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Improving the Identification and Prioritization of the Most Important Risks of Safety Equipment in FMEA with a Hybrid Multiple Criteria Decision-Making Technique

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Abstract

The purpose of this paper is to develop a new Failure Mode and Effect Analysis (FMEA) framework for identification, prioritization and improvement of failure modes. A hybrid Multiple Criteria Decision-Making (MCDM) method combining Stepwise Weight Assessment Ratio Analysis (SWARA) and VlseKriterijumska optimizacija I KOm-promisno Resenje (VIKOR) is used to rank the risk of failure modes identified in FMEA. For this purpose, the SWARA method is utilized to obtain the influential weights and then VIKOR technique is employed to give the prioritization levels for the failure modes in safety equipment. A case study of a gas company in Lorestan Province of Iran is provided to illustrate the potential application and benefits of the proposed FMEA approach. The obtained results show that the new risk priority model can be effective to find high risk failure modes and create suitable maintenance strategies. The proposed FMEA also can overcome the shortcomings, improve the effectiveness of the traditional FMEA and provide useful information to help in managing risks of safety equipment.

Keywords: Safety, Risk, Failure Modes and Effect Analysis (FMEA), Risk Priority Number (RPN), VIKOR technique, SWARA technique.

1 | Introduction

In the process industries such as the gas, oil, and petrochemical industries and power plants, the reliability of data, including failure of the equipment and the sequence of these events, is of substantial importance for securing system availability and production continuity [1]. The necessity of improving safety has always been realized whenever the lack of safety has led to the emergence of conditions with unpleasant social or economic consequences [2]. On one hand, the growth of industries and populations have increased potential risks, financial losses, and casualties more than ever. On the other hand, the flaws in the safety regulations and the enforcement of these regulations, the lack of satisfactory supervision and control, and, above all, the failure to consider safety considerations in designing processes and human errors have been the major causes of various irreversible accidents.

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As a result of all the mentioned factors and the importance of human safety and health, safety is considered a determinant in all phases of design, construction, and operation. Hence, different hazard analysis methods have been invented to identify the risk potential prior to the operations and to reduce the severity of possible consequences following an incident [3]. Risk assessment and prioritization form one of the most classic and scientific methods of simplification of the hazard potentials with a risk management approach. The Health, Safety and the Environment (HSE) notions have influenced different dimensions of the industrial, production, educational, and health safety, and workplace research processes. Risk assessment forms the basis for the management of the health, security, and environment of the personnel supervised by any manager [4]. The advancement of technologies for the oil and gas industries has also led to an increased level of equipment safety. However, the new equipment is not risk-free and these risks are accompanied by human errors. If an industry is connected to a large number of humans, the role of human errors becomes more substantial. Therefore, the identification and management of the risks in this industry are of significant importance given the extensive activities conducted by the National Iranian Gas Company and the provisional gas companies scattered all over Iran, and also considering the people's interaction with this industry [5]. Considering the importance of identification and prioritization of the main risks of safety installations, many methods have been introduced to carry out these tasks. The Failure Mode and Effect Analysis (FMEA) method is one of the main techniques used to identify and analyze relevant risks that can help us to improve the safety indicators of a given system. This technique is essentially used for qualitative analysis, which examines the systems or subsystems to identify the probable faults of system constituents and tries to evaluate the effects of probable faults on other components of the system. Despite the widespread use of this method, it has some major faults that pose some limitations on the use of this method especially when the goal is to identify main critical risks. The major limitations are summarized as follows [6]:

- *The combination of different risk factors can lead to the same number of priorities, while the nature of imposed risks is different.*
- *It is often difficult to exactly determine risk factors.*
- *The computational formula of risk factors is uncertain and without a strong scientific basis.*

Accordingly, this paper sought to improve the prioritization and identification of the highly hazardous risks in the gas industry using a hybrid Multiple Criteria Decision Making (MCDM) in order to remove the above-mentioned limitations. It is in line with the main purpose of the present paper, that is, identifying the safety risks of gas stations and prioritizing them to help reduce the losses and to manage the risks effectively.

2 | Theoretical Basics and Literature Review

In this section, the basic concepts including traditional FMEA method and its applications are reviewed in the oil and gas industry.

2.1 | The Traditional Failure Modes and Effects Analysis (FMEA)

An operational team consisting of the domain specialists should be formed in order to analyze FMA of a process because FMEA can be most effective when it is carried out by a team. If FMA is analyzed by a group rather than an individual, it will be more likely to identify potential faults. Thus, the scholars are recommended to analyze FMA by a team. FMEA is generally a preventive and completely mental method that entails predicting the errors and providing the method to prevent the errors. This prediction is made by the specialists about the process [6].

FMEA team often use the information collected about the performance of the previous generation of a plan to identify potential risks and the effects and causes creating the risks. If such information is not available, the information and experiences of the team are employed to do it. The proper implementation of FMEA will have effective results for identification of the risk. The next step is the critical analysis of the identified risks while taking into account the risk factors of Occurrence (O), Severity (S) and Detection (D). The main purpose of FMEA is to allow the analyzers to prioritize the failure modes of a system, design, process, product or services to allocate the limited resources to risky items. Traditionally, the prioritization of the failure modes in the FMEA is determined through Risk Priority Number (RPN) determined as the coefficient of risk factors D, S, and O for each risk [7]:

$$RPN = O \times S \times D, \quad (1)$$

Where O stands for likelihood of occurrence, S shows risk severity, D indicates likelihood of detection, and RPN represents risk priority number. The three risk factors are evaluated using a 10-point scale and the results are presented in *Tables 1*, *2* and *3,* respectively. Considering the results of RPN, it is now possible to rank the failure modes and then to take proper actions as for the high priority risks in order of priority grade. Risks priority number should be calculated again after correction to see whether or not the risks have been decreased. Also, the efficiency of the modifying action has been examined for each mode. Accordingly, it can be concluded that FMEA is a changing evidence that changes constantly with the aim of providing better services. In order to implement FMEA method, the main process of FMEA can be divided into several steps as shown in *Fig. 1*.

Table 1. Occurrence score to identify risks in FMEA [6] and [8].

Ranking	Probability of Failure	Possible Failure Rate
10	Extremely High	≥1 in 2
9	Very High	1 in 3
8	Repeated Failures	1 in 8
7	High	1 in 20
6	Moderately High	1 in 80
5	Moderate	1 in 400
4	Relatively Low	1 in 2000
3	Low	1 in 15,000
2	Remote	1 in 150,000
1	Nearly Impossible	≤1 in 1,500,000

Table 2. Detection score to identify risks in FMEA [6] and [8].

Ranking	Probability of Failure
10	Absolute Uncertainty
9	Very Remote
8	Remote
7	Very Low
6	Low
5	Moderate
4	Moderately High
3	High
2	Very High
1	Almost Certain

Table 3. Severity score to identify risks in FMEA [6] and [8].

Ranking	Effects
10	Hazardous without Warning
9	Hazardous with Warning
8	Very High
7	High
6	Moderate
5	Low
4	Very Low
3	Minor
2	Very Minor
1	None

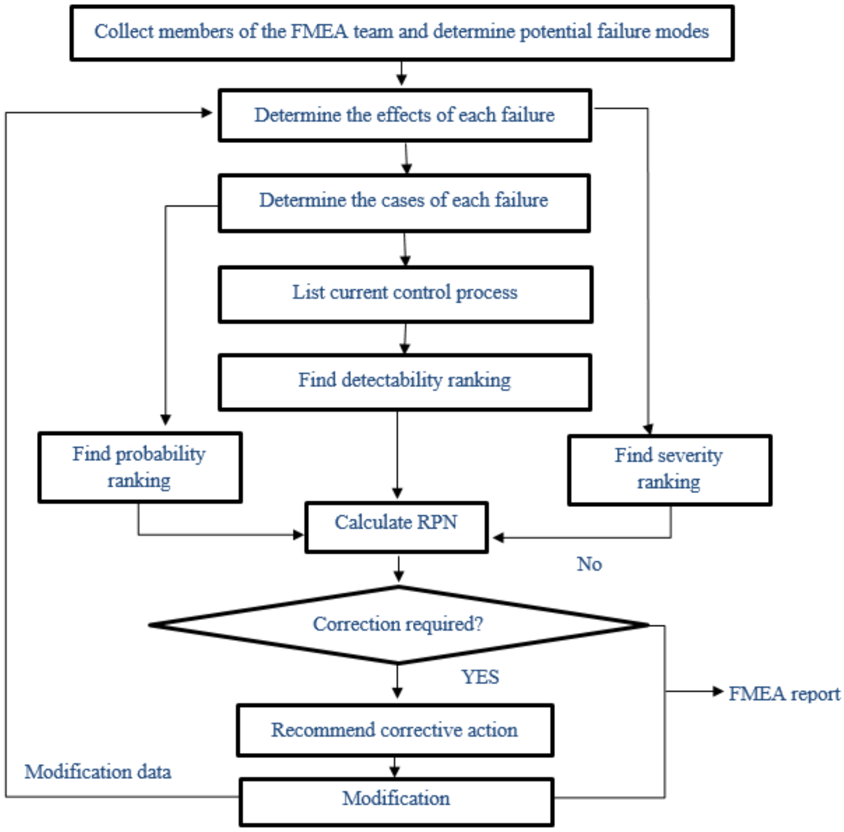

Fig. 1. Main process of FMEA [9].

2.2 | Literature Review about the Applications of FMEA Method in the Oil and Gas Industry and Improving It

Many authors have used FMEA in the field of gas and oil industry. For example, Ghaleh et al. [10] developed a framework based on FMEA method for safety risk assessment, which enables managers to evaluate the best safety risk using a ranking scheme. Liu et al. [11] evaluated the gas station safety risks in a case study using FMEA method. This method resulted in evaluating the most important risks. Hamidan and Dashti [12] used FMEA method to identify and determine the significance of HSE risks. They showed that FMEA method could also be used to identify and prioritize activities and risk indicators for planning in the prevention and elimination of significant risks. Vazdani et al. [13] applied FMEA method for investigation and detection of black spots and dangers in systems, which resulted in evaluating the most important risks. Ghasemi et al. [14] applied FMEA method for risk management in the Iran's gas refineries. Their research results indicated that various property damage risk factors embodied in gas refineries, including fire, explosion, error and omission, and machinery breakdown, were insurable risks. Kangavari et al. [15] applied FMEA method to identify risks in an Iranian petrochemical industry and found it to be a useful tool for identifying risk intervention priorities and effectiveness in a studied petrochemical industry. Petrovskiy et al. [16] considered the practical application of FMEA method to assess the operational reliability of the oil refineries' equipment regarded as a pressing problem for the oil-producing regions and countries. The paper describes the main steps of this approach to show its applicability for quantitative estimates of hazards of various defects in the equipment. Bandarja and Jozi [17] used FMEA method for risk assessment in the hydrocracking unit of Bandar Abbas Oil Co. Hekmatpanah and Fadavinia [18] applied FMEA method to improve the quality of products at Sepahan Oil Co. has and reported reduced oil waste. Their research results indicate that various risk factors, including HSE control system, are embodied in the oil company. In addition, due to the importance of using the technique and its shortcomings, many researchers have tried to improve the technique. Boral et al. [19] proposed a new integrated approach for FMEA using AHP and MAIRCA (Multi-Attribute Ideal Real Comparative Analysis) under uncertainty environment.

Tian et al. [20] used the combinational Best-Worst Method (BWM), Relative-Entropy (RE) and VlseKriterijumska optimizacija I KOm-promisno Resenje (VIKOR) methods to assess the risk events. In this study, risk events were selected as evaluating options and risk factors as criteria. They considered the relative weights of risk factors in its method for risk assessment and eliminating the shortcomings by considering the relative importance of the parameters S, O, and D in calculating RPN. Ghoushchi et al. [21] proposed a new approach for FMEA based on BWM and Multi-Objective Optimization by Ratio Analysis (MOORA) methods. In this method, they used MOORA approach to identify the risk events and applied the BWM method to obtain the weight of risk factors. The results indicate a full assessment and identification of the risks in comparison with other conventional methods such as FMEA and FMOORA. Fattahi and Khalilzadeh [22] presented a combination of methods based on FMEA method, extended Multiple Multi-Objective Optimization by Ratio Analysis (MULTIMOORA), and AHP method to evaluate risk in the Kerman Steel Industries Factory. Alvand et al. [23] proposed a new approach for FMEA based on SWARA and Weighted Aggregated Sum Product Assessment (WASPAS) methods. In this method, they used WASPAS approach to identify the risk events and applied SWARA method to obtain the weight of risk factors.

The above literature review shows that there are many studies on the application of traditional FMEA in the oil and gas industry. Despite many used methods and techniques in this field, risk identification and assessment in FMEA technique still need new researches, because previous researches have not paid attention to two important and necessary principles: 1) Lack of attention to better optimization in decision making, 2) Lack of utilizing a strong approach for determining the weights of evaluation criteria based on decision-makers' expected degree of importance. Fortunately, the current study considers this research gap and proposes an integrated approach for traditional FMEA. For this purpose, this study uses a FMEA framework by combining it with the VIKOR and SWARA methods to address this issue by improving the prioritization and identification of highly hazardous risks in the gas industry.

3 | The Proposed FMEA Model and Its Steps

To help risk analysts to formulate a more efficient and effective risk priority ranking for solving the problems concerning the traditional FMEA, the hybrid method was used for improving prioritization and identification in FMEA. This model consists of three main stages. First, traditional FMEA is used to for evaluating safety equipment risks. Then, the SWARA-VIKOR decision making technique is used to rank and improve the risks of the failure modes identified in FMEA. Finally, results are compared to provide the suitability and benefits of the proposed FMEA approach. The processes are schematically shown in *Fig. 2* and explained in detail in the following subsections.

Step 1. The traditional FMEA for determining failure effects.

In this step, the RPN was used to perform an FMEA analysis to identify and prioritize potential risks. RPN is obtained from the multiplication of the occurrence likelihood (O), severity (S) and detectability (D) factors. RPN forms the basis for the prioritization since S, O, and D criteria are rated on a scale of 1-10. Moreover, given the aforementioned score range, RPN varies between 1 and 1000 [2]. Hence, an RPN resulting from any corrective action is solely used to prioritize the actions [24].

Step 2. Application of SWARA-VIKOR techniques based on the FMEA for evaluation, identification, prioritization, and improvement of failure modes

In the second step, the identified potential risks were rated using the SWARA-VIKOR technique to compare the results from the decision-making technique with those of RPN. These two decision-making techniques are described as follows.

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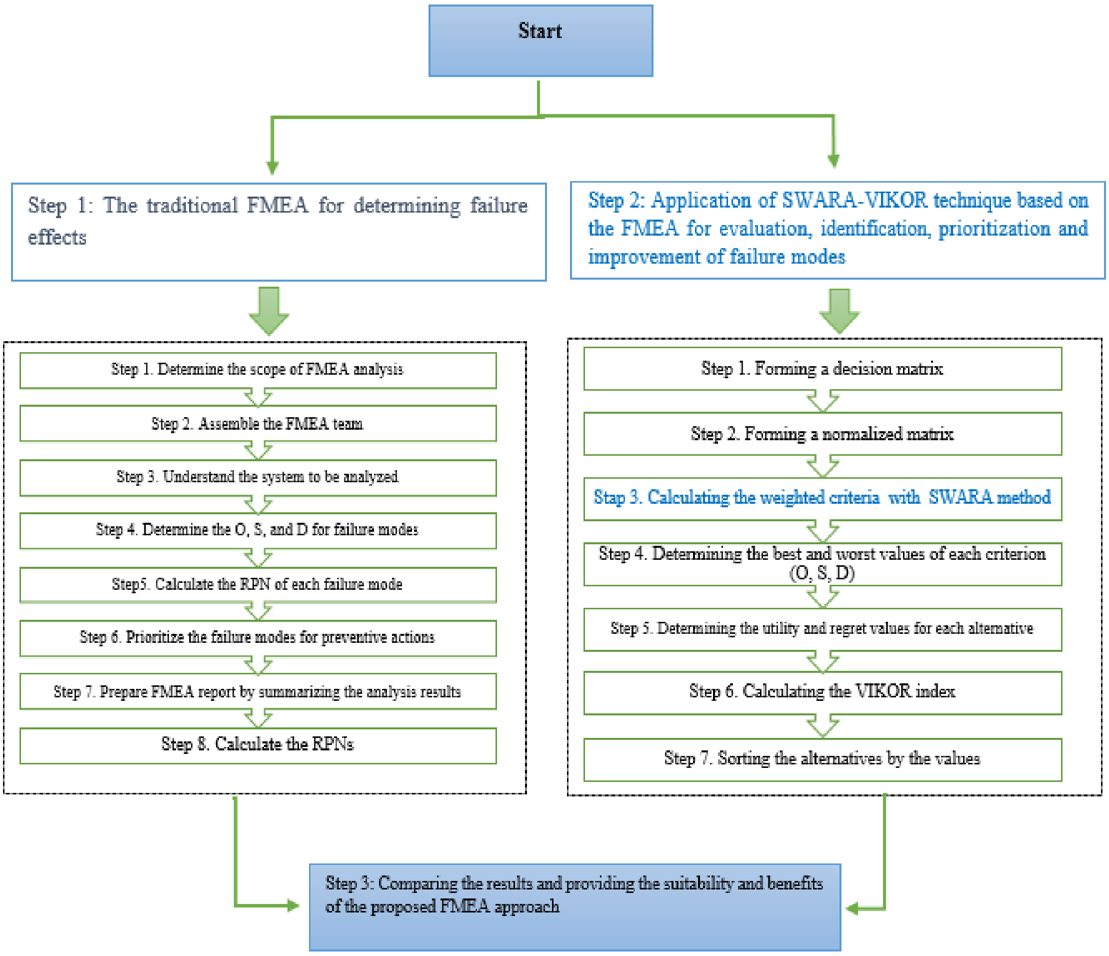

Fig. 2. The general framework of the proposed research algorithm.

3.1 | SWARA Technique

In many Multiple Attribute Decision Making (MADM) problems, weighting the indicators is considered as one of the most critical steps in the problem. SWARA method is, in fact, one of the newest methods in evaluating the weights in which experts play a significant role in calculating the weights [25]. Based on this method, the first and last ranks are assigned to the most and least important criteria, respectively. Finally, the average value of rankings given to each criterion by different experts determines the ranking and importance of that criterion. Therefore, SWARA method can be useful in cases where the priority of the criteria is specified. The use of SWARA method, as one of the group decision-making methods, is recommended in critical decision-making situations based on consensus among experts. This method is simple and easy to understand and has fewer paired comparisons compared to the hierarchical analysis and network analysis process methods [26]. Hence, in the current study, this method was used to calculate the weight of criteria. Based on this method, in the first step, the criteria are prioritized according to the consensus of experts. In the second step, the relative importance of criteria is determined compared to another. In general, SWARA method has five steps, which are described as follows [27]:

Step 1. Determining and sorting the evaluation criteria.

Evaluation criteria are determined in this step, given the factors such as the type and goals of the project, and then the criteria are evaluated in order of importance. The most important criteria are assigned a higher rank and the least important ones are assigned a lower rank.

Step 2. Sort the criteria based on the expected importance of experts.

First, the indicators considered as final by the decision-makers are selected and arranged based on their degree of importance. Accordingly, the most critical indicators are placed in the higher ranks, and the least important indicators are placed in the lower ranks.

Step 3. Get comparative importance of the average value (S_j) of criterion j from respondents.

In this step, determining the relative importance of the criteria (S_j) is that each criterion should be compared with its higher-ranking criterion. After determining all the relative importance scores cast by the experts, the geometric mean of respective scores is obtained to integrate their judgment. The output of this step is computing S_j.

Step 4. Calculate the coefficient k_j for each criterion using *Eq. (2):*

$$k_j = \begin{cases} 1 & j = 1, \\ s_j + 1 & j > 1. \end{cases} \quad (2)$$

Step 5. Determine the recalculated weighting factors q_j value using *Eq. (3)*:

$$q_j = \begin{cases} 1 & j = 1, \\ \frac{x_{j-1}}{k_j} & j > 1. \end{cases} \quad (3)$$

Step 6. The weights of criteria are calculated using *Eq. (4)*:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k}. \quad (4)$$

Where w_j represents the relative weights of criterion, and n represents the criteria number.

3.2 | VIKOR Technique

Step 1. Forming a decision matrix.

A decision matrix is formed similar to other MCDM techniques. To this aim, first a spectrum must be selected and therefore a nine-point Likert scale was used in this research. *Table 4* lists the results of decision matrix or the risk rating matrix in terms of the selected criteria (occurrence likelihood, detectability, and severity) [28].

Table 4. VIKOR spectrum.

Expression	Extremely high	High to extremely high	High	Moderate to high	Moderate	Low to moderate	Low	Low to extremely low	Extremely low
Quantitative value	9	8	7	6	5	4	3	2	1

Step 2. Forming a normalized matrix.

In the second step, the decision-making is normalized using the linear normalization method. The normalized matrix is shown by (N) and each entry is denoted by n_{ij}, which is calculated via dividing the corresponding entry in the initial matrix by the sum of the corresponding column entries:

$$n_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}. \quad (5)$$

Step 3. Determining the best and worst values of each criterion.

In this step, the best and worst values of each criterion are selected from all alternatives. The best value of a criterion in all alternatives is shown by f_j^* and the worst value is shown by f_j^-. Hence, f_j^*, and f_j^- are calculated through the following relations depending on the positive or negative criterion weight. If the criterion is positive, f_j^* and f_j^- are maximum and minimum values in the column, respectively.

$$f_j^* = \text{Max } f_j .$$
$$f_j^- = \text{Min } f_j . \quad (6)$$

However, if the criterion is negative, f_j^* and f_j^- are minimum and maximum values in the column, respectively.

$$f_j^* = \text{Minn } f_j .$$
$$f_j^- = \text{Max } f_j . \quad (7)$$

Step 4. Determining the utility and regret values for each alternative.

Opricovic introduced the notions of utility (S) and regret (R) to the VIKOR calculations. Utility (S) reflects the relative distance of the i-th alternative to the ideal solution, while regret (R) shows maximum regret of the i-th alternative for being distanced from the ideal point.

$$S_i = \sum_{j=1}^{n} W_j \cdot \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} .$$
$$R_i = \text{Max}\left[w_j \cdot \frac{f_j^* - f_{ij}}{f_j^* - f_j^-}\right]. \quad (8)$$

Step 5. Calculating the VIKOR index.

The VIKOR index (Q) for each alternative is calculated as follows:

$$Q_i = v \left[\frac{S_i - S^*}{S^- - S^*}\right] + (1 - v)\left[\frac{R_i - R^*}{R^- - R^*}\right].$$
$$S^* = \text{Min } S_i \; ; \; S^- = \text{Max } S_i. \quad (9)$$
$$R^* = \text{Min } R_i \; ; \; R^- = \text{Max } R_i.$$

Step 6. Sorting the alternatives by the values**.**

In this step, the alternatives are sorted by the values S, R, and Q in three groups from small to large. The best alternative is the one with the smallest Q value provided that the following two conditions are satisfied.

Condition 1. If the alternatives A1 and A2 have the first and second ranks among m alternatives, then

$$Q\,(A2) - Q\,(A1) \geq \frac{1}{m-1}. \quad (10)$$

Condition 2. If the alternative A has the highest rank at least in group R or S.

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If the first condition is not met, both alternatives are considered to be the best ones. If the second condition is not satisfied, alternatives A1 and A2 are considered the best ones [28].

Step 3. Comparing the results and providing the suitability and benefits of the proposed FMEA approach.

The outcomes of two last steps are evaluated and the output of two traditional FMEA and improved FMEA techniques are assisted in this step.

4 | Case Study: Identification and Prioritization of the Most Important Risks of Safety Equipment in Lorestan Gas Company

Lorestan Gas Company is an important company in Iran that is seeking to identify and prioritize the most important risks of safety equipment. For this purpose, the researchers established an expert group including the operation staff of Lorestan Gas Company in 2015, consisting of the operation, engineering, technical examination, and project implementation forces.

Table 5. Potential risks of safety equipment in Lorestan Gas Company.

Main Risk Codes	Main Risk Sub-Group Codes	Description
CGS Heater	CGS Heater 1	Heater coil perforation
CGS Heater	CGS Heater 2	Malfunction of the heater sparkle
CGS Heater	CGS Heater 3	Heater shutdown
CGS Heater	CGS Heater 4	Failure of the heater fuel reduction regulator
CGS Heater	CGS Heater 5	Detachment of the sensor of the fuel reduction system of the heater
Taghzie	Taghzie 1	Concentration of toxic dangerous gases in the manhole
Taghzie	Taghzie 2	Feeder line leakage
Taghzie	Taghzie 3	The seal-less feeder line valves
Taghzie	Taghzie 4	Failure of the feeder line pipes
Network	Network 1	Operating a regulator without informing the residents
Network	Network 2	Coverage of Sitols by asphalt
Network	Network 3	Fracture of the polyethylene pipes
Network	Network 4	Fracture of the regulators
CGS	CGS 1	Yoke coupling in the separators
CGS	CGS 2	Combination of air and gas in the tank below the separator during maintenance operations
CGS	CGS 3	Seal-less connections of the CGS station
CGS	CGS 4	Cracks in the pipe walls and equipment of the CGS station
CGS	CGS 5	Exposure of the filter element to air
CGS	CGS 6	Gage failure
CGS	CGS 7	Malfunction of the safety and shut-off vales in critical conditions
TBS	TBS 1	Sensor pipes detachment
TBS	TBS 2	Entrapment of high-pressure gas in the filter container during the maintenance
TBS	TBS 3	The supply of high-voltage electricity to the network by the CPS station
TBS	TBS 4	Perforation of the pipes and other TBS station equipment
TBS	TBS 5	Failure of the anodes in the CPS station

In this research, the main criterion for selecting the experts was the knowledge of installation safety and risk notions. A questionnaire as one of the most important data collection methods was used to attain the primary research goal. First, potential risks of gas distribution stations were identified by providing the standard FMEA worksheet to the experts and obtaining the initial data on potential risks of the gas stations. Afterward, the identified risks were saved in a uniform format and presented to the statistical population to determine the RPNs of the risks hidden to them and to express their opinions on the priority of each risk. Finally, using the arithmetic mean value, which is a measure of central tendency, both effective and potential risks to the gas stations were identified from the risks derived from the standard FMEA worksheet and low-priority risks were omitted from the worksheet. The following steps were then undertaken to achieve the main goal and implement a meaningful decision-making model:

Step 1. Providing a list of safety risks at gas distribution stations of Lorestan Gas Company.

Table 5 represents t results of the assessment and identification of safety risks posed to gas distribution stations of Lorestan Gas Company using the arithmetic mean values and results of the proposed method application along with the description of the risks and risk codes.

Step 2. The results of traditional FMEA for determining failure effects.

RPNs were calculated and the potential risks were identified after providing a list of the safety risks at the gas distribution stations of Lorestan Gas Company. Hence, after determining the occurrence likelihood (O), severity (S), and detectability (D) criteria, the numerical values associated with the risks were obtained using *Eq. (1)* and listed in *Table 6*.

Table 6. The ultimate priorities of the risks based on traditional FMEA.

Main Risk Codes	Main Risk Sub-Group Codes	Final RPN	Identify and Priority
	CGS Heater 1	219	1
	CGS Heater 2	204.4	3
CGS Heater	CGS Heater 3	148.6	11
	CGS Heater 4	144.8	12
	CGS Heater 5	143	13
	Taghzie 1	205.5	2
Taghzie	Taghzie 2	202.9	4
	Taghzie 3	119.8	14
	Taghzie 4	117.1	15
	Network 1	200.2	5
Network	Network 2	192.4	7
	Network 3	163.1	10
	Network 4	112.2	17
	CGS 1	195.8	6
	CGS 2	110.4	18
	CGS 3	75.9	21
CGS	CGS 4	71.1	22
	CGS 5	71	23
	CGS 6	67.9	24
	CGS 7	66.7	25
	TBS 1	186.7	8
	TBS 2	175.4	9
TBS	TBS 3	115.7	16
	TBS 4	110.4	19
	TBS 5	79.3	20

Step 3. Results of the SWARA-VIKOR techniques application based on the FMEA for evaluation, identification, prioritization, and improvement of failure modes.

Different steps of the SWARA-VIKOR techniques must be taken consecutively to prioritize the identified risks. Hence, a summary of step-by-step application of important phases of this technique is presented in the following.

Step 1. Calculating the criteria weights using SWARA technique.

After identifying important research risks, the weighting of the decision criteria (O, S, and D) is carried out step-by-step based on expert opinion according to the above-mentioned steps. As observed in *Table 7*, based on the first step of the SWARA method, the expert is asked to arrange the criteria in the order of importance; priority is shown in the second column of the table. Also, the second to fifth steps of the SWARA method can be observed in columns three and four, respectively. Finally, by considering

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the steps of the SWARA method and weighting normalization, their final weight is shown in column five. Based on the results of weighting by the experts, it was found that the risk severity index possesses higher priority than the risk occurrence and risk detection indices, indicating the importance of the issue to experts.

Table 7. Weight of criteria.

Criteria Code	W_j
S	0.47
O	0.322
D	0.214

Step 2. Evaluating and identify risk of the safety equipment risks using VIKOR.

In this study the VIKOR method, as one of the most important methods is used to rank important risks. Accordingly, based on the above explanation, at first, a decision matrix is formed. The matrix involves rows and columns, with columns assigned to the criteria and rows allotted to research options. Each cell is used to evaluate an option based on a single criterion. The decision matrix is completed by experts and is subsequently merged with the arithmetic mean method, as shown in *Table 8*. Then, the decision matrix is normalized based on *Eq. (5)*. In this study, O and S criteria have a positive aspect, while D criterion has a negative aspect. The normal matrix is given in *Table 9*.

Table 8. Data on 25 potential safety risks of the gas stations.

Main risk codes	Main risk sub-group codes	S	O	D
CGS Heater	CGS Heater 1	5.80	3.70	2.95
	CGS Heater 2	5	5.05	5.15
	CGS Heater 3	5.90	4.30	4.23
	CGS Heater 4	6.50	5.45	4.90
	CGS Heater 5	6.80	3.85	3.10
Taghzie	Taghzie 1	4	5.25	3.33
	Taghzie 2	4.20	5.15	2.96
	Taghzie 3	5.40	3.60	4.62
	Taghzie 4	4.71	4.20	3.45
Network	Network 1	4.85	3.86	3
	Network 2	3.90	3.85	3.90
	Network 3	6.20	4.20	4.10
	Network 4	6.80	4.90	4.89
CGS	CGS 1	6.40	5.95	4.30
	CGS 2	5.90	5.30	5.35
	CGS 3	6.65	5.90	4.60
	CGS 4	5.90	5.62	5
	CGS 5	4.92	7.51	3.83
	CGS 6	4.55	6.60	2.95
	CGS 7	6.72	4.83	5.50
TBS	TBS 1	5	4.85	5.20
	TBS 2	6.90	4.50	6
	TBS 3	6.80	4.90	4.62
	TBS 4	4.55	4.90	4.55
	TBS 5	4.90	6.80	3.05

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Table 9. VIKOR normal decision-making matrix.

Main risk codes	Main risk sub-group codes	S	O	D
CGS Heater	CGS Heater 1	0.205	0.145	0.137
	CGS Heater 2	0.177	0.198	0.239
	CGS Heater 3	0.209	0.169	0.196
	CGS Heater 4	0.230	0.214	0.227
	CGS Heater 5	0.241	0.151	0.144
Taghzie	Taghzie 1	0.142	0.206	0.154
	Taghzie 2	0.149	0.202	0.137
	Taghzie 3	0.191	0.141	0.214
	Taghzie 4	0.167	0.165	0.160
Network	Network 1	0.172	0.151	0.139
	Network 2	0.138	0.151	0.181
	Network 3	0.219	0.165	0.190
	Network 4	0.241	0.192	0.227
CGS	CGS 1	0.226	0.233	0.199
	CGS 2	0.209	0.208	0.248
	CGS 3	0.235	0.232	0.213
	CGS 4	0.209	0.221	0.232
	CGS 5	0.174	0.295	0.177
	CGS 6	0.161	0.259	0.137
	CGS 7	0.238	0.190	0.255
TBS	TBS 1	0.177	0.190	0.241
	TBS 2	0.244	0.177	0.278
	TBS 3	0.241	0.192	0.214
	TBS 4	0.161	0.192	0.211
	TBS 5	0.173	0.267	0.141

After completing the second, third, and fourth phases of the VIKOR decision-making technique, the most important step is taken involving the determination of the regret and utility of each alternative and the calculation of the VIKOR index (see *Table 10*).

Table 10. The utility and regret of each alternative and the VIKOR index.

Main risk codes	Main risk sub-group codes	Utility (S) Value	Regret (R) Value	Final VIKOR index (Q) Value	Rank
CGS Heater	CGS Heater 1	0.486	0.314	0.452	15
	CGS Heater 2	0.655	0.298	0.581	17
	CGS Heater 3	0.511	0.264	0.402	14
	CGS Heater 4	0.369	0.170	0.134	3
	CGS Heater 5	0.328	0.301	0.290	9
Taghzie	Taghzie 1	0.667	0.454	0.822	24
	Taghzie 2	0.618	0.423	0.731	23
	Taghzie 3	0.674	0.322	0.634	20
	Taghzie 4	0.651	0.343	0.644	21
Network	Network 1	0.625	0.321	0.589	18
	Network 2	0.838	0.470	1.000	25
	Network 3	0.463	0.273	0.370	13
	Network 4	0.367	0.215	0.199	6
CGS	CGS 1	0.302	0.128	0.013	2
	CGS 2	0.507	0.182	0.278	8
	CGS 3	0.288	0.133	0.006	1
	CGS 4	0.456	0.157	0.194	5
	CGS 5	0.372	0.310	0.343	11
	CGS 6	0.443	0.368	0.492	16
	CGS 6	0.428	0.221	0.262	7
TBS	TBS 1	0.675	0.298	0.599	19
	TBS 2	0.462	0.248	0.333	10
	TBS 3	0.348	0.215	0.181	4
	TBS 4	0.695	0.368	0.721	22
	TBS 5	0.379	0.313	0.354	12

According to the calculation results, the coverage of sitols by asphalt and the concentration of toxic dangerous gases in the manholes seal-less connections of the CGS station and yoke coupling in the separators gained the first and second ranks. Now it is time to check the first condition, i.e. 0.01≤0.04. Although this condition is not satisfied, the second condition is satisfied stating that the best alternative must have the first rank in at least one of the R or S groups. In other words, the coverage of sitols by asphalt and the concentration of toxic dangerous gases in the manhole are both selected as the most important risks posed to the gas distribution stations.

5 | Sensitivity Analysis of the Proposed Approach

In this section, the sensitivity analysis was carried out to test the stability of proposed hybrid method by exchanging the weight of each criterion with another criterion. The criteria weights have the greatest effect on ranking alternatives. The decision-maker must know the reliability of the results for decision making. Because of uncertainties in various stages of multiple-attribute decision-making, it is necessary to perform sensitivity analysis on a problem before selecting the final alternative. Therefore, sensitivity analysis is recommended after obtaining the ranking alternatives. To analysis the sensitivity was carried out to test by exchanging the weight of each criterion with another criterion. There were three different formulated scenarios of the interchanging as follows:

- *Scenario 1: Weight change of S-O.*
- *Scenario 2: Weight change of S-D.*
- *Scenario 3: Weight change of O-D.*

In each scenario, the alternatives' score is calculated by VIKOR method, and the alternatives are ranked (see *Table 11*).

Table 11. Ranking of alternatives for different scenarios.

Main risk codes	Main risk sub-group codes	Ranking of alternatives for different scenarios		
		Scenario 1	Scenario 2	Scenario 3
CGS Heater	CGS Heater 1	22	9	8
	CGS Heater 2	14	22	20
	CGS Heater 3	20	14	9
	CGS Heater 4	6	15	7
	CGS Heater 5	18	7	2
Taghzie	Taghzie 1	13	6	24
	Taghzie 2	11	4	22
	Taghzie 3	24	20	15
	Taghzie 4	21	13	19
Network	Network 1	23	11	18
	Network 2	25	19	25
	Network 3	19	12	6
	Network 4	10	16	5
CGS	CGS 1	2	5	1
	CGS 2	9	21	14
	CGS 3	3	8	3
	CGS 4	7	18	10
	CGS 5	1	2	13
	CGS 6	5	3	17
	CGS 7	12	23	12
TBS	TBS 1	17	24	21
	TBS 2	15	25	16
	TBS 3	8	10	4
	TBS 4	16	17	23
	TBS 5	4	1	11

Table 11 shows that, in most cases, the ranking of alternatives did not change or had small modifications as illustrated in *Table 11*, indicating that alternative CGS 2 was highly sensitive to change in criteria weights. Hence, it can be considered the most sensible alternative, and because of the least change in the significance of factors, its rank changes. Alternatives CGS Heater 1, CGS Heater 3, Taghzie 2, CGS 2, TBS 2, and TBS 5 are less sensitive to weight changes compared to alternative CGS 2. The rest of the alternatives can be categorized as alternatives that are not sensitive since the sensitivity is not very significant.

6 | Results and Discussion

The current study aimed to present a novel hybrid approach to evaluate the risks of safety equipment. Accordingly, the types of risks involved in safety equipment were identified, which ultimately improved the results of traditional FMEA method. A combination of several MCDM methods, including the SWARA and VIKOR methods was proposed based on traditional FMEA method. Subsequently, the proposed method was applied to the gas company in Lorestan Province of Iran, and the validity of findings was examined concerning the following aspects:

To illustrate the effectiveness of proposed approach, traditional RPN method based on study of Rahimi et al. [27] and the novel hybrid approach are implemented in a case study. *Table 12* indicates the results of multiple risk rankings using the novel hybrid approach and the traditional RPN method. As shown, the proposed model is superior to other methods. First, it shows that there is a significant difference between the rankings offered by two traditional approaches and the proposed approach. The reason for these inconsistent rankings is mainly related to the relative importance of parameters S, O, and D in calculating RPN and weight of the criteria in which changes in the rankings presented for the risk states were not considered in the traditional ranking. Also, in a typical RPN, different sets of O, S, and D may have the same RPN value, but differ in the ranking by the proposed model. Thus, given this deep gap, the novel hybrid approach can solve this problem by providing accurate rankings for each risk and distinguishing the results well.

Table 12. Comparing the rankings.

Main Risk Codes	Main Risk Sub-Group Codes	Traditional FMEA	Proposed Hybird Approach
CGS Heater	CGS Heater 1	21	15
	CGS Heater 2	3	17
	CGS Heater 3	11	14
	CGS Heater 4	12	3
	CGS Heater 5	13	9
Taghzie	Taghzie 1	2	24
	Taghzie 2	4	23
	Taghzie 3	14	20
	Taghzie 4	15	21
Network	Network 1	5	18
	Network 2	7	25
	Network 3	10	13
	Network 4	17	6
CGS	CGS 1	6	2
	CGS 2	18	8
	CGS 3	1	1
	CGS 4	22	5
	CGS 5	23	11
	CGS 6	24	16
	CGS 7	25	7
TBS	TBS 1	8	19
	TBS 2	9	10
	TBS 3	16	4
	TBS 4	19	22
	TBS 5	20	12

By comparing the results of above methods (see *Table 12*), combining SWARA and VIKOR methods based on FMEA method can be used to improve the risk assessment and prioritization of safety equipment. The results presented in *Table 12* indicate that the highest risk mode is still CGS 3, despite some differences in ranking risk modes, which confirms the results obtained from the proposed approach. The proposed hybrid approach allows us to detect the root causes of some safety equipment failures, to achieve the main objectives of the project, and to examine the risk assessment problem more appropriately and accurately.

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7 | Conclusions

Gas company managers usually face with a variety of risks and failing to manage these risks result in delays, cost overruns, and failure to meet project quality and safety requirements. Many of these consequences can be avoided by adopting an appropriate scientific approach for risk identification. Due to importance of risk identification and prioritization, a novel hybrid approach was presented for the risk assessment of safety equipment. The proposed approach involves combining SWARA-VIKOR methods based on FMEA technique to assess and detect the risks of safety requirements. In the hybrid approach, SWARA method was used to determine the relative importance of the parameters S, O, and D in calculating the weight of criteria, and VIKOR method employed to prioritize the detected risks. In addition to solving the typical RPN problems, the proposed approach can take advantage of two novel multi-criteria decision-making methods to improve the risk assessment of safety requirements. Furthermore, a case study validated the proposed model as an effective and efficient risk identification tool for prioritizing risk modes in FMEA for further corrective actions. By using the proposed hybrid approach, we attempted to introduce a method for providing appropriate analyses to project managers by detecting important risks in decision-making and determining significant risks. Finally, an appropriate framework was provided to improve the risk assessment of safety requirements via FMEA and a guidance was recommended to perform the risk analysis in other projects and industries.

References

[1] Pittiglio, P., Bragatto, P., & Delle Site, C. (2014). Updated failure rates and risk management in process industries. *Energy procedia*, *45*, 1364-1371.

[2] Ghasemkhani, R. (2011). *Identification and assessment of process hazards in units 101 and 104 of phases 9 and 10 of south pars* (MSc Thesis, Chemical Engineering Islamic Azad University). Retrieved from https://elmnet.ir/article/10500397-31552/

[3] Mohammad Fam, I. (2007). *Safety audit.* Fanavaran Publication. (**In Persian**). https://www.gisoom.com/book/1425543/

[4] Yar Ahmadi, R., & Moridi. P. (2012). Health, safety and environmental risk assessment in laboratory sites. *Journal of health and safety at work*, *2*(1), 11-26. (**In Persian**). http://jhsw.tums.ac.ir/article-1-10-fa.html

[5] Mohammad Fam, I., & Ehsani, H. R. (2005). Quantitative risk assessment of pipelines. *2nd scientific research conference on assistance and rescue management*. Tehran. (**In Persian**). https://civilica.com/doc/35158/

[6] Liu, H. C. (2016). FMEA using uncertainty theories and MCDM methods. In *FMEA using uncertainty theories and MCDM methods* (pp. 13-27). Springer, Singapore. https://doi.org/10.1007/978-981-10-1466-6_2

[7] Liu, H. C., Liu, L., & Liu, N. (2013). Risk evaluation approaches in failure mode and effects analysis: a literature review. *Expert systems with applications*, *40*(2), 828-838.

[8] Rahimi, Y., Tavakkoli-Moghaddam, R., Iranmanesh, S. H., & Vaez-Alaei, M. (2018). Hybrid approach to construction project risk management with simultaneous FMEA/ISO 31000/evolutionary algorithms: empirical optimization study. *Journal of construction engineering and management*, *144*(6), 04018043.

[9] Li, Z., & Chen, L. (2019). A novel evidential FMEA method by integrating fuzzy belief structure and grey relational projection method. *Engineering applications of artificial intelligence*, *77*, 136-147.

[10] Ghaleh, S., Omidvari, M., Nassiri, P., Momeni, M., & Lavasani, S. M. M. (2019). Pattern of safety risk assessment in road fleet transportation of hazardous materials (oil materials). *Safety science*, *116*, 1-12.

[11] Liu, Y., Kong, Z., & Zhang, Q. (2018). Failure modes and effects analysis (FMEA) for the security of the supply chain system of the gas station in China. *Ecotoxicology and environmental safety*, *164*, 325-330.

[12] Hamidan, N., & Dashti, S. (2018). Risk Assessment of oil reservoirs of Amout-E-Arvand free zone area at the explotiation phase using FMEA method. *Journal of health*, *9*(4), 389-402.

[13] Vazdani, S., Sabzghabaei, G., Dashti, S., Cheraghi, M., Alizadeh, R., & Hemmati, A. (2017). FMEA techniques used in environmental risk assessment. *Environment & ecosystem science (EES)*, *1*(2), 16-18.

[14] Ghasemi, S., Mahmoudvand, R., & Yavari, K. (2016). Application of the FMEA in insurance of high-risk industries: a case study of Iran's gas refineries. *Stochastic environmental research and risk assessment*, *30*(2), 737-745.

[15] Kangavari, M., Salimi, S., Nourian, R., & Askarian, A. (2015). An application of failure mode and effect analysis (FMEA) to assess risks in petrochemical industry in Iran. *Iranian journal of health, safety and environment*, *2*(2), 257-263.

[16] Petrovskiy, E. A., Buryukin, F. A., Bukhtiyarov, V. V., Savich, I. V., & Gagina, M. V. (2015). The FMEA-Risk analysis of oil and gas process facilities with hazard assessment based on fuzzy logic. *Modern applied science*, *9*(5), 25-37.

[17] Bandarja, M., & Jozi, S. A. (2014). Health, safety, and environmental risk assessment for hydrocracker unit of Bandar Abbas in refinement of Oil Company by EFMEA method. *Journal of environmental studies*, *39*(4), 105-124. (**In Persian**). DOI: 10.22059/jes.2014.36465

[18] Hekmatpanah, M., & Fadavinia, A. (2011). The evaluation and application of FMEA in Sepahan Oil Co. *International journal of industrial and manufacturing engineering*, *5*(4), 769-774.

[19] Boral, S., Howard, I., Chaturvedi, S. K., McKee, K., & Naikan, V. N. A. (2020). An integrated approach for fuzzy failure modes and effects analysis using fuzzy AHP and fuzzy MAIRCA. *Engineering failure analysis*, *108*, 104195. https://doi.org/10.1016/j.engfailanal.2019.104195

[20] Tian, Z. P., Wang, J. Q., & Zhang, H. Y. (2018). An integrated approach for failure mode and effects analysis based on fuzzy best-worst, relative entropy, and VIKOR methods. *Applied soft computing*, *72*, 636-646.

[21] Ghoushchi, S. J., Yousefi, S., & Khazaeili, M. (2019). An extended FMEA approach based on the Z-MOORA and fuzzy BWM for prioritization of failures. *Applied soft computing*, *81*, 105505. https://doi.org/10.1016/j.asoc.2019.105505

[22] Fattahi, R., & Khalilzadeh, M. (2018). Risk evaluation using a novel hybrid method based on FMEA, extended MULTIMOORA, and AHP methods under fuzzy environment. *Safety science*, *102*, 290-300.

[23] Alvand, A., Mirhosseini, S. M., Ehsanifar, M., Zeighami, E., & Mohammadi, A. (2021). Identification and assessment of risk in construction projects using the integrated FMEA-SWARA-WASPAS model under fuzzy environment: a case study of a construction project in Iran. *International journal of construction management*, 1-23. https://doi.org/10.1080/15623599.2021.1877875

[24] Azar Barin, R. (2000). *Evaluation of safety of bilerboard recovery systems in Iran's wood and paper workshop by FMEA method and appropriate solutions* (MSc Thesis, University of Medical Sciences Tarbiat Modarres University). Retrieved from https://elmnet.ir/Article/10074871-71901/

[25] Keršuliene, V., Zavadskas, E. K., & Turskis, Z. (2010). Selection of rational dispute resolution method by applying new step-wise weight assessment ratio analysis (SWARA). *Journal of business economics and management*, *11*(2), 243-258.

[26] Mavi, R. K., Goh, M., & Zarbakhshnia, N. (2017). Sustainable third-party reverse logistic provider selection with fuzzy SWARA and fuzzy MOORA in plastic industry. *The international journal of advanced manufacturing technology*, *91*(5), 2401-2418.

[27] Rahimi, Y., Tavakkoli-Moghaddam, R., Iranmanesh, S. H., & Vaez-Alaei, M. (2018). Hybrid approach to construction project risk management with simultaneous FMEA/ISO 31000/evolutionary algorithms: Empirical optimization study. *Journal of construction engineering and management*, *144*(6), 04018043. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29CO.1943-7862.0001486

[28] Yoon, K. P., & Hwang C. L. (1995). *Multiple attribute decision making: an introduction*. Sage publication.

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