard using the scale, as shown in Fig. 5.

Table 3 Final risk parameter weights obtained from Bayesian BWM

Risk parameter	Weight	Rank
Occurrence	0.142	5
Frequency	0.192	3
Severity	0.248	1
Detectability	0.163	4
Cost	0.051	6
Sensitivity to PPE non-utilization	0.203	2

In this study, while three risk parameters (frequency, severity, and sensitivity to PPE non-utilization) use a 6-point scale, two of them (detectability and cost) use a 10-point scale. The only occurrence parameter uses a 7-point scale as in the classical Fine-Kinney method (Gul et al. 2021). The aggregated evaluations of OHS experts in numerical variables (the corresponding linguistic terms are given in Fig. 5) for each hazard with respect to six risk parameters are demonstrated as in Table 4. In the last column of this Table, the weight values obtained from Bayesian BWM have been attached.

Following the remaining steps explained in Sect. 3.3., final VIKOR index values (S, R and Q) are obtained. The results are given in Table 5. The ranking orders are also determined based on Q values. The ranking results are demonstrated in Fig. 6.

The Q values of VIKOR indicate that the most crucial hazard is Hazard-7 (Rank = 1): Electricity. This stems from uncovered cables and electrical outlets. It is related to the electrical equipment maintenance-repair activity field of the plant. The least crucial hazard is Hazard-16 (Rank = 53), which emerged as a result of the employee's personal materials in the workplace. It leads to theft and workplace disorganization.

After carrying out the risk assessment, the most serious risks as determined by the proposed approaches. Regarding the electricity hazard (Hazard-7), which had the highest possible risk rating, the following preventive measure was suggested: To prevent electric shocks and electrical fires, the power cable's end should not be exposed. Periodic control should be provided with a checklist. Since the working area is a wet and dusty environment, it should be ensured that the electrical sockets are a closed system and the lighting should be watertight. The current situation should be checked simultaneously (Singh 2016). Personnel productive equipment (PPE) should be at the maximum protection level in CE standards and desired norms (Flores et al. 2016). Authorized and trained personnel should be employed in maintenance work. Regarding the electricity hazard (Hazard-6), which had the second-highest possible risk rating, the following preventive measure was suggested: It should be ensured that the extension cables are checked frequently. The cables whose insulation is damaged should be replaced. It should also be ensured that the extension cables are collected and stored in the designated place after the work is completed. Work should be done using double insulated, shock, and crush-resistant

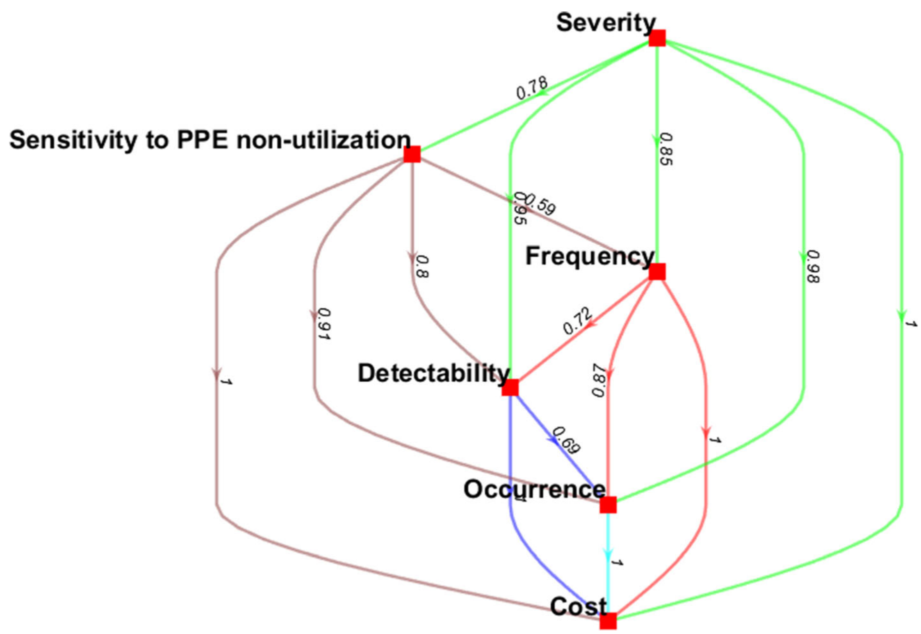


Fig. 4 Credal ranking representation of risk parameters

Numerical value	Definition of «Occurrence»
10	Might well be expected
6	Quite possible
3	Unusual but possible
1	Only remotely possible
0.5	Conceivable but very unlikely
0.2	Practically impossible
0.1	Virtually impossible

Numerical value	Definition of «Frequency»
10	Continuous (Hourly)
6	Frequent (Daily)
3	Occasional (Weekly)
2	Unusual (Monthly)
1	Rare (A few per year)
0.5	Very rare (Yearly)

Numerical value	Definition of «Severity»
100	Catastrophic (Many fatalities or $10^7 damage)
40	Disaster (Few fatalities or $10^6 damage)
15	Very serious (Fatality or $10^5 damage)
7	Serious (Serious injury or $10^4 damage)
3	Important (Disability or $10^3 damage)
1	Noticeable (Minor first aid accident or $10^2 damage)

Numerical value	Definition of «Sensitivity to PPE non-utilization»
5	Maximum
4	Absolutely high
3	Higher than low
2	Lower than high
1	Absolutely low
0.5	Negligible

Numerical value	Definition of «Detectability»
10	Absolutely impossible
9	Too far
8	Far
7	Very low
6	Low
5	Moderately
4	Moderately high
3	High
2	Very high
1	Almost certain

Numerical value	Definition of «Cost»
10	91%-100%
9	81%-90%
8	71%-80%
7	61%-70%
6	51%-60%
5	41%-50%
4	31%-40%
3	21%-30%
2	11%-20%
1	1%-10%

Fig. 5 Scales for the applied six risk parameters

extension cables constantly on the ground. Regarding the electricity hazard (Hazard-51), the following preventive measure was suggested: the electrical installation should be checked to comply with the standards, and inappropriate electrical installation should be changed. Periodic checks of the electrical installation should be carried out by authorized persons once a year and recorded. In case of failure in the electrical installation, earth leakage relays should be activated. Regarding the electricity hazard (Hazard-4), the following preventive measure was suggested: It should be ensured that there are residual current protection relays that automatically break the circuit in a short time when there is any leakage current in the panels. Leakage current relays should be in the main panels and the interior panels and machine panels within the whole enterprise. Regarding the electricity hazard (Hazard-5,

Table 4 Aggregations of OHS expert judgments on hazards

Hazard	Risk parameter						Hazard	Risk parameter					
	O	F	S	D	C	SNP		O	F	S	D	C	SNP
Hazard-1	4.8	2	11.8	5	5	2.8	Hazard-28	1.8	2.2	18.4	2.8	4.8	3.2
Hazard-2	2.8	1.8	4.6	4.8	3.4	2.2	Hazard-29	2	2.2	11.8	2.2	3.8	3.4
Hazard-3	2.6	1.2	52	2.2	2	4.2	Hazard-30	2	2.2	8.6	2.4	3.6	3.4
Hazard-4	1.7	1	64	2.4	3.8	4.4	Hazard-31	3.6	2.8	13.6	2.4	3.8	3.8
Hazard-5	2.1	1.8	35	2	2	4	Hazard-32	1.5	1.2	11.8	3	4.2	3.8
Hazard-6	3.8	2.2	47	1.8	2.8	4	Hazard-33	3	2	4.6	5.4	3.2	2.2
Hazard-7	3.4	2	52	2.2	2.8	4	Hazard-34	3	2.6	6.2	4.8	3	2.2
Hazard-8	2	2.8	5.4	2.2	4.2	2.8	Hazard-35	4.2	2.8	7	5.6	3	3.6
Hazard-9	4.8	4.8	3.8	3.2	5.4	2.6	Hazard-36	2.6	1.2	3	5.8	2	1
Hazard-10	2.2	2.2	8.6	4.4	3.4	2.8	Hazard-37	4.2	1.8	3	2.8	3.2	2.8
Hazard-11	1.8	4.4	3.8	4.4	4.8	1.8	Hazard-38	3	1.6	3	2.8	2.6	3.4
Hazard-12	3.6	4.2	4.6	5.6	2.6	1	Hazard-39	1.8	1.4	5.4	3.4	3.4	3.6
Hazard-13	2.6	3.6	6.2	4.8	3.6	1.4	Hazard-40	1.4	1.6	5.4	3.8	4.8	3.6
Hazard-14	1	1.4	3.4	6	1.4	1.6	Hazard-41	2.6	2.4	6.2	1.8	3.8	3.4
Hazard-15	2.6	2.6	6.2	3	2.8	2.6	Hazard-42	2.6	1.6	3.8	1.8	2.8	3.8
Hazard-16	0.9	0.7	2.2	6.2	1.8	1.4	Hazard-43	4.2	2.2	6.2	1.2	3.6	5
Hazard-17	3.6	3.8	3	4.4	3	2.4	Hazard-44	1.8	1.6	6.2	1.8	3.6	3.8
Hazard-18	1.8	1.4	3	3.2	2.8	2	Hazard-45	3	1	4.6	2.8	2.8	3.4
Hazard-19	2.6	2	13.4	3.8	3	2.6	Hazard-46	1.2	2	35	3.2	4.6	2.4
Hazard-20	2.5	1.2	8.6	3	6.6	3.4	Hazard-47	1.4	1	7.8	4.8	3.8	2.8
Hazard-21	2.6	2	10.2	3	3.8	3.4	Hazard-48	3	1.6	5.4	3.2	3.6	3
Hazard-22	1.8	1.1	11.8	2.4	3.8	3.8	Hazard-49	3	1.2	10.2	2.4	3.2	3.6
Hazard-23	3.6	1.8	11.8	2.8	3.6	4	Hazard-50	2.6	1	7	2.4	3	3
Hazard-24	2.6	2.6	7	3.4	2.8	4.4	Hazard-51	3.8	1.7	35	2.2	5.6	3.6
Hazard-25	3	3.2	3.8	3.2	2.8	3.8	Hazard-52	4.4	0.9	25	1.2	5.2	3.8
Hazard-26	1.8	1.4	5.4	4.2	3.2	3.8	Hazard-53	3	1.8	13.4	3.8	5.8	3.4
Hazard-27	3.2	0.6	4.6	5.6	2.2	2.8	**Weight**	**0.142**	**0.192**	**0.248**	**0.164**	**0.051**	**0.204**

Bold inidicates weight values obtained from Bayesian BWM

Hazard-3, and Hazard -52), the following preventive measure was suggested: Panel covers must be kept closed at all times. Panels whose covers are left open must be closed. Training should be given to employees. Employees should always have informed about the risk. New staff must be trained. Insulating mats should be placed in front of the panels to prevent electric shock. It should be ensured that worn mats are replaced with new ones. Insulating mats should be provided for the departments' electrical panels, and warning signs should be added. Regarding the electric heater and power tools (Hazard-46), the following preventive measure was suggested: While working with power tools, there should be no deformation in the cable and tool. Simultaneously, while working with a power hand tool, care should be taken that the working area is not wet and damp due to the risk of possible electrical leakage. Before the work, the environmental conditions for a safe working area should be established under the work instructions. Regarding the hazard, which is prolonged standing and sitting at work (Hazard-1), the following preventive measure was suggested: Practical training should be given to the employee about musculoskeletal disorders. It should be ensured that newly recruited personnel receive training. More resting periods should be supplied. Employees should have rest hours and rest areas (Upadhyay and Pandey 2016). Regarding the Hazard-36 and similar hazards, the following preventive measure was suggested: Due to the working principle of the machine, it is necessary to have emergency stops and wires to reduce the severity of the damage in case the employee's hands, clothes, etc. are caught in rotating parts that cannot be completely protected. The operational status of the current system is checked periodically and documented. Regarding the other hazards which had the relatively low possible risk rating, the following common preventive measure was suggested: Personnel productive equipment (PPE) should be at the

Table 5 Results of VIKOR-specific indexes (S, R & Q)

Hazard	S	R	Q	Hazard	S	R	Q
Hazard-1	0.504	0.209	0.416	Hazard-28	0.632	0.183	0.479
Hazard-2	0.668	0.238	0.766	Hazard-29	0.670	0.209	0.645
Hazard-3	0.509	0.164	0.230	Hazard-30	0.678	0.222	0.712
Hazard-4	0.469	0.173	0.213	Hazard-31	0.550	0.202	0.449
Hazard-5	0.585	0.138	0.220	Hazard-32	0.683	0.209	0.664
Hazard-6	0.455	0.144	0.069	Hazard-33	0.634	0.238	0.719
Hazard-7	0.446	0.131	0.000	Hazard-34	0.621	0.232	0.674
Hazard-8	0.695	0.235	0.790	Hazard-35	0.468	0.229	0.448
Hazard-9	0.474	0.242	0.511	Hazard-36	0.751	0.245	0.908
Hazard-10	0.638	0.222	0.656	Hazard-37	0.660	0.245	0.783
Hazard-11	0.609	0.242	0.698	Hazard-38	0.688	0.245	0.822
Hazard-12	0.572	0.238	0.633	Hazard-39	0.694	0.235	0.788
Hazard-13	0.625	0.232	0.680	Hazard-40	0.672	0.235	0.759
Hazard-14	0.767	0.243	0.924	Hazard-41	0.675	0.232	0.748
Hazard-15	0.677	0.232	0.751	Hazard-42	0.710	0.242	0.838
Hazard-16	0.807	0.248	1.000	Hazard-43	0.565	0.232	0.597
Hazard-17	0.561	0.245	0.645	Hazard-44	0.722	0.232	0.813
Hazard-18	0.797	0.245	0.973	Hazard-45	0.707	0.238	0.820
Hazard-19	0.647	0.203	0.586	Hazard-46	0.625	0.132	0.255
Hazard-20	0.657	0.222	0.682	Hazard-47	0.708	0.226	0.767
Hazard-21	0.637	0.216	0.628	Hazard-48	0.676	0.235	0.764
Hazard-22	0.700	0.209	0.688	Hazard-49	0.675	0.216	0.679
Hazard-23	0.582	0.209	0.523	Hazard-50	0.744	0.229	0.830
Hazard-24	0.569	0.229	0.587	Hazard-51	0.506	0.141	0.128
Hazard-25	0.577	0.242	0.653	Hazard-52	0.588	0.178	0.397
Hazard-26	0.659	0.235	0.740	Hazard-53	0.573	0.203	0.484
Hazard-27	0.663	0.238	0.759				

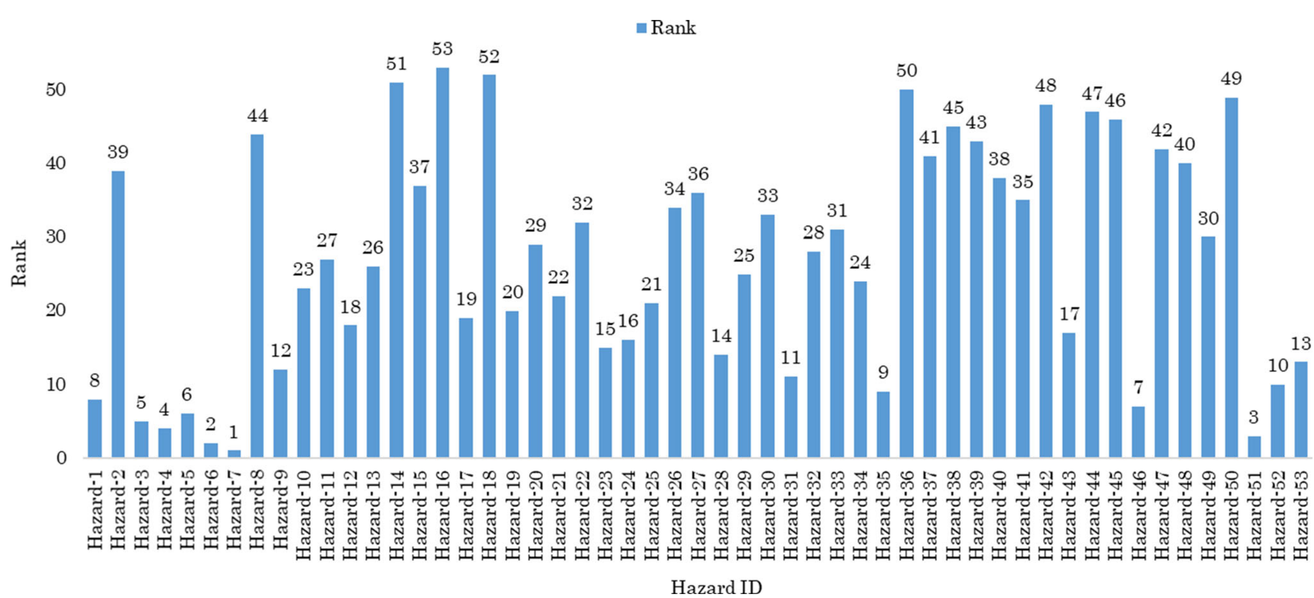


Fig. 6 Hazard ranks by VIKOR Q values

maximum protection level, maintenance procedures should be established, instructions should be prepared and notified to employees, and compliance with these instructions should be constantly monitored. Care should be taken that dust on the part being cleaned does not come to the worker or the machinery in the vicinity. glasses should be used for this procedure, making a sufficient fire extinguishing device, employees should be informed and trained in locking, labeling, and the continuity of the necessary environment for safe maintenance work should be ensured. If the shelves used in the work area are not fixed in case of an earthquake, the employee may fall over them. It should be ensured that the shelves in the work area are fixed to the wall. Authorized and trained personnel should be employed in maintenance work. Maintenance, repair, cleaning, and lubrication should not interfere with the machine in operation. Employees should always have informed about the risk. According to the hazard groups, lack of knowledge about the danger symbols on the chemical substances increases the risk of accidents. To reduce the risk of work accidents, it should be ensured that employees are informed about the hazard signs (Ak 2019). For this, the plate should be provided and hung. Ancillary personnel should be assigned after explaining the work to be done when necessary.

Table 6 Risk parameter weights obtained from classical BWM

Risk parameter	Weight	Rank
Occurrence	0.149	5
Frequency	0.194	3
Severity	0.255	1
Detectability	0.158	4
Cost	0.036	6
Sensitivity to PPE non-utilization	0.207	2

3.4 Validation study

In this section, some validation tests for obtained ranking results are provided. These tests include a comparative study and a sensitivity analysis. The existing approach (Bayesian BWM and VIKOR) and an alternative approach that uses classical (the original and proposed by Rezaei 2015) BWM integrated with VIKOR are compared for the comparative study. The risk parameter weights obtained from classical BWM are shown in Table 6.

Figure 7 shows that the comparison results regarding hazard ranks and VIKOR Q index values by both approaches. When we compare the results obtained by both approaches, we observe very few rank variations between

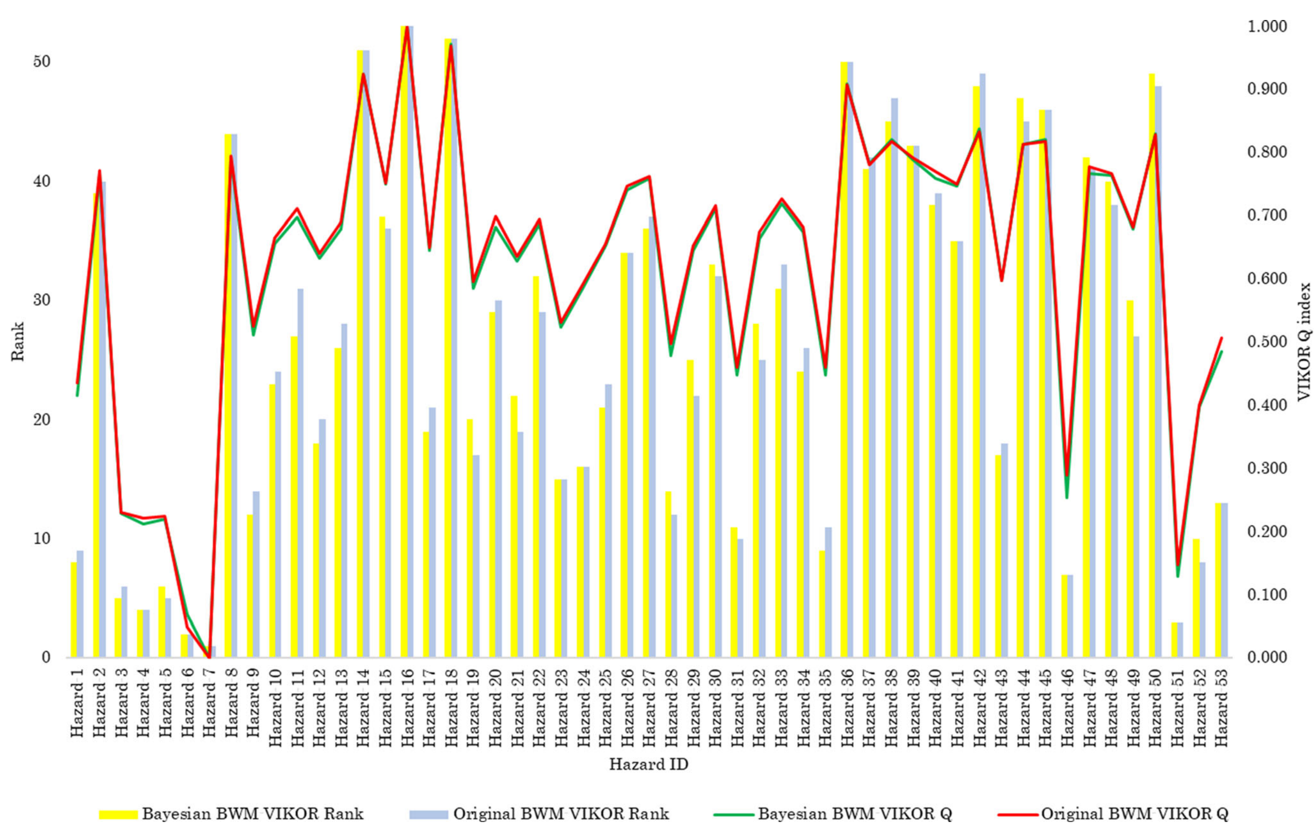


Fig. 7 Comparative study results: comparison in hazard ranks and VIKOR Q index values by two approaches

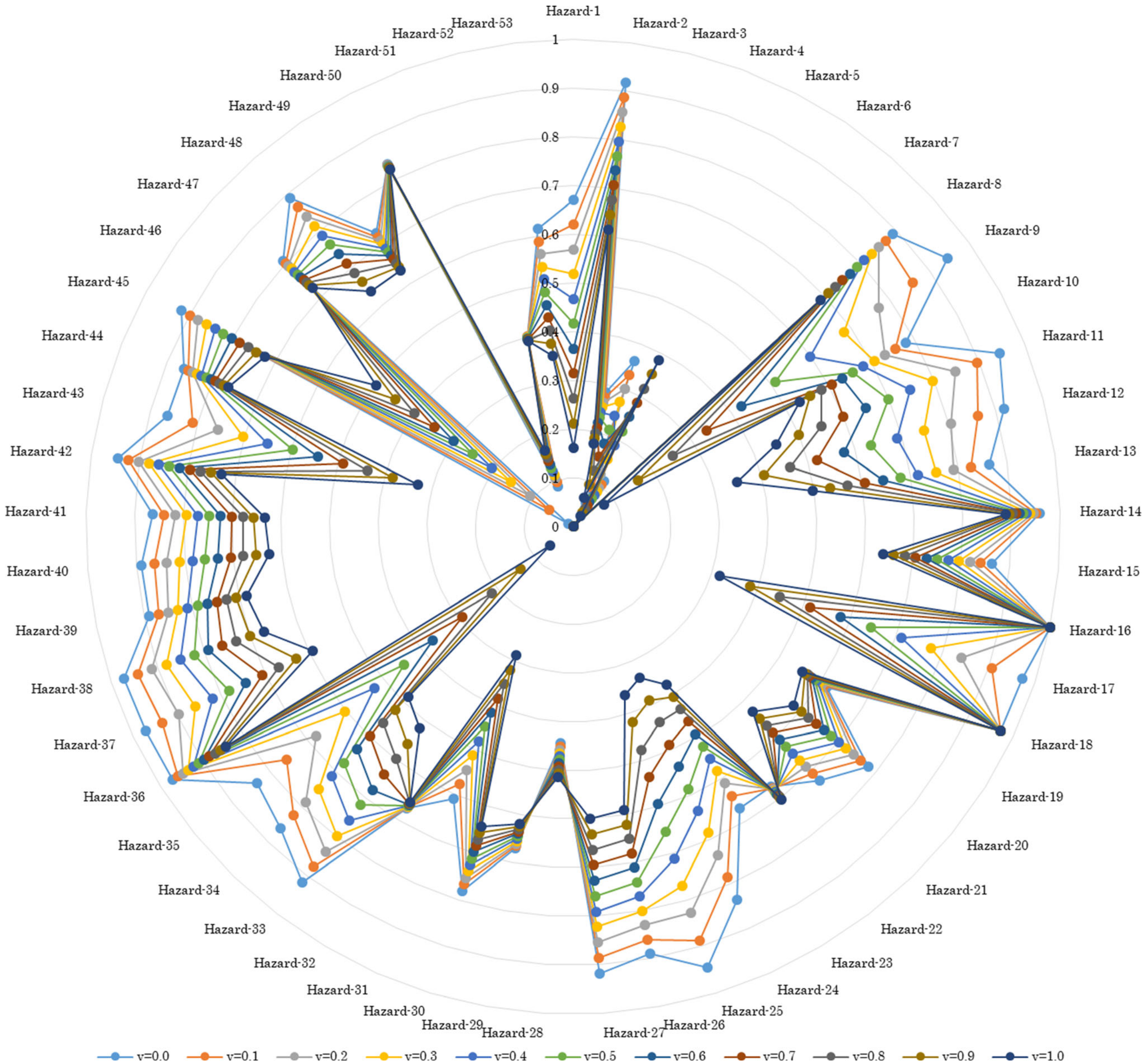


Fig. 8 Sensitivity study results: VIKOR Q value changes in times of ten different v value experiments

them. We calculated a Spearman rank correlation coefficient between the ranking results of both approaches. The coefficient is observed as 1. At the same time, we also applied a correlation analysis between the Q values of both approaches. The correlation coefficient is obtained as 0.99. Although we do not observe drastic rank variations between the current study and the benchmarking model, it can be claimed that the application of this proposed approach is novel in the ORA domain.

The second validation work is a sensitivity analysis that has been performed by the varying value of maximum group utility (indicated with "v" in the text). Initially, we have set the v value to 0.5 in the proposed holistic approach. Ten different experiments from 0.0 to 1.0, with 0.1 intervals are run. Results of Q values from these experiments are combined in Fig. 8.

It is easily inferred from Fig. 8. the Hazard-7 has the best rank for each experiment, Hazard-16 has the worst rank for each v value experiment.

4 Conclusion

Activities in the textile industry involve various hazards, from harmful chemicals to mechanical and electricity-related risks. These hazards arise from the product, process, human and working environment, and the risks associated with them should be evaluated and prioritized. In this context, comprehensive methods are developed from classical ORA methods and eliminate classical techniques' troublesome aspects. Previous studies have shown that classical techniques require a time-consuming and burdensome data collection process and that experts' evaluations without group decisions in full consensus are not sufficiently objective. Regarding this situation, it has become important to engage a group of experts, bring together these multiple experts' choices, reach a consensus without loss of knowledge, and provide a probabilistic perspective for the ORA problem.

Therefore, the current study suggests a decision-making approach that can address these concerns. This approach is achieved by the integration of Bayesian BWM and VIKOR multi-criteria decision methods. The proposed model provides a framework for prioritizing risks in the textile production process based on multiple expert evaluations. To demonstrate the model's applicability, 53 types of risks emerging at the observed factory were prioritized with the proposed framework. In summary, the main contributions of the proposed approach are as follows.

(1) Bayesian BWM method has been applied for the first time in the literature in a real-life (for a production facility) ORA problem.

(2) There is a structure in the procedural steps of the holistic Bayesian BWM and VIKOR that allows experts to explain their evaluations easily.

(3) The case study is shown in an an easy-to-apply structure for all practitioners and researchers who are interested in risk assessment issues.

(4) A benchmark study with the integrated classic BWM and VIKOR approach is provided to observe risk ranking changes.

Although this study will add innovation to the literature within the scope of practice and methodology, the following issues may be considered in future studies. The accident statistics experienced in the past periods in the factory can be used to calculate the *occurrence probability of hazardous event* parameters. Risk parameters can be weighted by establishing a large number of experts. Fuzzy extensions of the methods used can be used to express better the hesitations experienced by decision-makers.

Funding Not applicable.

Declarations

Conflict of interest The authors declare no conflict of interest.

References

Ahn J, Noh Y, Park SH, Choi BI, Chang D (2017) Fuzzy-based failure mode and effect analysis (FMEA) of a hybrid molten carbonate fuel cell (MCFC) and gas turbine system for marine propulsion. J Power Sour 364:226–233

Ak MF (2019) A neuro-fuzzy-based multi-criteria risk evaluation approach a case study of underground mining. In: Al-Turjman F (ed) Artificial intelligence in IoT: transactions on computational science and computational intelligence. Springer, Cham

Ak MF (2020) A comparative analysis of breast cancer detection and diagnosis using data visualization and machine learning applications. Healthcare 8:111

Başhan V, Demirel H, Gul M (2020a) A novel risk evaluation approach for frequently encountered risks in ship engine rooms. Brodogradnja: Teorija i praksa brodogradnje i pomorske tehnike 71(2): 31–54

Başhan V, Demirel H, Gul M (2020) An FMEA-based TOPSIS approach under single valued neutrosophic sets for maritime risk evaluation: the case of ship navigation safety. Soft Comput 24(24):18749–18764

Celik E, Gul M, Aydin N, Gumus AT, Guneri AF (2015) A comprehensive review of multi criteria decision making approaches based on interval type-2 fuzzy sets. Knowl-Based Syst 85:329–341

ÇSGB, (2018). https://www.ailevecalisma.gov.tr/medias/7193/tekst%C4%B0l-sektoer%C3%BCnde-%C4%B0%C5%9F-sa%C4%9Fli%C4%9Fi-goezet%C4%B0m%C4%B0-rehber%C4%B0.pdf

Delice EK, Can GF (2020) A new approach for ergonomic risk assessment integrating KEMIRA, best–worst and MCDM methods. Soft Comput 24(19):15093–15110

Demir P, Gul M, Guneri AF (2020) Evaluating occupational health and safety service quality by SERVQUAL: a field survey study. Total Qual Manag Bus Excell 31(5–6):524–541

Di Bona G, Silvestri A, Forcina A, Petrillo A (2018) Total efficient risk priority number (TERPN): a new method for risk assessment. J Risk Res 21(11):1384–1408

Dong JY, Yuan FF, Wan SP (2017) Extended VIKOR method for multiple criteria decision-making with linguistic hesitant fuzzy information. Comput Ind Eng 112:305–319

Doumpos M, Grigoroudis E (2013) Multicriteria decision aid and artificial intelligence. Wiley, UK

Flores LS, Teixeira AR, Rosito LPS, Seimetz BM, Dall'Igna C (2016) Pitch and loudness from tinnitus in individuals with noise induced hearing loss. Int Arch Otorhinolaryngol 20(03):248–253

Mohammadi M, Rezaei J (2020) Bayesian best-worst method: a probabilistic group decision making model. Omega 96:102075

Gao H, Ran L, Wei G, Wei C, Wu J (2020) VIKOR method for MAGDM based on q-rung interval-valued orthopair fuzzy information and its application to supplier selection of medical consumption products. Int J Environ Res Public Health 17(2):525

Ghoushchi SJ, Yousefi S, Khazaeili M (2019) An extended FMEA approach based on the Z-MOORA and fuzzy BWM for prioritization of failures. Appl Soft Comput 81:105505

Grassi A, Gamberini R, Mora C, Rimini B (2009) A fuzzy multi-attribute model for risk evaluation in workplaces. Saf Sci 47(5):707–716

Gul M (2018) A review of occupational health and safety risk assessment approaches based on multi-criteria decision-making methods and their fuzzy versions. Hum Ecol Risk Assess Int J 24(7):1723–1760

Gul M, Ak MF (2018) A comparative outline for quantifying risk ratings in occupational health and safety risk assessment. J Clean Prod 196:653–664

Gul M, Ak MF (2020) Assessment of occupational risks from human health and environmental perspectives: a new integrated approach and its application using fuzzy BWM and fuzzy MAIRCA. Stoch Environ Res Risk Assess 34:1231–1262
Gul M, Yucesan M, Celik E (2020) A manufacturing failure mode and effect analysis based on fuzzy and probabilistic risk analysis. Appl Soft Comput 96:106689
Gul M, Mete S, Serin F, Celik E (2021) Fine-kinney-based fuzzy multi-criteria occupational risk assessment: approaches, case studies and python applications. Springer, New York
Guo S, Zhang W, Gao X (2020) Business risk evaluation of electricity retail company in China using a hybrid MCDM method. Sustainability 12(5):2040
Hafezalkotob A, Hafezalkotob A (2017) A novel approach for combination of individual and group decisions based on fuzzy best-worst method. Appl Soft Comput 59:316–325
http://www.sgk.gov.tr/wps/portal/sgk/tr/kurumsal/istatistik/sgk_istatistik_yilliklari
ISO, (2019). https://www.iso.org/standard/72140.html
Jahan A, Mustapha F, Ismail MY, Sapuan SM, Bahraminasab M (2011) A comprehensive VIKOR method for material selection. Mater Des 32(3):1215–1221
Kabakulak T (2019) Bir Tekstil İşletmesinde Risk Değerlendirme Uygulaması: 5x5 Matris ve HAZOP. Karaelmas İş Sağlığı Ve Güvenliği Dergisi 3(2):97–111
Kaya G (2020) The Use of multi-criteria decision-making methods to support risk prioritisation. Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management, Detroit, Michigan, USA, August 9 - 11, 2020
Khameneh AZ, Kılıçman A (2019) Multi-attribute decision-making based on soft set theory: a systematic review. Soft Comput 23(16):6899–6920
Lee D, Lim H, Lee D, Cho H, Kang KI (2019) Assessment of delay factors for structural frameworks in free-form tall buildings using the FMEA. Int J Concrete Struct Mater 13(1):2
Li L, Wang X, Rezaei J (2020) A Bayesian best-worst method-based multicriteria competence analysis of crowdsourcing delivery personnel. Complexity 2020:1–17
Liang F, Brunelli M, Rezaei J (2020) Consistency issues in the best worst method: measurements and thresholds. Omega. 96:102175
Lipol LS, Haq J (2011) Risk analysis method: FMEA/FMECA in the organizations. Int J Basic Appl Sci 11(5):74–82
Liu R, Hou LX, Liu HC, Lin W (2020) Occupational health and safety risk assessment using an integrated SWARA-MABAC model under bipolar fuzzy environment. Comput Appl Math 39(4):1–17
Mi X, Tang M, Liao H, Shen W, Lev B (2019) The state-of-the-art survey on integrations and applications of the best worst method in decision making: Why, what, what for and what's next? Omega 87:205–225
Mohammadi M, Rezaei J (2020) Bayesian best-worst method: a probabilistic group decision making model. Omega 96:102075
Mohammadi M, Rezaei J (2020) Evaluating and comparing ontology alignment systems: an MCDM approach. J Web Semant 64:100592
Mou Q, Xu Z, Liao H (2016) An intuitionistic fuzzy multiplicative best-worst method for multi-criteria group decision making. Inf Sci 374:224–239
Nowak M, Mierzwiak R, Butlewski M (2020) Occupational risk assessment with grey system theory. CEJOR 28(2):717–732
Opricovic S (1998) Multicriteria optimization of civil engineering systems Faculty of Civil Engineering, Belgrade 2(1), 5–21
Opricovic S, Tzeng GH (2004) Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS. Eur J Oper Res 156(2):445–455
Pelissari R, Oliveira MC, Abackerli AJ, Ben-Amor S, Assumpção MRP (2021) Techniques to model uncertain input data of multicriteria decision-making problems: a literature review. Int Trans Oper Res 28(2):523–559
Peng X, Dai J (2020) A bibliometric analysis of neutrosophic set: two decades review from 1998 to 2017. Artif Intell Rev 53(1):199–255
Rafieyan E, Khorsand R, Ramezanpour M (2020) An adaptive scheduling approach based on integrated best-worst and VIKOR for cloud computing. Comput Indust Eng 140:106272
Rezaei J (2015) Best-worst multi-criteria decision-making method. Omega 53:49–57
Rezaei J (2016) Best-worst multi-criteria decision-making method: some properties and a linear model. Omega 64:126–130
Singh N (2016). Safety and health issues in workers in clothing and textile industries. Int J Home Sci 2(3)
Sotoodeh K (2020) Failure mode and effect analysis (FMEA) of pipeline ball valves in the offshore industry. J Fail Anal Prev 20(4):1175–1183
Tang J, Liu X, Wang W (2021) A hybrid risk prioritization method based on generalized TODIM and BWM for Fine-Kinney under interval type-2 fuzzy environment. Human and Ecological Risk Assessment: An Int J 27(4):954–979
Tian ZP, Wang JQ, Zhang HY (2018) An integrated approach for failure mode and effects analysis based on fuzzy best-worst, relative entropy, and VIKOR methods. Appl Soft Comput 72:636–646
Upadhyay KK, Pandey AC (2016) Occupational exposure and awareness of occupational safety and health among cloth dyeing workers in Jaipur India. Iran J Health Saf Environ 3:540–546
Valipour M, Yousefi S, Jahangoshai Rezaee M, Saberi M (2021) A clustering-based approach for prioritizing health, safety and environment risks integrating fuzzy C-means and hybrid decision-making methods. Stoch Environ Res Risk Assess. https://doi.org/10.1007/s00477-021-02045-6
Yang JJ, Lo HW, Chao CS, Shen CC, Yang CC (2020) Establishing a sustainable sports tourism evaluation framework with a hybrid multi-criteria decision-making model to explore potential sports tourism attractions in Taiwan. Sustainability 12(4):1673
Yazdi M, Nedjati A, Zarei E, Abbassi R (2020) A novel extension of DEMATEL approach for probabilistic safety analysis in process systems. Saf Sci 121:119–136
Yucesan M, Kahraman G (2019) Risk evaluation and prevention in hydropower plant operations: a model based on Pythagorean fuzzy AHP. Energy Policy 126:343–351
Zhang X, Mohandes SR (2020) Occupational health and safety in green building construction projects: a holistic Z-numbers-based risk management framework. J Clean Prod 275:122788