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RESEARCH ARTICLE

Control measure prioritization in Fine – Kinney-based risk assessment: a Bayesian BWM-Fuzzy VIKOR combined approach in an oil station

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Abstract

The Fine – Kinney is a risk assessment method widely used in many industries due to its ease of use and quantitative risk evaluation. As in other methods, it is a method that recommends taking a series of control measures for operational safety. However, it is not always possible to implement control measures based on the determined priorities of the risks. It is considered that determining the priorities of these measures depends on many criteria such as applicability, functionality, performance, and integrity. Therefore, this study has studied the prioritization of control measures in Fine – Kinney-based risk assessment. The criteria affecting the prioritization of control measures are hierarchically structured, and the importance weights of the criteria are determined by the Bayesian Best–Worst Method (BBWM). The priorities of control measures were determined with the fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje (FVIKOR) method. The proposed model has been applied to the risk assessment process in a petrol station's liquid fuel tank area. According to the results obtained with BBWM, the most important criterion affecting the prioritization of control measures is the *applicability* criterion. It has an importance weight of about 42%. It is followed by *performance* with 31%, *functionality* with 18%, and *integrity* with 10%, respectively. FVIKOR results show that the "Periodic control of the ventilation device" measure is the top priority for Fine – Kinney risk assessment. "The absence of any ducts or sewer pits that may cause gas accumulation in the tank area and near the dispenser; Yellow line marking of entry and exit and vehicle roads; Placing of speed limit warning signs" has been determined as a secondary priority. On conclusion, this proposed model is expected to bring a new perspective to the work of occupational health and safety analysts, since the priority suggested by Fine – Kinney risk analysis methods is not always in the same order as the one in the stage of taking action, and the source, budget, and cost/benefit ratio of the measure affect this situation in practice.

Keywords Fine – Kinney · Control measure prioritization · Bayesian Best–Worst Method · VIKOR · Fuzzy set theory · Liquid fuel tank

Introduction

A risk assessment is a careful examination of what and how much harm can be done to people in your workplace, so you can gauge whether you have taken enough action to prevent harm or whether you need to take more action. Risk assessment aims to foresee how, where, and how the harm to health may occur before anyone is injured or sick, if possible, and to take precautions from the very beginning. In this sense, it is a proactive approach. One method that performs risk assessment in workplaces in a simple, understandable, and uncomplicated way is the Fine – Kinney risk assessment method (Fine 1971; Kinney and Wiruth 1976). Although the first recommended version has some handicaps, apart from the improved versions, it is frequently used in the industry

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and is successfully applied in occupational safety processes (Gul et al. 2021a; b). As in other risk analysis methods such as L-matrix, Hazard and Operability Analysis (HAZOP), and Failure Modes and Effects Analysis (FMEA), some preventive control measures are put forward regarding the prioritized risks in this method (Marhavilas et al. 2020; Gul et al. 2019; Liu 2016). However, these control measures may not consistently be implemented in line with the priority of risks. Because some basic criteria affect this situation (Rausand 2013; Hollnagel 2008). The literature states these as applicability, functionality, performance, and integrity (Cheraghi et al. 2022). There has not been much space in the literature on this subject, which constitutes an important argument at the "control" stage in the risk management scheme. This study was carried out to remedy this gap and address the prioritization of control measures with a sound scientific framework. This paper has studied the prioritization of control measures in the Fine – Kinney risk assessment method.

When previous studies are examined in terms of methodology, it is seen that this problem is generally solved by cost–benefit analysis or mathematical modeling (with combinatorial optimization modeling) (Baladeh et al. 2019; Cheraghi et al. 2018; Caputo et al. 2011). However, cost–benefit analysis approaches the problem only from criteria that include cost items, which we call "applicability." On the other hand, working with a limited objective and increasing the number of objectives in studies with combinatorial optimization modeling prolongs the processing time and makes the problem more complex (Cheraghi et al. 2022). Therefore, a framework based on multi-criteria decision-making (MCDM) approaches is proposed in this study. In the literature, geographical information system (GIS) integrated with MCDM approaches also has been used for better informed decision analysis and decision making for environmental impact monitoring and assessment (Omarzadeh et al., 2022; Feizizadeh et al. 2021).

MCDM is a field of operations research that aims to select the best alternative, prioritize, and sort alternatives with a set of mathematical procedures. As with other decision problems, MCDM seeks solutions to many risk assessments and management (Gul et al. 2021b). The decision-making procedure for risk assessment requires considering a range of hazards based on different risk parameters. For this purpose, it has come to the fore in recent years as a powerful tool that will help decision-makers prioritize the risks that emerged in their facilities and reduce the risks to an acceptable level. Risk assessment includes many elements with different objectives and criteria. The main feature of MCDM methods is that they provide flexibility on the judgments of the decision-makers. These methods aim to reach the ideal decision by assigning performance scores and weights. When MCDM is injected into a classical risk assessment procedure, "risk parameter" may refer to elements of a classic risk analysis tool. For example, in a Fine – Kinney approach, these are probability, exposure, and consequence. In FMEA, severity, occurrence, and detection are the basic parameters. Other components of this process include hazard list (with relevant risk definitions), MCDM method for risk parameter weighting (e.g., Analytic Hierarchy Process-AHP, Analytic Network Process-ANP, Best–Worst Method-BWM), MCDM method for risk prioritization (e.g., Technique for Order of Preference by Similarity to Ideal Solution-TOPSIS, VlseKriterijumska Optimizacija I Kompromisno Resenje-VIKOR, Grey Relational Analysis-GRA, Weighted Batch Product Evaluation-WASPAS, Complex Proportional Assessment-COPRAS), and decision-maker/expert. Since MCDM is a frequently used area in risk assessment (Gul 2018), it is a concept that allows to evaluate and prioritize the control measures that need to be taken based on the criteria of applicability, functionality, performance, and integrity (Cheraghi et al. 2022).

Bayesian Best–Worst Method (BBWM) (Mohammadi and Rezaei 2020a), which is an improved version of a new MCDM method called BWM (Rezaei 2015; 2016), was preferred in determining the importance weights of the criteria affecting the prioritization of the recommended control measures in the Fine – Kinney method, which is the first stage of the problem in this paper. This method reduces the loss of information in group decision-making compared to classical BWM. In classical BWM, the optimal importance weights of the criteria are found when solving the problem according to the evaluation of a single decision-maker or by solving the problem separately for more than one decision-maker and taking the final average. However, with BBWM, a Monte-Carlo simulation-based structure from a probabilistic perspective prevents information loss. Although BBWM has been used in risk analysis before in the literature (Ak et al. 2022; Yucesan et al. 2021; Yanilmaz et al. 2021), its use in prioritizing risk control measures is new and first.

On the other hand, the fuzzy VIKOR method (Opricović, 1998) prioritizes the control measures proposed by applying Fine – Kinney depending on the criteria weights determined. This practice forms the second phase of our approach. The integration of fuzzy logic into the VIKOR method eliminates the uncertainty in decision-making and the difficulty of not working with precise data (with the help of triangular fuzzy numbers and the linguistic variables they express) (Gul et al. 2016). Thus, a completely holistic framework is structured and employed in a real-case study application. This case study is concerned with a risk analysis process in a petrol station's liquid fuel tank area.

Literature review

A four-legged literature review has been conducted to reveal the last point reached in the literature of MCDM methods, which constitute the methodology used to

prioritize control measures and solve this problem. To do this, previous contributions regarding the topic of "prioritization of control measures in risk assessment studies" are provided in the first sub-section. Then, recent efforts on Fine – Kinney occupational risk assessment have been addressed in the second sub-section. In the third and fourth sub-sections, review of recent literature on BBWM and FVIKOR have been presented. In the light of these four sub-sections, the main focus of the study in the literature has been identified in the last sub-section.

Previous studies regarding control measure prioritization

The concept of control measures has been put forward with many different definitions in the literature. They are considered in the context of the own terminology of the method by which the risk assessment is carried out. For example, in HAZOP, it is referred to as recommendations (safety measures/preventive measures), while in process hazard analysis (PHA), it is expressed as management decision-making rules (Caputo et al. 2013a; b; Kotek and Tabas 2012; Moore 1997). For Fine – Kinney, this is called control measures. Generally, these measures are processed depending on the feasibility of making the change, the effectiveness of the recommendation, the stability of the recognized hazard, and the importance of the recommendation (Moore 1997). Other factors include cost, ease of completion, scheduling issues, and public or employee perception of the risk of the value of a safeguard (Cheraghi et al. 2022; Caputo et al. 2013a; b). Cheraghi et al. (2022)'s study is the study of such factors to the literature with a hierarchical framework. In that study, the factors affecting the prioritization of HAZOP recommendations are presented as 22 sub-criteria under four main criteria. They developed a hierarchical framework with six sub-criteria under the main criteria of performance, applicability, and functionality and four sub-criteria under the main criterion of integrity. Since this hierarchical structure for control measures contains a very up-to-date and comprehensive repository, we have used an adapted version of this hierarchy in our current study.

Previous studies regarding Fine – Kinney risk assessment

Fine – Kinney is a traditional risk assessment method that has long been used to address potential hazards and associated risks. This method is a combination of three parameters: probability, exposure, and consequence; numerically, calculating the risk is determined as the product of the crisp numbers given to these three parameters. Here, there are handicaps in taking the importance level of risk parameters equally and choosing crisp numbers that do not provide flexibility in evaluating the risk quantitatively (Gul et al. 2021b). This method combines fuzzy logic theory to reflect and transform uncertain risk information expressed by linguistic variables (Wang et al. 2022a; b; Çalış Boyacı and Selim 2022; Tang et al. 2021; Gul et al. 2021b, 2018; Zhang et al. 2020; Wang et al. 2018). In addition, it is frequently applied together with MCDM methods since it reflects the nature of the decision problem in determining the importance weights of the parameters and prioritizing the risks (Can and Toktas 2021; Zhu et al. 2019; Kokangül et al. 2017). Miscellaneous applications of this method, apart from MCDM/fuzzy set theory, are performed (Dagsuyu et al. 2020; Gul and Celik 2018). Dagsuyu et al. (2020) combined Fine – Kinney with *k*-means and hierarchical clustering algorithms to overcome its limitations. In Gul and Celik (2018), a fuzzy rule-based system is designed according to the rail transportation risk assessment processes under Fine–Kinney. Table 1 also summarizes the previous studies on Fine – Kinney risk assessment method scrutinizing different aspects and novelties of each one.

Previous studies regarding BBWM

Since the BBWM method is a relatively new MCDM method, it has not been applied to many areas in the literature. However, it has been applied to fields such as information technology and management (Liang et al. 2022; Abkenar et al. 2022; Mohammadi and Rezaei 2020b), supply chain, and logistics management (Munim et al. 2022; Kelly et al. 2022; Liu et al. 2021; Li et al. 2020), transportation (Huang et al. 2021), disaster management (Yanilmaz et al. 2021), risk assessment and management (Tusher et al. 2022; Ak et al. 2022), manufacturing (Alkan et al. 2022), water resource management (Dogani et al. 2020), tourism (Yang et al. 2020), and education (Gul and Yucesan 2021; Hsu et al. 2021) with the advantage of eliminating information loss in group decision-making. It is used either as singleton or in conjunction with an auxiliary MCDM method in many practical applications. Mohammadi and Rezaei (2020b) applied BBWM and an expert-based collective performance evaluator for assessing and comparing ontology alignment systems. Liu et al. (2021) identified and ranked the possible barriers in implementing sustainable supply chain blockchain technology by BBWM. In the same industry, Li et al. (2020) made a competence analysis for Chinese takeaway delivery platforms using singleton BBWM. BBWM was integrated with a modified preference ranking organization method for enrichment evaluations (PROMETHEE) in evaluating airport resilience on a different track. Recently, Yanilmaz et al. (2021) applied BBWM to an open field "disaster science." They extended the disaster hazard analysis techniques of

Table 1 Overview of the previous studies on Fine – Kinney risk assessment method

Reference	Applied industry	Combined concept(s)/method(s)	Novelty/innovative aspect(s)	Comparative study	Sensitivity analysis
Wang et al. (2022a)	Manufacturing	Weighted power average operator, Cumulative prospect theory, ORESTE	The proposed model has the ability to capture the reference dependence effects and detailed relationships among hazards and considers the influence of the deviation of risk evaluation information	Performed	Performed
Wang et al. (2022b)	Construction	Gained and lost dominance score, Interval type-2 fuzzy sets, Maclaurin symmetric mean operator	The proposed model has the ability in aggregating the complex and uncertain risk evaluation information from heterogeneous decision-makers and considers inter-dependencies among multi-risk parameters	Performed	Performed
Çalış Boyacı and Selim (2022)	Health	Hesitant fuzzy linguistic term set	Occupational health and safety risks in an operating room of a public hospital are handled by the combined approach	Performed	Performed
Can and Toktas (2021)	NA	Advanced QFD, Modified KEMIRA-M	An advanced stochastic risk assessment is proposed	Non-performed	Performed
Tang et al. (2021)	Marine	TODIM, BWM, Interval type-2 fuzzy sets	The proposed hybrid approach handles the expression problem of the team members' uncertain evaluation information, considers the relative importance degrees of risk parameters, and determines the risk priority orders of hazards, which can simulate the experts' bounded rational behavior under uncertain environment	Performed	Performed
Dagsuyu et al. (2020)	Textile	*K*-means clustering	Clustering algorithms are integrated with Fine–Kinney risk assessment for the first time in the literature	Performed	Non-performed
Zhang et al. (2020)	Transportation	Fuzzy AHP	The paper introduces a combination method for airport operation situation risk assessment	Non-performed	Performed
Zhu et al. (2019)	Transportation	TODIM, Choquet integral	The paper includes interactive relationships between risk criteria and psychological behaviors of decision-makers into consideration for risk assessment of subway train door system	Performed	Performed
Gul et al. (2018)	Defense	AHP, VIKOR, Fuzzy sets	The proposed method enables group decision-making in assessing hazards and uses relative importance among three risk parameters	Performed	Performed
Gul and Celik (2018)	Transportation	Fuzzy rule-based expert system	The fuzzy rule-based system captures nonlinear causal relationships between Fine–Kinney parameters	Performed	Non-performed
Wang et al. (2018)	Marine	Extended MULTIMOORA, Choquet integral	The proposed method considers the interaction relationships between risk parameters	Performed	Performed

Table 1 (continued)

Reference	Applied industry	Combined concept(s)/method(s)	Novelty/innovative aspect(s)	Comparative study	Sensitivity analysis
Kokangül et al. (2017)	Manufacturing	AHP	The relation between the risk class assessment in the Fine – Kinney risk assessment and the AHP points has been examined, and the risk class intervals for AHP have been determined	Performed	Non-performed
Current study	Energy	Bayesian BWM, Fuzzy VIKOR	The prioritization of control measures in Fine – Kinney-based risk assessment has been firstly studied in the literature	Performed	Performed

(FEMA: Federal Emergency Management Agency; SMUG: Seriousness Manageability Urgency Growth) with BBWM and determined the priority orders of disaster hazards in a Turkish city. Ak et al. (2022) developed a BBWM-VIKOR approach for occupational health, safety, and environmental risk assessment in the textile industry. Alkan et al. (2021) proposed a model to select the most appropriate sustainable construction material via BBWM and Simple Additive Weighting (SAW). Dogani et al. (2020) prioritized the resilience indicators of a plain placed in Iran to groundwater resources reduction by BBWM. Yang et al. (2020) combined rough decision-making trial and evaluation laboratory (DEMATEL) and BBWM to determine influential relationships in the concept of sustainable development into sports tourism. In addition to all these application areas, it has also been used in problems related to education. In Gul and Yucesan (2021)'s study, a university ranking model is proposed for the Turkish higher education system by BBWM-TOPSIS integrated model. On the other side, Hsu et al. (2021) proposed a framework of epidemic prevention work and further explored the importance and priority of epidemic prevention works of COVID-19 by BBWM. Table 2 also demonstrates the previous studies on BBWM summarizing application areas and novelties of each one.

Previous studies regarding FVIKOR

The fuzzy VIKOR method has emerged by integrating the theory shaped by the un-sharp boundaries of fuzzy logic into the VIKOR MCDM method. The fuzziness here is the concept of fuzzy theory created by "triangular fuzzy numbers." It is different and older than the newly developed extensions such as intuitionistic, type-2, Pythagorean, and spherical. Its field of application remains and is applied to many real-world problems (Gul et al. 2016). In FVIKOR, as in other distance-based MCDM methods, a ranking is obtained based on the distance to the ideal solution (Chang 2014; Opricovic 2011). The main goal in the integration of fuzzy logic is always related to its success in reflecting uncertainty in decision-making. With FVIKOR, a compromise solution is achieved with maximum group utility of the majority and minimum individual regret of the opponent (Celik et al. 2021; Samanlioglu 2019). Some extensions of VIKOR in fuzziness have been merged with MCDM and applied to the risk assessment problems in recent years (Ramavandi et al. 2021; Erdoğan et al. 2021; Rathore et al. 2021; Guo et al. 2019; Gul et al. 2019; Mete et al. 2019; Gul and Ak 2018; Tian et al. 2018; Mohsen and Fereshteh 2017).

Main focus of the study in the literature

The literature reviews presented in the four sub-sections above show that although fuzzy logic and MCDM methods

Table 2 Overview of the previous studies on BBWM

Reference	Applied industry	Combined concept(s)/method(s)	Novelty/ınnovative aspect(s)
Liang et al. (2022)	Information technology and management	Difference-quotient gray relational analysis	Evaluated the comprehensive performance of 5G base station by BBWM-GRA approach
Abkenar et al. (2022)	Information technology and management	No auxiliary concept/method	Determined the ımportance of barriers to IoT ımplementation by BBWM
Mohammadi and Rezaei (2020b)	Information technology and management	No auxiliary concept/method	Evaluated and compared ontology alignment systems by BBWM
Munim et al. (2022)	Supply chain and logistics management	No auxiliary concept/method	Identified 16 key measures implemented during COVID-19 in the ready-made garments sector and assessed their priority degree by BBWM
Kelly et al. (2022)	Supply chain and logistics management	No auxiliary concept/method	Identified what barriers prevent the successful implementation of a closed-loop supply chain to the medical device manufacturing by BBWM
Liu et al. (2021)	Supply chain and logistics management	No auxiliary concept/method	Identified and ranked the challenges of implementing sustainable supply chain blockchain technology by BBWM
Li et al. (2020)	Supply chain and logistics management	Multicriteria competence analysis	Proposed a BBWM-based multicriteria competence analysis of crowdsourcing delivery personnel
Huang et al. (2021)	Transportation	PROMETHEE	Proposed a novel assessment model for evaluating airport resilience
Yanilmaz et al. (2021)	Disaster management	FEMA, SMUG	Conducted a disaster hazard analysis for a region by BBWM enhanced with some classical disaster risk reduction methods
Tusher et al. (2022)	Risk assessment and management	No auxiliary concept/method	Cyber security risk assessment in autonomous shipping by BBWM
Ak et al. (2022)	Risk assessment and management	VIKOR	Proposed an occupational health, safety, and environmental risk assessment approach in textile production industry
Alkan et al. (2022)	Manufacturing	SAW	Applied BBWM-based decision model to sustainable construction material selection
Dogani et al. (2020)	Water resource management	AHP	Ranked resilience indicators of Mashhad plain to groundwater resources reduction by BBWM
Yang et al. (2020)	Tourism	VIKOR	Established a hybrid sustainable sports tourism evaluation framework
Gul and Yucesan (2021)	Education	TOPSIS	Developed a new university ranking model by the aid of BBWM and TOPSIS methods
Hsu et al. (2021)	Education	No auxiliary concept/method	Proposed a framework of epidemic prevention work and further explored the importance and priority of epidemic prevention works for colleges and universities

are frequently used in risk assessment; they are rarely used together to prioritize control measures, which is an important component of a risk assessment study. Therefore, this integrated approach is proposed. In this context, the focal points (contributions to the literature) of this approach are summarized below:

1) For the first time, an approach is presented. Control measures recommended for the Fine – Kinney risk assessment method are prioritized under applicability, functionality, performance, and integrity criteria.
2) The importance levels of the criteria that impact the application of control measures in Fine – Kinney-based risk assessment without loss of information within the scope of group-decision-making process in risk management have been obtained by BBWM. Here, both the credal sorting feature of BBWM and the less pairwise comparison ability of classical BWM are utilized.
3) For Fine – Kinney, the priority of control measures is carried out with FVIKOR. An appropriate methodology is followed by taking the opinions of the expert group and using the weights obtained from the BBWM. It comes from its ability to model the uncertainty of experts' opinions with the integration of fuzzy logic theory. This is a strength of the proposed approach.
4) Finally, applying the proposed approach to assessing emerged risks in a gas station liquid fuel tank area provides a systematic and comprehensive argument for practitioners in practice. An OHS analyst who wants to prioritize their systems' risk assessment and risk control measures can easily adapt this approach.

Methodology

This section includes the components of the methodology used in the study. First, the Fine – Kinney risk assessment method is briefly introduced. It then provides information about the decision-making analyst group that evaluated the proposed approach. In the third stage, the hierarchy of criteria, which impacts the prioritization of the risk control measures, is introduced. Following this, the procedure followed in weighting these criteria with BBWM and the procedure followed in prioritizing control measures with FVIKOR are explained step by step. A general overview of the research methodology is graphized in Fig. 1.

Fine – Kinney risk analysis concept

This method was first introduced in the work of Fine (1971) and was published by Kinney and Wiruth (1976) to form this classical version. It is an easy to use and numerical analysis method. It consists of the combination of three parameters: probability, exposure, and consequence, and a result is obtained by multiplying the scale values (seven for probability and six for both exposure and consequence parameters) of the three parameters numerically (Kuleshov et al. 2021; Çınar et al. 2021; Derse 2021). According to the result, actions (i.e., control measures) are put on the agenda (Gul et al. 2021b).

Risk analysis decision-making team

The process in a petrol station's liquid fuel tank area requires expertise, and the proper selection of the decision-making team is critical to a successful evaluation. Likewise, it will provide significant support in determining the risk parameters, criteria, and list of hazards within the risk assessment decision-making model. In this case, five experts were chosen to participate in the decision-making process: two A-class occupational safety experts, two petroleum engineers, and one fuel station manager. Decision-makers were selected by considering their titles, educational backgrounds, and experience in the gas station and liquid fuel filling processes. While petroleum engineers have more than 10 years of experience in the fuel filling industry, occupational safety experts are the people who inspect the stations on site. The fuel station manager is also the manager of 2 separate stations, a civil engineer and contractor, and has 9 years of experience. All experts consist of people who have completed their undergraduate education in engineering and have field and sector experience.

Criteria hierarchy affecting control measures

Cheraghi et al. (2022) developed a comprehensive hierarchy regarding the criteria pool that influences the prioritization of the recommendations presented as a result of HAZOP. Although the method we use in risk analysis is Fine – Kinney, the criteria affecting the implementation of the proposed control measures are likely to be similar. So we adapted this hierarchy and decided to use it in our application, as presented in Fig. 2.

There are six sub-criteria under the performance criterion (Cheraghi et al. 2022; Caputo et al. 2013a; Rausand 2013; Hollnagel 2008). C11-Efficiency refers to the ability of a control measure to affect high-risk hazards. C12: Adequacy describes the ability of a control measure to reduce risks to an acceptable level. C13: Range is expressed as the ability of a control measure to affect different risks. C14: Effectiveness relates to the amount of risk reduced by a control measure. C15: Response time indicates the time it takes for a control measure to complete its function, taking into account a deviation. C16: New hazard avoidance is the potential of a control measure to introduce new hazards. The applicability criterion includes six sub-criteria as in

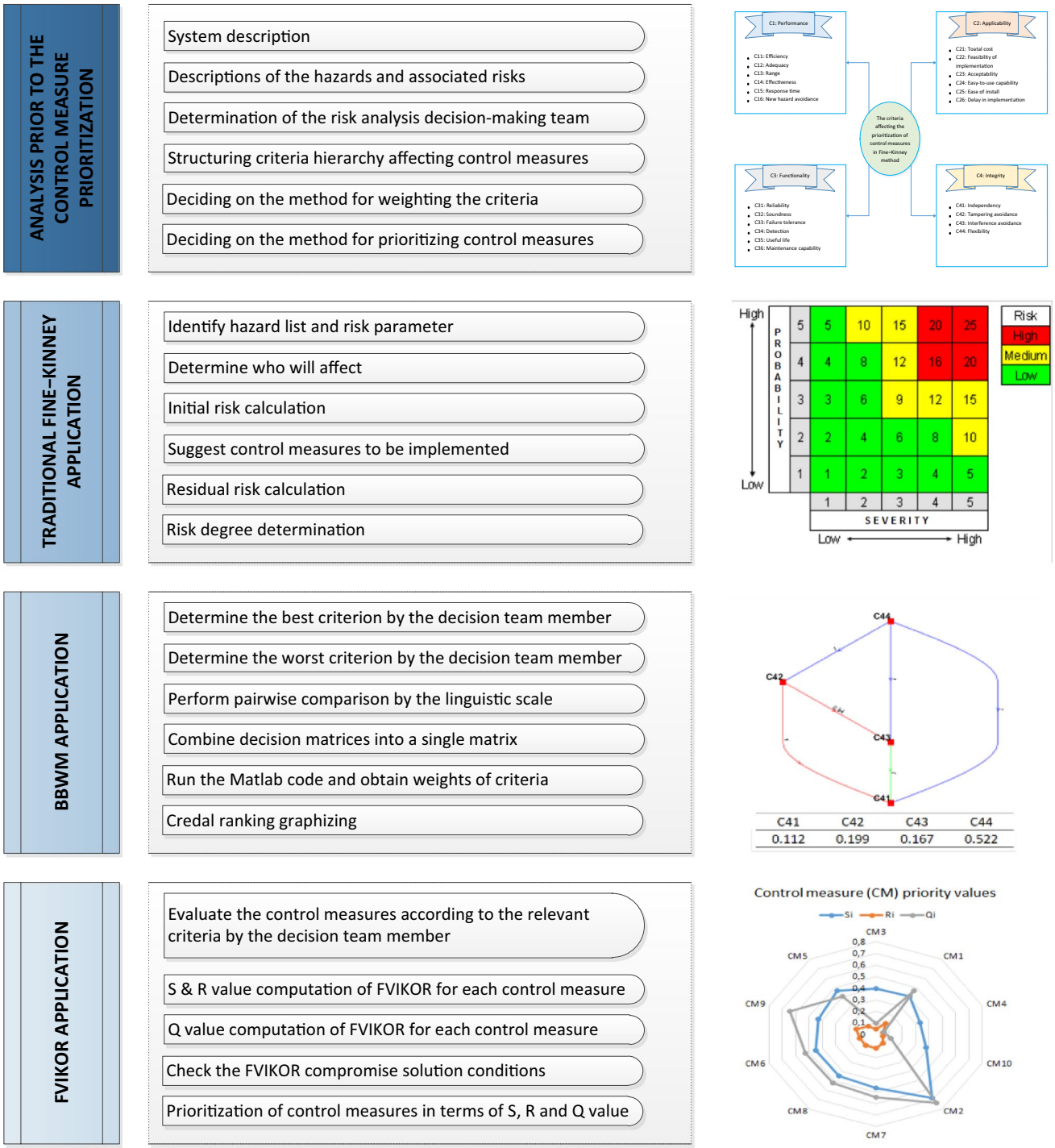


Fig. 1 The flowchart for the research methodology

the performance criterion. C21: Total cost is expressed as the sum of cost items such as purchase, implementation, maintenance, and operating expenses incurred to deploy a control measure. C22: The feasibility of implementation shows the feasibility of applying a control measure in the context of available information, resources, rules, and legal obligations. C23: Acceptability is defined as the degree to which stakeholders accept a control measure. C24: Easy-to-use capability indicates the effort required to use a control measure, while C25: Ease of install indicates the effort required to implement a control measure. C26: Delay in implementation sub-criterion indicates the time

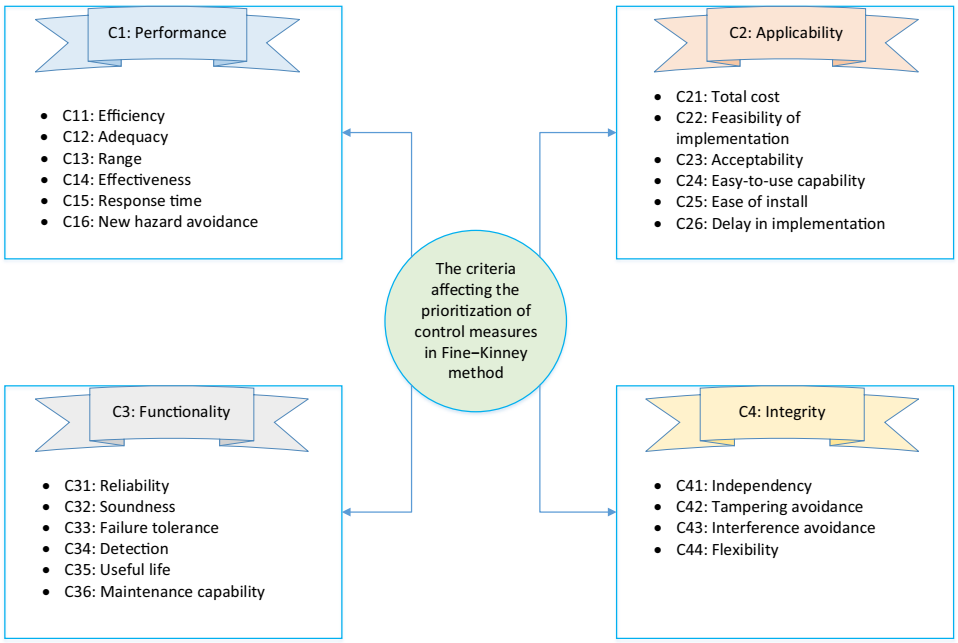


Fig. 2 The criteria hierarchy affecting the priority of control measures in Fine – Kinney [Adapted from Cheraghi et al. (2022)]

required to implement a control measure. The functionality criterion consists of six sub-criteria. C31: Reliability is the probability that a control measure will perform a function under a given condition and time constraint. C32: Soundness indicates the resilience of the control measure against extreme events. C33: Fault tolerance refers to the ability of a control measure to perform its function if it has partially failed. C34: Detection relates to the probability that an error in a control measure will be detected. C35: Useful life refers to the expected operational life of a control measure, depending on its conditions and use. Finally, C36: Maintenance capability refers to the effort required to maintain a control measure in good condition and the time required to correct it. The last criterion is integrity includes four sub-criteria. C41: Independency is the ability of a control measure to function independently of other systems. C42: Tampering avoidance is the difficulty of intentionally disrupting the function of a control measure. C43: Interference avoidance refers to the restrictions a control measure may impose on the function of other control measures. C44: Flexibility indicates the degree to which a control measure may adopt to perform in different situations.

Weighting the criteria via Bayesian BWM

This stage of the approach we propose in this article involves determining the importance weights of the effective factors in prioritizing control measures with BBWM. Unlike the classic BWM, BBWM has some steps. These steps include formulations whose explicit codes are given in Mohammadi and Rezaei (2020a) and can be analyzed with Matlab. The process followed here is introduced step by step below.

Step 1 – Each decision-maker team member determines the best and worst criteria/sub-criteria based on their evaluation.
Step 2 – Each decision-maker team member compares the best criterion with the others and the others with the worst criterion pair wisely. The linguistic values used in the assessment here are taken from the scale in Rezaei (2015)'s study regarding traditional BWM.
Step 3 – The decision matrices obtained in the first two stages were combined into a single matrix and injected into the Matlab code, which they shared openly in Mohammadi and Rezaei (2020a).
Step 4 – The matrix of importance weight vectors, credal ranking graphs, and reliability probability values in credal ranking graphs of each criterion/sub-criteria are obtained. Here it is necessary to open a separate parenthesis on the credal ranking. This feature reveals the reliability probability of each criterion's superiority over the other and its superiority power.

Prioritizing the control measures via FVIKOR

Although there are different versions of the FVIKOR algorithm that vary from study to study (Rostamzadeh et al. 2015; Chang 2014; Girubha and Vinodh 2012; Opricovic 2011), this study presents the method proposed by Awasthi and Kannan (2016) since the crisp weight vector from

BBWM can be easily injected into this method. Many case studies have been applied before. In this method, first the concept of defuzzification is employed and then return to traditional VIKOR is followed. The steps of the method are as follows:

Step 1 – The decision-making team member evaluates each control measure according to the relevant criteria (these are as many as the number of sub-criteria given in "Criteria hierarchy affecting control measures" sub-section and 22 sub-criteria), considering the fuzzy triangular numbers presented in Table 3 and the corresponding linguistic variables. After these evaluations are collected, each decision-making team member's evaluation is defuzzified. This evaluation is named as decision matrix. It includes the ratings of a team member on control measures to each criterion (22 sub-criteria in "Criteria hierarchy affecting control measures" sub-section). The transformation of the fuzzy evaluations of each team member from fuzzy into crisp values is conducted by Eq. (1). A triangular fuzzy number $\tilde{x}_{ij} = \left(x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u}\right)$ can be converted by Eq. (1):

$$x_{ij} = \frac{x_{ij}^{l} + 4x_{ij}^{m} + x_{ij}^{u}}{6} \tag{1}$$

Here, while $\tilde{x}_{ij}$ defines a triangular fuzzy number, its defuzzified version is demonstrated as x_{ij}. Moreover, x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u} refer to the lower, medium and upper value of a triangular fuzzy number, respectively.

Step 2 – The best and worst values of all criteria ratings $(j = 1, 2, \ldots, n)$ and control measures $(i = 1, 2, \ldots, m)$ are determined using Eqs. (2)-(3).

Table 3 Linguistic terms and corresponding triangular fuzzy values (Chen 2000)

Linguistic variable	Triangular fuzzy number $\tilde{x}_{ij} = \left(x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u}\right)$
Negligible	(0,0,1)
Very low	(0,1,2)
Low	(1,2,3)
Medium low	(2,3,4)
Medium	(3,4,5)
Medium high	(4,5,6)
High	(5,6,7)
Very high	(6,7,8)
Absolutely high	(7,8,9)
Maximum	(8,9,9)

$$f_j^{*} = \max_i\{x_{ij}\}; f_j^{-} = \min_i\{x_{ij}\}(\text{benefit criteria}) \tag{2}$$

$$f_j^{*} = \min_i\{x_{ij}\}; f_j^{-} = \max_i\{x_{ij}\}(\text{cost criteria}) \tag{3}$$

Step 3 – The values of S_i and R_i are calculated using Eqs. (4)-(5). These values represent two of the three different ranking values (utility measure and regret) specific to the VIKOR method. The solution obtained by minimum S_i is with a maximum group utility ("majority" rule), and the solution obtained by minimum R_i is with a minimum individual regret of the "opponent."

$$S_i = \sum_{j=1}^{n} w_j \frac{f_j^{*} - x_{ij}}{f_j^{*} - f_j^{-}} \tag{4}$$

$$R_i = \max_j \; w_j \frac{f_j^{*} - x_{ij}}{f_j^{*} - f_j^{-}} \tag{5}$$

Step 4 – The Q_i values are calculated using Eq. (6). It is defined as core ranking index (aggregating index) and represents the third of three different VIKOR indices.

$$Q_i = v\frac{S_i - S^{*}}{S^{-} - S^{*}} + (1 - v)\frac{R_i - R^{*}}{R^{-} - R^{*}} \tag{6}$$

where $S^{*} = \min_i S_i; S^{-} = \max_i S_i; R^{*} = \min_i R_i; R^{-} = \max_i R_i$. Moreover, v is the weight for the strategy of maximum group utility, and $1 - v$ is the weight of the individual regret.

Step 5 – Alternatives are ranked by sorting the values S, R, and Q in ascending order.

Step 6 – As a compromise solution, the alternative that is the best ranked by the measure Q (minimum) is proposed if the two conditions (acceptable advantage and acceptable stability in decision making) are satisfied (Awasthi and Kannan 2016; Rostamzadeh et al. 2015; Chang 2014; Girubha and Vinodh 2012; Opricovic 2011).

Application results of the methodology

System description

Oil stations sell fuel for road motor vehicles and are usually located at points adjacent to highways. Fuel dispensers fill gasoline, diesel, compressed natural gas, CGH2, HCNG, LPG, liquid hydrogen, kerosene, alcohol fuel (methanol, ethanol, butanol, propanol), biofuels (such as straight vegetable oil, biodiesel), or others into fuel tanks inside vehicles. They then calculate the financial cost of the fuel transferred to the vehicle. These stations also have mini-type markets. They typically sell confectionery, alcoholic beverages, tobacco

products, lottery tickets, soft drinks, snacks, coffee, newspapers, magazines and, in some cases, small grocery items such as milk. A typical overview of an oil station with its components is shown in Fig. 3. Although these facilities are small in terms of volume, many dangers and risks arise from them because the process and the transported substance are dangerous goods. There are many risks in titles such as offices, add-ons, electrical panels, material stacking, electrical maintenance repair, dispensers, liquid fuel tanks, LPG tanks, traffic in the station area, lighting, first-aid, and emergency activities. Of course, the most sensitive of these is the risks related to the liquid fuel tank area. Therefore, the main focus of this study has been determined as this area.

Results of traditional Fine – Kinney application

Before applying the proposed approach in this study, it will be useful to show the traditional Fine – Kinney application and its results. Therefore, we first present the risk assessment for the liquid fuel tank site within the scope of the study.



Fig. 3 Demonstration of an oil station with its components

Ten different sources of danger and risk have been identified and Table 4 expresses these together with their codes. Then, risk assessment was carried out using the evaluation scales of the three parameters of the traditional Fine – Kinney method. Table 5 presents the results of the risk assessment performed. Among these results, at least one control measure for every ten hazards, initial risk value calculation, and residual risk calculation after control measure, who is affected by these risks and what the current situation, is being stated. As a result of the risk assessment, it was recommended to use ten different control measures. However, in the real world, taking action for all these measures at the same time can be difficult considering time, money, and resource constraints. In this case, it is necessary to prioritize these emerging control measures. The following two sub-sections contain the results obtained by applying the proposed approach in this context.

Results of BBWM application

For the BBWM application, evaluations of 24 decision-making team members have been used to determine criteria/sub-criteria weights identified in Fig. 2. In each evaluation, a form has been used. Decision making team consists of the personnel working in the field who contributed to the study during the determination of the criteria and the calculation of the weights of each criterion. All of the evaluators are authorized personnel at the oil stations. It is user-friendly and includes brief examples of how each decision-making team member can make the pairwise comparisons according to the BBWM logic. The group has filled this form, consisting of gas station employees and employers operating in Antalya, and inputs have been collected for BBWM. These inputs are then transformed into a total of five decision matrices (one is regarding the main criteria, and the other four are on the sub-criteria) and solved in Matlab. The criteria weights and credal ranking graphs obtained are shown in

Table 4 Descriptions of the risks emerged in the area of the liquid fuel tank

Code	Hazard description
HAZ1	Formation of an explosive atmosphere as a result of the accumulation of gas coming out of liquid fuel tanks in certain areas
HAZ2	Check the levels of liquid fuel tanks visually
HAZ3	Lack of periodic checks of the ventilation systems of liquid fuel tanks
HAZ4	Entering liquid fuel tanks without making the necessary measurements
HAZ5	Overfilling of liquid fuel tanks
HAZ6	Failure of regular and emergency ventilation system when liquid fuel is filled
HAZ7	Fuel leakage as a result of not being protected against corrosion (rusting) after the location and placement of the liquid fuel tank
HAZ8	No grounding to get rid of static electricity accumulations during filling
HAZ9	Explosion as a result of the tank being exposed to sparks
HAZ10	Sniffing the gas emitted as a result of opening the fuel tank

Table 5 Results of traditional Fine – Kinney application for the liquid fuel tank area in the oil station.

Hazard	Risk	Who affected?	Initial risk calculation			
			Probability	Exposure	Consequence	Risk degree
HAZ1	Fire, Explosion	All Employees	3	3	100	900
HAZ2	Explosion, Poisoning	All Employees	3	3	40	360
HAZ3	Explosion, Poisoning	All Employees	3	1	40	120
HAZ4	Explosion, Poisoning	All Employees	3	1	40	120
HAZ5	Fire, Explosion	All Employees	3	1	40	120
HAZ6	Explosion, Poisoning	All Employees	3	1	40	120
HAZ7	Fire, Explosion	All Employees	3	1	40	120
HAZ8	Fire, Explosion	All Employees	3	1	40	120
HAZ9	Fire, Explosion	All Employees	3	1	40	120
HAZ10	Occupational disease, Poisoning	All Employees	3	1	40	120
Hazard	**Control measures to be implemented**	**Current situation**	**Final risk calculation (Residual risk analysis)**			
			Probability	Exposure	Consequence	Risk degree
HAZ1	CM1: Any duct or sewer entrance, etc., may cause gas accumulation in the tank area and near the dispenser. absence of pits; yellow line marking of entry and exit and vehicle roads; placing speed limit warning signs	There are no pits to cause gas accumulation.	1	1	40	40
HAZ2	CM2: Level controls of liquid fuel tanks by authorized persons with automatic measuring devices	Level determination is made by authorized persons and electronic systems.	1	1	40	40
HAZ3	CM3: Periodic checking of the ventilation device	Periodic checks are carried out at regular intervals.	0.5	1	40	20
HAZ4	CM4: Cleaning of tanks by authorized personnel by the main company	The tanks are cleaned by the authorized personnel of the main company.	0.5	1	40	20
HAZ5	CM5: Max. filling below capacity	Maximum being filled below capacity.	0.5	1	40	20
HAZ6	CM6: Necessary controls of the liquid fuel tank system by authorized personnel and meeting the necessary standards (TS 12820- TS 11939)	Periodic checks are made.	0.5	1	40	20
HAZ7	CM7: Carrying out cathode protection by periodically checking the tanks once a year.	Periodic checks are made.	0.5	1	40	20
HAZ8	CM8: Filling by the filling instruction	There is a refill Instruction.	0.5	1	40	20
HAZ9	CM9: Ex proof of the tank assembly	Tank assembly is explosion protected.	0.5	1	40	20
HAZ10	CM10: Controlled opening of the fuel tank by authorized personnel and training of the personnel on the subject	It is opened by authorized personnel.	0.5	1	40	20

Fig. 4. Figure 4 shows the credal ranking of main criteria and sub-criteria sets, which shows the degree of certainty about the relations of main and sub-criteria. For instance, according to Fig. 4(b), range (C13) sub-criterion is certainly more important than the response time (C15) sub-criterion with the confidence of 1. It is more desirable than sub-criterion accuracy C12 with the confidence of 0.97. According to the results obtained from the evaluations of the decision-making group, the criterion with the highest importance among the main criteria is C2, the applicability criterion. It has a significant level of about 42%. It was followed by C1 (performance) with 31%, C3 (functionality) with 18% and C4 (integrity) with 10%, respectively. As for the sub-criteria, the criteria with the highest and lowest importance are as follows: Among the sub-criteria under the performance criterion, the highest priority was C14 (efficiency) with approximately 31%, while the lowest priority sub-criterion was C15 (response time) with 9%. Among the sub-criteria under the applicability criterion, the highest priority was C21 (total cost) with approximately 36%, while the lowest priority sub-criterion was C22 (feasibility of implementation) with 9%. Among the sub-criteria under the functionality criterion, the highest priority was C33 (failure tolerance) with approximately 34%, while the lowest priority sub-criterion was C31 (reliability) with 10%. Among the sub-criteria under the integrity criterion, the highest priority was C44 (flexibility) with approximately 52%, while the lowest priority sub-criterion was C41 (independency) with 11%.

The local criterion weight values obtained here should be converted to global weights in the next section, where the priorities of Fine – Kinney control measures are determined. In this context, global criteria weights are given in Fig. 5.

Results of FVIKOR application

The first step of the FVIKOR implementation phase is for each decision-maker team member to evaluate the ten control measures (CMs) according to 22 sub-criteria considering the triangular fuzzy numbers and their corresponding linguistic variables given in Table 3. Then, all of these evaluations have aggregated by taking the arithmetic average. We have added each decision maker's evaluation as a Supplementary material to the paper. Readers can access it from there. The aggregated decision matrix obtained has been subjected to defuzzification. Equation (1) is used for this operation. The results obtained are given in Table 6. Then, using Eqs. (2) and (3), the best and worst values have been obtained. Another point to note here is that the sub-criteria C15, C16, C21, C26, C41, C42, and C43 are cost criteria, while the others are benefit criteria. Finally, the S, R, and Q values are given in Eqs. (4–6) are calculated. These results are also given in Table 7. According to the results by FVIKOR, "CM3: Periodic checking of the ventilation device" has the lowest Q value (0.060). It is followed by "CM1: The absence of any ducts or sewer pits that may cause gas accumulation in the tank area and

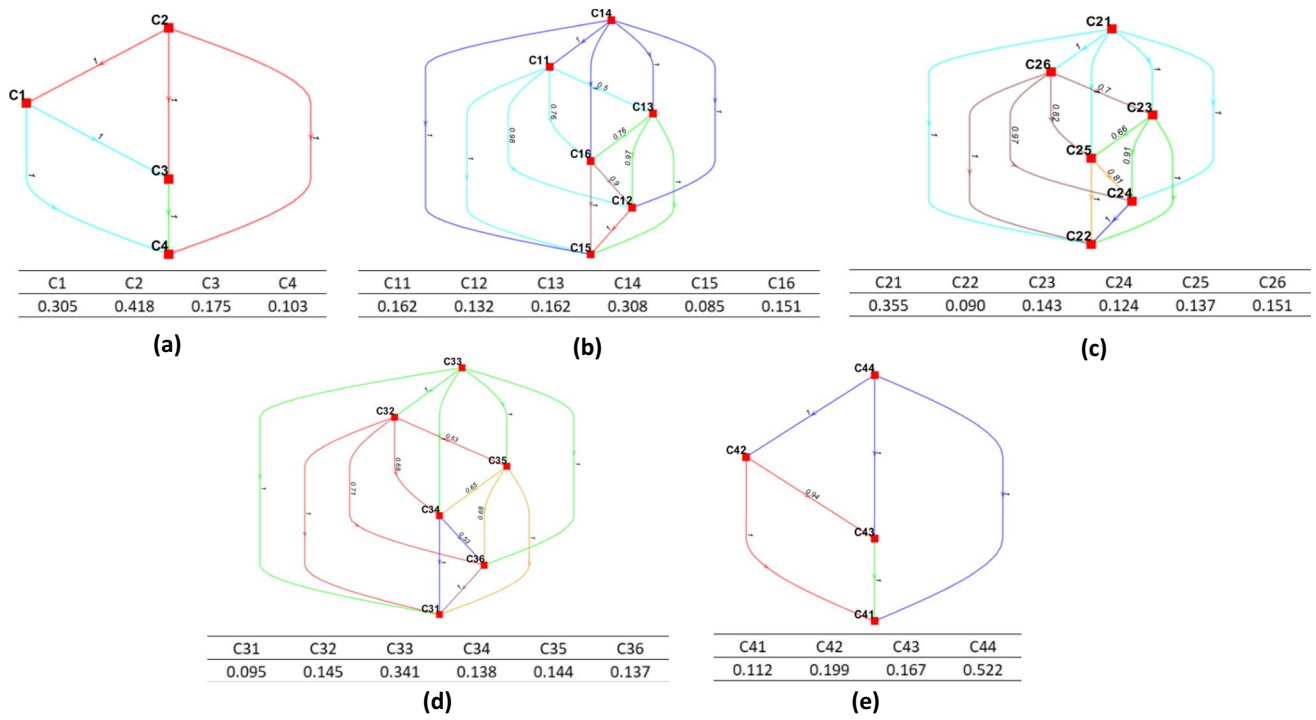


Fig. 4 Credal ranking graphs with weight values of **a** the main criteria, **b** performance sub-criteria, **c** applicability sub-criteria, **d** functionality sub-criteria, and **e** integrity sub-criteria

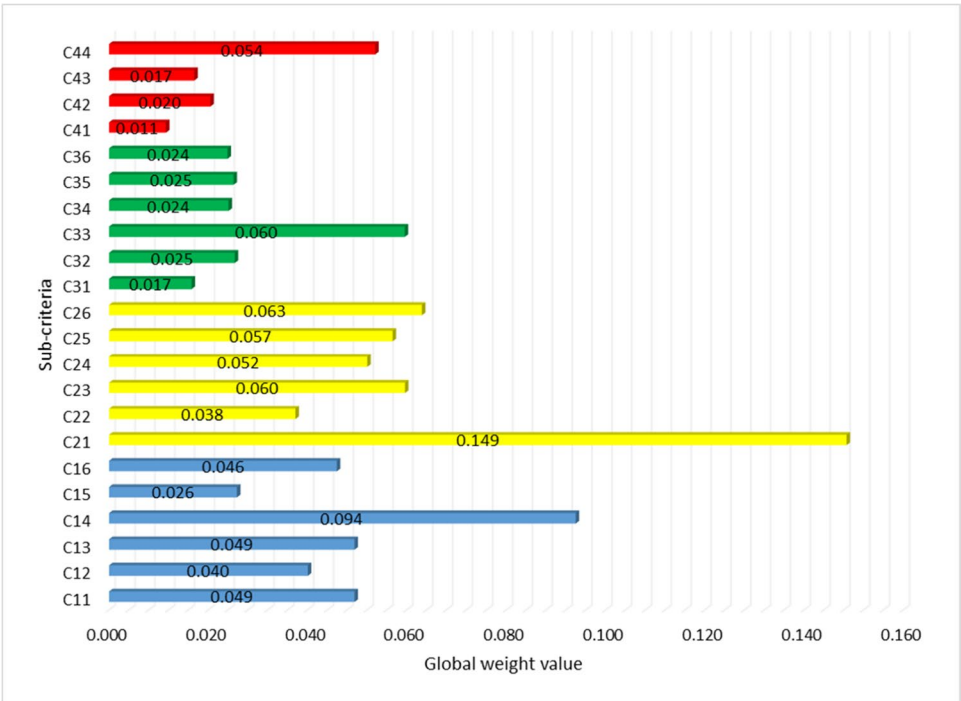


Fig. 5 Global weights for the twenty-two sub-criteria

near the dispenser; yellow line marking of entry and exit and vehicle roads; placing of speed limit warning signs" and "CM4: Cleaning of tanks by authorized personnel by the main company" with their Q values of 0.094 and 0.111, respectively. Ranking in the same order as the Q indices according to the S and R indices is CM7, and it is in the sixth rank according to the size of all three indices. In addition, CM3 with the lowest Q value also has the lowest value

Table 6 Aggregated evaluations of decision-maker team on control measures (CMs) for the 22 sub-criteria

CMs	Sub-criteria																					
	C11	C12	C13	C14	C15	C16	C21	C22	C23	C24	C25	C26	C31	C32	C33	C34	C35	C36	C41	C42	C43	C44
CM1	6.20	5.80	5.67	7.00	5.60	6.00	2.60	5.60	4.80	6.00	5.20	4.80	4.40	4.40	4.20	6.00	5.20	5.20	5.80	4.60	4.40	5.80
CM2	6.00	7.00	6.00	6.00	2.00	7.00	6.00	6.00	5.00	6.00	6.00	2.00	7.00	7.00	2.00	6.00	7.00	6.00	6.00	6.00	5.00	5.80
CM3	6.20	6.00	5.40	6.00	5.40	5.00	2.00	5.40	6.00	6.00	6.00	5.60	5.00	5.40	5.40	5.60	6.00	6.00	6.00	5.60	5.00	5.80
CM4	6.00	6.00	6.00	6.00	5.60	5.40	3.60	6.00	6.00	6.00	6.00	4.60	5.60	5.60	5.20	4.60	6.00	6.00	6.00	3.40	3.20	3.20
CM5	2.20	4.20	4.00	3.80	4.00	4.00	2.80	4.00	2.80	4.00	4.00	4.00	4.20	4.00	4.00	4.00	4.00	2.40	4.00	4.00	4.00	4.20
CM6	6.00	6.00	6.00	6.00	5.60	5.00	6.00	6.00	6.00	6.00	4.80	6.00	6.00	6.00	4.00	6.00	6.00	5.80	6.00	2.00	6.00	6.00
CM7	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.20	6.00	4.00	6.00	6.00	5.00	5.00	6.00	6.00	6.00	2.20	2.00	2.00
CM8	8.83	8.67	8.67	8.83	5.00	7.00	6.00	6.00	6.00	6.00	4.00	6.00	6.00	8.83	1.00	6.00	6.00	5.80	5.60	2.00	2.20	2.00
CM9	8.67	8.83	8.67	8.67	6.00	7.00	7.00	6.00	6.00	6.00	6.00	5.00	6.00	6.00	1.00	6.00	6.00	6.00	5.80	2.20	2.00	2.00
CM10	6.00	6.00	6.00	6.00	5.00	6.00	5.00	6.00	6.00	6.20	6.00	6.00	6.00	6.00	1.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00

Table 7 Final FVIKOR scores (S, R, and Q) of each control measures

Control measure (CM)	S	R	$Q(v=0.5)$
CM1	0.397	0.044	0.094
CM2	0.409	0.119	0.470
CM3	0.330	0.057	0.060
CM4	0.379	0.053	0.111
CM5	0.684	0.094	0.738
CM6	0.464	0.119	0.547
CM7	0.446	0.119	0.522
CM8	0.449	0.119	0.526
CM9	0.430	0.149	0.641
CM10	0.467	0.089	0.408

in the S index (0.330), while it ranks third with a value of 0.057 in the R index.

After the FVIKOR application, whether two conditions are fulfilled have been checked. If the first condition is met, the second is checked. If the second condition is not met, the first two alternatives are best; all Q_i alternatives are indifferent if the difference of the last and first is less than $\frac{1}{M-1}$. Here M represents the number of alternatives, which in our problem is 10. By Q_i values, the best ranked is CM3 and the second ranked is CM1. In case of $v=0.5$; $Q(\text{CM1})-Q(\text{CM3})$ equal to $0.094-0.060=0.034$ which is less than $1/(10-1)=0.11$. The first condition is not met even if CM3 is the best ranked by S_i value. In this case, when the controls are made, it is seen that there is no superiority between the two best options (CM3 and CM1 control measures) in terms of ranking. If picking up CM1, CM3, and CM4, the difference is $0.051=0.111-0.060$. So, it does not meet the first condition, and the three control measures were considered indifferent.

On a different track, if we increase the maximum group utility parameter (parameter v), for example, when we set a value of $v=1$ or so close to 1; two of the FVIKOR conditions regarding compromise solution are also met. That is, the difference between the 1st and 2nd order control measures with the lowest Q value under $v=1$ setting becomes $Q(\text{CM3})-Q(\text{CM4})=0.14-0.00=0.14\geq 0.11$ and it satisfies the first condition. At the same time, since CM3 is in the first place according to the S index, the second condition is also met. In this case, CM3 becomes the top priority control measure.

Practical implications

After applying the BBWM-FVIKOR combined approach in a petrol station has been carried out for the liquid fuel tank area, the obtained results have important implications for the liquid fuel tank area and filling process of the petrol stations.

The first of these is that there are critical risks such as explosion and poisoning due to the lack of periodic controls of the ventilation systems of the liquid fuel tanks and the periodic control of the ventilation device against this. Ventilation equipment and controls play a critical role in fuel derivatives and filling processes (Srinivasan et al. 2006). Poor ventilation environment and failure to control the devices have serious risks, and periodical controls are at the forefront of the issues that should be given priority (Corvaro et al. 2016; Chandrasekaran 2016).

The second significant risk is that the gas coming out of the liquid fuel tanks creates an explosive atmosphere as a result of accumulation in certain areas. Control measures to be taken against this: "There are no channels or sewer entrance pits around the tank area, yellow line signs of entrance and exit and vehicle roads, speed limit warning signs are placed." As a result of a gas accumulation from liquid fuel tanks, it has serious risks that may cause mass deaths and injuries such as fire and explosion. It is important to minimize this risk that there are no warning signs, markings, channels, or sewer pits in the physical conditions of the working environment. (Evans 2009; Akyuz and Celik 2015).

Table 8 Results of comparative study

Control measure (CM)	This study (FVIKOR)		FTOPSIS (Tan et al. 2010)	
	Q value ($v=0.5$)	Rank	CC value	Rank
CM1	0.0944	2	0.0277	3
CM2	0.4696	5	0.0278	2
CM3	0.0604	1	0.0303	1
CM4	0.1112	3	0.0273	6
CM5	0.7385	10	0.0214	10
CM6	0.5471	8	0.0268	7
CM7	0.5217	6	0.0266	8
CM8	0.5261	7	0.0273	5
CM9	0.6415	9	0.0276	4
CM10	0.4083	4	0.0258	9

In the liquid fuel tank area, entering the liquid fuel tanks without making the necessary measurements carries risks such as fire and explosion, both for the personnel, the person, and the environment. At this point, the cleaning process must be controlled by authorized personnel who have knowledge and training on the subject. The cleaning process contributes to minimizing possible risks with a proactive approach. Authorized personnel should be selected from people familiar with the process and know the properties of the substance and material used (Sanpeng et al. 2010). Cleaning activities should also be supported with mechanical systems in large-scale enterprises (Wang and Yuan 2012).

The results obtained in our study, in which the measures to be taken in the liquid fuel tank area are evaluated and prioritized, marginally distinguishing the first three measures from other measures according to expert opinions. The inferences obtained by prioritizing the measures to be taken similar and control measures are presented.

Validation of the results

To prove the validity of the results obtained in the existed study, a comparison has been made with another MCDM method, FTOPSIS. In this context, Tan et al. (2010)'s FTOPSIS approach has been followed in the benchmarking study. The final closeness coefficient values of the FTOPSIS and the Q values of the FVIKOR ($v=0.5$) obtained in this study have been compared. The results are given in Table 8.

Conclusion

This study focuses on prioritizing control measures, which is an important problem that is not found in the risk assessment literature. First of all, the importance weights of the criteria affecting prioritization of the control measures recommended in the Fine – Kinney risk assessment have been determined by BBWM. BBWM has been preferred since it allows many decision-makers to combine their pairwise evaluations without loss of information and to show the relative importance levels of the criteria via credal ranking more transparently. Then, priorities of control measures have been determined with FVIKOR, an integrated MCDM method with fuzzy logic, since it better reflects uncertainty in expert evaluations, which is an important concept in risk assessment decisions. The proposed approach has been applied for the liquid fuel tank area, one of the most important activities in an oil station. Although the results produced by the proposed approach are close to the recommended and prioritized measures with the classical Fine – Kinney, it is seen that it produces a more robust order of control measures than the traditional method.

Although the application of the methodology has been demonstrated for a Fine – Kinney study, it can be applied to control measure selection problems of various methods (such as FMEA, decision matrix technique) in the context of risk assessment and management. However, the priority suggested by risk analysis methods may not always have the same order as in the taking action phase. In the real world, the measure's resource, budget, and cost/benefit ratio always affect this situation as a constraint. This proposed approach is expected to bring a new perspective to the work of occupational health and safety analysts and offers a solution to an important problem in risk assessment.

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Author contribution Muhammet Gul made the literature review, developed the theoretical formulation of BBWM-FVIKOR, performed the analytic calculations of BBWM and FVIKOR, and performed the numerical analysis. Melih Yucesan performed the analytic calculations of BBWM, performed the numerical analysis, and contributed to the final version of the manuscript. Muhammet Fatih Ak made the data collection and contributed to the analysis of the numerical results and final version of the manuscript.

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Declarations

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Consent to participate Not applicable.

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References

Abkenar ZA, Lajimi HF, Hamedi M, Parkouhi SV (2022) Determining the importance of barriers to IoT implementation using bayesian best-worst method. In: Rezaei J, Brunelli M, Mohammadi M (eds) Advances in Best-Worst Method. BWM 2021. Lecture Notes in Operations Research. Springer, Cham

Ak MF, Yucesan M, Gul M (2022) Occupational health, safety and environmental risk assessment in textile production industry through a Bayesian BWM-VIKOR approach. Stoch Env Res Risk Assess 36:629–642

Akyuz E, Celik E (2015) A fuzzy DEMATEL method to evaluate critical operational hazards during gas freeing process in crude oil tankers. J Loss Prev Process Ind 38:243–253

Alkan R, Yucesan M, Gul M (2022) A multiattribute decision-making to sustainable construction material selection: a bayesian BWM-SAW hybrid model. In: Rezaei J, Brunelli M, Mohammadi M (eds) Advances in Best-Worst Method. BWM 2021. Lecture Notes in Operations Research. Springer, Cham

Awasthi A, Kannan G (2016) Green supplier development program selection using NGT and VIKOR under fuzzy environment. Comput Ind Eng 91:100–108

Baladeh AE, Cheraghi M, Khakzad N (2019) A multi-objective model to optimal selection of safety measures in oil and gas facilities. Process Saf Environ Prot 125:71–82

Çalış Boyacı A, Selim A (2022) Assessment of occupational health and safety risks in a Turkish public hospital using a two-stage hesitant fuzzy linguistic approach. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-021-18191-x

Can GF, Toktas P (2021) An advanced stochastic risk assessment approach proposal based on KEMIRA-M, QFD and Fine-Kinney hybridization. Int J Inf Technol Decis Mak 20(1):431–468

Caputo AC, Pelagagge PM, Palumbo M (2011) Economic optimization of industrial safety measures using genetic algorithms. J Loss Prev Process Ind 24(5):541–551

Caputo AC, Pelagagge PM, Salini P (2013a) AHP-based methodology for selecting safety devices of industrial machinery. Saf Sci 53:202–218

Caputo AC, Pelagagge PM, Salini P (2013b) A multi-criteria knapsack approach to economic optimization of industrial safety measures. Saf Sci 51(1):354–360

Celik E, Yucesan M, Gul M (2021) Green supplier selection for textile industry: a case study using BWM-TODIM integration under interval type-2 fuzzy sets. Environ Sci Pollut Res 28(45):64793–64817

Chandrasekaran S (2016) Health, safety, and environmental management in offshore and petroleum engineering. John Wiley & Sons. https://doi.org/10.1002/9781119221449

Chang TH (2014) Fuzzy VIKOR method: a case study of the hospital service evaluation in Taiwan. Inf Sci 271:196–212

Chen CT (2000) Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy Sets Syst 114(1):1–9

Cheraghi M, Omidvar B, Eslami BAA, Jafari HR, Younesi AM (2018) Corrective actions selection in the safety risk management process using mathematical modeling. J Health Saf Work 8(3):283–298

Cheraghi M, Baladeh AE, Khakzad N (2022) Optimal selection of safety recommendations: a hybrid fuzzy multi-criteria decision-making approach to HAZOP. J Loss Prev Process Ind 74:104654

Çınar F, Solmaz MS, Çakmak E (2021) Evaluation of ship manoeuvres in port by using fuzzy Fine Kinney method. Int J Environ Geoinformatics 8(4):537–548

Corvaro F, Giacchetta G, Marchetti B, Recanati M (2016) Reliability, availability, maintainability (RAM) study, on reciprocating compressors API 618. Petroleum 3:1–7

Dagsuyu C, Oturakci M, Essiz ES (2020) A new Fine-Kinney method based on clustering approach. Int J Unc Fuzz Knowl Based Syst 28(03):497–512

Derse O (2021) A new approach to the Fine Kinney method with AHP based ELECTRE I and math model on risk assessment for natural disasters. J Geogr 42:155–164

Dogani A, Dourandish A, Ghorbani M (2020) Ranking of resilience indicators of mashhad plain to groundwater resources reduction by Bayesian Best-Worst Method. Water Irrig Manag 10(2):301–316

Erdoğan M, Kaya İ, Karaşan A, Çolak M (2021) Evaluation of autonomous vehicle driving systems for risk assessment based on three-dimensional uncertain linguistic variables. Appl Soft Comput 113:107934

Evans DJ (2009) A review of underground fuel storage events and putting risk into perspective with other areas of the energy supply chain. Geol Soc Spec Publ 313:173–216

Feizizadeh B, Omarzadeh D, Ronagh Z, Sharifi A, Blaschke T, Lakes T (2021) A scenario-based approach for urban water management in the context of the COVID-19 pandemic and a case study for the Tabriz metropolitan area. Iran. Sci Total Environ 790:148272

Fine WT (1971) Mathematical evaluations for controlling hazards. J Safety Res 3(4):157–166

Girubha RJ, Vinodh S (2012) Application of fuzzy VIKOR and environmental impact analysis for material selection of an automotive component. Mater Des 37:478–486

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, Celik E (2018) Fuzzy rule-based Fine-Kinney risk assessment approach for rail transportation systems. Hum Ecol Risk Assess Int J 24(7):1786–1812

Gul M, Yucesan M (2021) Performance evaluation of Turkish Universities by an integrated Bayesian BWM-TOPSIS model. Socio-Economic Planning Sciences. https://doi.org/10.1016/j.seps.2021.101173

Gul M, Ak MF, Guneri AF (2019) Pythagorean fuzzy VIKOR-based approach for safety risk assessment in mine industry. J Safety Res 69:135–153

Gul M, Celik E, Aydin N, Gumus AT, Guneri AF (2016) A state of the art literature review of VIKOR and its fuzzy extensions on applications. Appl Soft Comput 46:60–89

Gul M, Guven B, Guneri AF (2018) A new Fine-Kinney-based risk assessment framework using FAHP-FVIKOR incorporation. J Loss Prev Process Ind 53:3–16

Gul M, Mete S, Serin F, Celik E (2021a) Fine–Kinney occupational risk assessment method and its extensions by fuzzy sets: a state-of-the-art review. In: Fine–Kinney- based fuzzy multi-criteria occupational risk assessment. Studies in Fuzziness and Soft Computing, vol 398. Springer, Cham. https://doi.org/10.1007/978-3-030-52148-6_1

Gul M, Mete S, Serin F, Celik E (2021b) Fine–Kinney-based fuzzy multicriteria occupational risk assessment, vol 398. Springer, Springer Nature Cham, Switzerland. https://doi.org/10.1007/978-3-030-52148-6

Guo J, Lin Z, Zu L, Chen J (2019) Failure modes and effects analysis for CO 2 transmission pipelines using a hesitant fuzzy VIKOR method. Soft Comput 23(20):10321–10338

Hollnagel E (2008) Risk+ barriers= safety? Saf Sci 46(2):221–229

Hsu WCJ, Lo HW, Yang CC (2021) The formulation of epidemic prevention work of COVID-19 for colleges and universities: priorities and recommendations. Sustainability 13(4):2081

Huang CN, Liou JJ, Lo HW, Chang FJ (2021) Building an assessment model for measuring airport resilience. J Air Transp Manag 95:102101

Kelly R, Ghadimi P, Wang C (2022) Barriers to closed-loop supply chains implementation in Irish Medical Device Manufacturers: Bayesian best–worst method analysis. In: Ghadimi P, Gilchrist MD, Xu M (eds) Role of Circular Economy in Resource Sustainability. Sustainable Production, Life Cycle Engineering and Management. Springer, Cham. https://doi.org/10.1007/978-3-030-90217-9_5

Kinney GF, Wiruth AD (1976) Practical risk analysis for safety management. Naval Weapons Center China Lake CA, USA, pp 1–20

Kokangül A, Polat U, Dağsuyu C (2017) A new approximation for risk assessment using the AHP and Fine Kinney methodologies. Saf Sci 91:24–32

Kotek L, Tabas M (2012) HAZOP study with qualitative risk analysis for prioritization of corrective and preventive actions. Procedia Eng 42:808–815

Kuleshov VV, Skuba PY, Ignatovich IA (2021) Assessment of the severity of the last accident based on the Fine-Kinney Method. In: IOP Conference Series: Earth and Environmental Science, Vol. 720, No. 1. IOP Publishing, p 012094

Li L, Wang X, Rezaei J (2020) A Bayesian best-worst method-based multicriteria competence analysis of crowdsourcing delivery personnel. Complexity 2020:17. https://doi.org/10.1155/2020/4250417

Liang M, Li W, Ji J, Zhou Z, Zhao Y, Zhao H, Guo S (2022) Evaluating the Comprehensive Performance of 5G Base Station: A Hybrid MCDM Model Based on Bayesian Best-Worst Method and DQ-GRA Technique. Math Probl Eng 2022:15. https://doi.org/10.1155/2022/4038369

Liu HC (2016) FMEA using uncertainty theories and MCDM methods. In FMEA using uncertainty theories and MCDM methods. Springer, Singapore, pp 13–27

Liu P, Hendalianpour A, Hamzehlou M, Feylizadeh MR, Razmi J (2021) Identify and rank the challenges of implementing sustainable supply chain blockchain technology using the Bayesian best worst method. Technol Econ Dev Econ 27(3):656–680

Marhavilas PK, Filippidis M, Koulinas GK, Koulouriotis DE (2020) An expanded HAZOP-study with fuzzy-AHP (XPA-HAZOP technique): application in a sour crude-oil processing plant. Saf Sci 124:104590

Mete S, Serin F, Oz NE, Gul M (2019) A decision-support system based on Pythagorean fuzzy VIKOR for occupational risk assessment of a natural gas pipeline construction. J Nat Gas Sci Eng 71:102979

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

Mohammadi M, Rezaei J (2020b) Evaluating and comparing ontology alignment systems: an MCDM approach. J Web Semant 64:100592

Mohsen O, Fereshteh N (2017) An extended VIKOR method based on entropy measure for the failure modes risk assessment–A case study of the geothermal power plant (GPP). Saf Sci 92:160–172

Moore DA (1997) The use of a ranking matrix and recommendation prioritization system for process hazard analysis studies. Process Saf Prog 16(2):83–85

Munim ZH, Mohammadi M, Shakil MH and Ali SM (2022) Assessing measures implemented by export-oriented RMG firms in an emerging economy during COVID-19. Comput Ind Eng 165:107963

Omarzadeh D, Pourmoradian S, Feizizadeh B, Khallaghi H, Sharifi A, Kamran KV (2022) A GIS-based multiple ecotourism sustainability assessment of West Azerbaijan province, Iran. J Environ Plan Manag 65(3):490–513

Opricović S (1998) VIKOR method. In: Praščević Ž (ed) Multicriteria optimization of civil engineering systems. University of Belgrade - Faculty of Civil Engineering, Belgrade, pp 142–175 (in serbian)

Opricovic S (2011) Fuzzy VIKOR with an application to water resources planning. Expert Syst Appl 38(10):12983–12990

Ramavandi B, Darabi AH, Omidvar M (2021) Risk assessment of hot and humid environments through an integrated fuzzy AHP-VIKOR method. Stoch Environ Res Risk Assess 35(12):2425–2438

Rathore R, Thakkar JJ, Jha JK (2021) Evaluation of risks in foodgrains supply chain using failure mode effect analysis and fuzzy VIKOR. Int J Qual Reliab Manag 38(2):551–580. https://doi.org/10.1108/IJQRM-02-2019-0070

Rausand M (2013) Risk assessment: theory, methods, and applications (Vol. 115). John Wiley & Sons

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

Rostamzadeh R, Govindan K, Esmaeili A, Sabaghi M (2015) Application of fuzzy VIKOR for evaluation of green supply chain management practices. Ecol Ind 49:188–203

Samanlioglu F (2019) Evaluation of influenza intervention strategies in Turkey with fuzzy AHP-VIKOR. J Healthc Eng 2019:9. https://doi.org/10.1155/2019/9486070

Sanpeng D, Xiaoli X, Chongning L, Xinghui Z (2010) Research on the oil tank sludge cleaning robot system. In: 2010 International Conference on Mechanic Automation and Control Engineering. IEEE, pp 5938–5942. https://doi.org/10.1109/MACE.2010.5536657

Srinivasan G, Kumar KVS, Rajendran B, Ramalingam PV (2006) The fast breeder test reactor - Design and operating experiences. Nucl Eng Des 236:796–811

Tan YT, Shen LY, Langston C, Liu Y (2010) Construction project selection using fuzzy TOPSIS approach. J Model Manag 5(3):302–315. https://doi.org/10.1108/17465661011092669

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. Hum Ecol Risk Assess 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

Tusher HM, Munim ZH, Notteboom TE, Kim TE, Nazir S (2022) Cyber security risk assessment in autonomous shipping. Marit Econ Logist. https://doi.org/10.1057/s41278-022-00214-0

Wang AJ, Yuan H (2012) Application of cows crude oil tank cleaning technology in Tuha oil field. Pipeline Techn Equip 5

Wang W, Liu X, Qin Y (2018) A fuzzy Fine-Kinney-based risk evaluation approach with extended MULTIMOORA method based on Choquet integral. Comput Ind Eng 125:111–123

Wang W, Ding L, Liu X, Liu S (2022a) An interval 2-Tuple linguistic Fine-Kinney model for risk analysis based on extended ORESTE method with cumulative prospect theory. Inf Fusion 78:40–56

Wang W, Jiang W, Han X, Liu S (2022b) An extended gained and lost dominance score method based risk prioritization for Fine-Kinney model with interval type-2 fuzzy information. Hum Ecol Risk Assess Int J 28(1):154–183

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

Yanilmaz S, Baskak D, Yucesan M, Gul M (2021) Extension of FEMA and SMUG models with Bayesian best-worst method

for disaster risk reduction. International J Disaster Risk Reduction 66:102631

Yucesan M, Gul M, Celik E (2021) A holistic FMEA approach by fuzzy-based Bayesian network and best–worst method. Complex Intell Syst 7(3):1547–1564

Zhang X, Xing X, Xie Y, Zhang Y, Xing Z, Luo X (2020) Airport operation situation risk assessment: combination method based on FAHP and Fine Kinney. ICTE 2019. American Society of Civil Engineers, Reston, pp 436–447

Zhu J, Wang R, Li Y (2019) Risk assessment of subway train door system based on Fine-Kinney and TODIM. China Saf Sci J 29(10):167

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