Failure Mode and Effects Analysis: A Decision Making Risk prioritization Approach

Abstract

Failure Mode and Effect Analysis (FMEA) is a method of risk assessment that is broadly utilized to identify, predict as well as mitigate possible defects in products, operations, and systems prior to the occurrence of a negative incident. However, inaccurate results may be generated due to the uncertain conditions under which risk assessment using the FMEA. Therefore, there is need to mitigate the uncertainty, particularly randomness and fuzziness in the assessment process. This can be achieved by using Grey number to develop the FMEA and VIKOR methods to fix several hindrances related to the risk priority number (RPN) of the traditional FMEA. This paper aims to compare the Grey VIKOR with the traditional FMEA to present more accurate ranking. In the first step Grey system was used to rank failure modes and select risk elements to join vulnerability into subjective judgments. Thereafter, VIKOR method was applied for prioritizing and evaluating failure modes. The results of comparative analysis indicate the adequacy and versatility of the proposed method in dealing with real-world issues.

Keywords: potential failure modes and effects analysis, risk assessment, grey numbers, method VIKOR

1. Introduction

Due to increased competition, rising expectations and customer demand, and rapid technological changes, the obligations of producers today are rapidly increasing. Hence, the lack of diversity in product operation may lead to loss of market share. For this reason, organizations are using techniques that can facilitate the production and manufacture of flawless and competitive products. One of such techniques is the failure modes and effects analysis (FMEA). This technique is based on "prevention before the fact". The FMEA is designed to identify, predict, and eliminate, all possible failure modes or points of failure within system design, processes, or products before they reach the consumers (Samatis, 1995). The main advantage of the FMEA has been the use of data to recognize and categorize possible hazards within systems, processes and products and mitigate associated risks (Lago et al, 2012; Toornanloo et al, 2018; Altuntas and Kansu 2019). Despite its perceived advantages, the FMEA has several flaws which negatively impact its ability to effectively predict and address potential failure modes. To address these limitations, this paper proposes the use of a multiple criteria decision-making tool, hereafter referred to as MCDM (Yang et al., 2009), that integrates fuzzy logic based grey systems.

To the best of our knowledge, there is no study that focuses on the limitations of the traditional FMEA and how it may be addressed based on integration of fuzzy logic and grey systems theory. We attempt to do this in this paper. The next section presents the research background, and then methodology. Following this, the research results, and discussions are presented. The chapter closes by drawing salient points with respect to the adoption of the fuzzy logic based grey systems approach and recommending the use of this model to facilitate proactive risk assessment and management, including optimal decision making, in complex situations.

2. Research Background

2.1. The FMEA Dilemma

The traditional FMEA is a risk management tool that is chiefly concerned with; (a) identifying and evaluating risk, causes, effects, and criticality of potential system, design, service, and/or process failure; (b) reducing the probability of system failure; and/or (c) mitigating the negative impact if a system fails (Jun and Huibin et al., 2012). The FMEA is used in the automotive, chemical, electronic, mechanical, and nuclear industries, including the health and technology sectors (Chang & Cheng, 2011; Chin et al., 2009; Sharma & Kumar, 2005; Gilchrist, 1993).

Despite its perceived advantages, the traditional FMEA has several limitations which are mostly linked to the risk priority number (RPN) (Lim and Tray 2006; Liu et al., 2013; Omidvar and Nirumand, 2017). However, only three of these limitations will be presented here. The first, and arguably the most debated limitation is that different series of the Severity, Occurrence, and Detection risk factors may produce the same RPN value, despite varying risk consequences (Pillay and Wang, 2003; Yener and Can, 2021), and complication in the true assessment of the three risk agents and unclear math formulas for computing RPN (Liu et al., 2013 and Mardani Shahri et al., 2021). Closely linked to this is the second limitation, which has to do with the equal and superficial weighting allocated to the three risk factors, even though they each impact the critical urgency of a single failure mode differently (Carmignani, 2009). In response to this, Kmenta et al. (1999), suggest that the Detection risk factor should be eliminated or assigned less importance than the Severity and Occurrence risk factors. The third limitation relates to the subjectivity of the values assigned to the Severity, Occurrence, and Detection risk factors, and how this might lead to incorrect final analysis and results. To illustrate, two FMEA computed by different analysts may yield different RPNs for the same failure mode because they may have assigned different random values to the Severity, Occurrence and Detection risk factors (Carmignani, 2009). Several studies have been conducted to address the limitations articulated in the previous paragraph. See for example Li and Chen (2019); Di Bona et al. (2018); and Carmignani (2009).

Mardani Shahri and et al. in 2021 presented a new technique to hazard evaluation and/or classification on failure mode and impact examination. Framed within a Pythagorean fuzzy environment, they addressed the deficiencies of FMEA using a popular MCDM approach named PF-VIKOR. The outcomes demonstrate that the proposed strategy is judicious and substantial. Ruinan Dang et al. in 2021 carried out the research for site selection of island photovoltaic charging station on the basis of MCDM. Meanwhile, fuzzy VIKOR method was utilized to classify the alternatives.

2.2. Addressing the Limitations of the FMEA: The Hybridization of MCDM

Fuzzy based approaches are increasingly employed in some areas to improve decision making based on attributes. Usually, a range of attributes are considered including chemical, electrical, magnetic, manufacturing, material availability, material costs and environmental impact, and performance characteristics (Muhammet et al., 2018). As such, the criteria adopted in complex decision making involving a range of alternatives and criteria, are multi-dimensional and underpinned by the subjective views of decision makers, which is where MCDM comes in.

MCDM is an umbrella term for the different methods used by people to rank decisions in order of preferences where two or more criteria exist (Ho, 2008; Ikuobas Emovon et al., 2020; Tan Tan et al.,2021). It does this by breaking complex problems into smaller, and manageable pieces (Mardini et al., 2015) The MCDM presents a systematic approach to selecting an optimum alternative from a range of alternatives by simultaneously considering stipulated decision-making criteria and the perceptions of decision makers (Kabir et al., 2014).

Table 1 : illustrates brief rundown of popular MCDM apparatuses showing rule of decision making along with innovator, year of innovation, worthiness and defects. (Ikuobase Emovon et al; 2020).

MCDM method	Principle of decision making	Inventor/Year	Merits	Demerits
AHP	deal arrangement is gotten based on grade of significance of norm and choices. The issue is for the most part organized in progressive arrange some time recently arrangement is sort.	Thomas Saaty: 1970	There is no need to extra apparatus for scale weight assurance	The procedure gets to be more intricate as standard and options increases
TOPSIS	The method assesses the ideal elective by using separations to useful and gloomy arrangement	Hwang and Yoon:1981	The strategy evaluates the perfect elective by putting in divisions to useful and defeatist course of action	e arrangement strategy does not alter independent of number of choice criteria and options The relationship among scale are not recognized within the assessment of Euclidean remove. In expansion, vector normalization might be needed in fathoming issue that are multi-dimensional
PROMETHEE	The device is an outclassing technique which illuminate a choice issue on the premise of comparing choices whereas pondering the decisions deviation regarding decision rules	Brans and Vicke, 1982	The handle does not need total normalization	Standards loads have to be assessed with various device. Moreover, Inclination work ought to be described
ELECTRE	The strategy of ELECTRE creates arrangement based on characterizing outclassing connection betwixt two decisions all at once. A couple of the variation of the apparatus are ELECTRE I and II	Benayoun Roy: 1968	The procedure may give arrangement indeed when there have been lost information	Within the nonattendance of computer program, strategy is measurably troublesome because of complicated assessment methods involve
VIKOR	Within the nonappearance of computer program, method is computationally troublesome due to complex assessment strategies include	Opricovic, 1990	Approach is an overhauled assortment of TOPSIS	Within the confront of clashing situation, technique becomes challenging
Ashby	Chart give implies of evaluating execution of choices by looking at extent among stuff properties. The finest elective has been the most elevated execution record	Ashby, 1992	The method is exceptionally important for starting materials screening	The view is restricted to three decision attributes
COPRAS	The strategy uses coordinate and relative conditions of noteworthiness and productivity rating of options with regard to clashing choice scale to specify ideal solution	Zavadskas and Kaklauskas:1996	The strategy is basic and so far functional in tackling stuff selection difficulty	It very unsteady as information variety may result to alter in in general positioning
PSI (Preference selection index)	It could be a clever methodology which pick ideal elective among numerous choices out attending respective significance among choice scale	Maniya and Bhatt, 2010	The procedure dodges the test of allotting comparative significance betwixt choice norm.	has been made on quantifiable estimation which might require PC programming to diminish computational time
MAUA	The procedure bids a road for orderly compromise among decision measures in arrange for finest elective to be	Fishburn: 1965; Keeney: 1969; Raiffa: 1969	clination arrange for options are assessed at the same time	Choice property result is questionable

	selected from different means			

The hybridization of MCDM methods (for example, AHP, PROMETHEE, and VIKOR) promotes precision in prioritizing failure modes by eliminating the RPN limitations of the traditional FMEA. AHP can be used to determine the weights for each risk factor, and PROMETHEE may be used to prioritize the failure mode based on the weights of risk factors. VIKOR facilitates clarity in decision making in the presence of conflicting indicators, via its multi-criteria component. It promotes compromise by providing a “middle-ground” strategy that maximizes utility and minimizes subjectivity in decision-making. In short, VIKOR ensures optimum decision-making, by selecting the closest possible solution.

Thus, the criteria for decision making is presented using linguistic quantifiers like good, fair, and poor, which are useful when addressing complex problems. The concept of fuzzy logic is relevant here because it relates natural language to computer reasoning via linguistic quantifiers (Ramadan and Abou, 2000). Fuzzy logic can be used to successfully address issues emanating from uncertain and ambiguous information (Zadeh, 1978). Thus, integrating fuzzy login into grey systems theory may enhance resolution of multi-response, complex problems, and significantly improve the performance features of the process (Das et al., 2016). The grey based fuzzy technique has been successfully deployed in the past (Pattnaik, et al., 2013; Liu et al., 2009; Ahilan et al., 2009; and Hsiao et al., 2008), and is discussed next.

2.3. Grey Systems Theory

The Grey Systems Theory was introduced in 1982 by Deng. The theory is an effective way to address problems associated with uncertainty and incomplete information (bounded rationality). It does so by drawing out relevant knowledge from available information (Liu et al; 2016; Song Ding et al.,2022). As a mathematical concept, the grey systems theory has become widely used in multi-criteria decision making, mostly because of the prevalence of uncertain systems with incomplete information and small samples (Andrew, 2011). One of the ways in which the grey systems theory is applied is through mathematical analysis of systems with incomplete information or small samples.

In a 2020 study, Shuwei Wang et al, utilized a hierarchical expectation approach dependent on the dark framework hypothesis to forecast urban heat supply. Their forecast strategy was installed in hereditary calculation improvement with the target capacity of a back contrast proportion to achieve the most elevated exactness. Likewise, in 2019, Xinham Qiao et al, effectively forecasted the pollution on insulator surface in power system with the application of grey theory. Equally, Dong et al (2006) study evidenced their successful application of the grey theory along with linguistic variables in addressing multi-criteria decision-making under conditions of uncertainty. Wu et., (2018), proposed novel fraction grey manner to foresee unclear energy utilization in China, and this new model beat many criteria, concluding good predicting capability and trustworthy implementation.

Liou and Lo (2018) presented a modern approach that handles multiple criteria making in conjuction with grey hypothesis for FMEA. This approach shows that it is possible to include the anticipated fetched into the first RPN to return the real asset restrictions, think about the diverse loads of seriousness, incident, delectability, and charge based on the best–worst method (BWM) in RPN component computation, and utilize the grey stretch etymological factors to oversee data vulnerability.

Recently, in order to predict nuclear energy accurately to make sure reliable electricity supply and ease natural corruption difficulties Song Ding et al.(2022) sent an upgraded structure-versatile dim model by hypothetically giving the summed up time reaction work and precisely changing the foundation esteem dependent on Simpson's value. The outcome consistently illustrated that new method was reasonable.

3. Methodology

3.1. FMEA method

The aim of this study is to compare grey VIKOR with the traditional FMEA method to provide a more accurate ranking. A case study, which evaluate the risk factors for fire extinguisher failure, is presented to illustrate the application of the proposed model in a grey environment. For this purpose this study uses FMEA, a method in the field of reliability programming, to identify risks in the mechanical components of a fire extinguisher and all potential failure modes. To extract information from specialists, many experts and analysts of fire extinguisher who has accurate information about the work process and implementation of this device were used. Using verbal expressions, these experts prioritized the S, O, and D parameters. Finally, the criteria weight and parts prioritization were done based on the modern grey VIKOR method.

However, analysis of potential failure or error scenarios in traditional FMEA is a method frequently used to prevent errors in manufacturing and service industries. There are 10 steps involved in analysing potential failure and effects. These steps are shown in Figure 1.

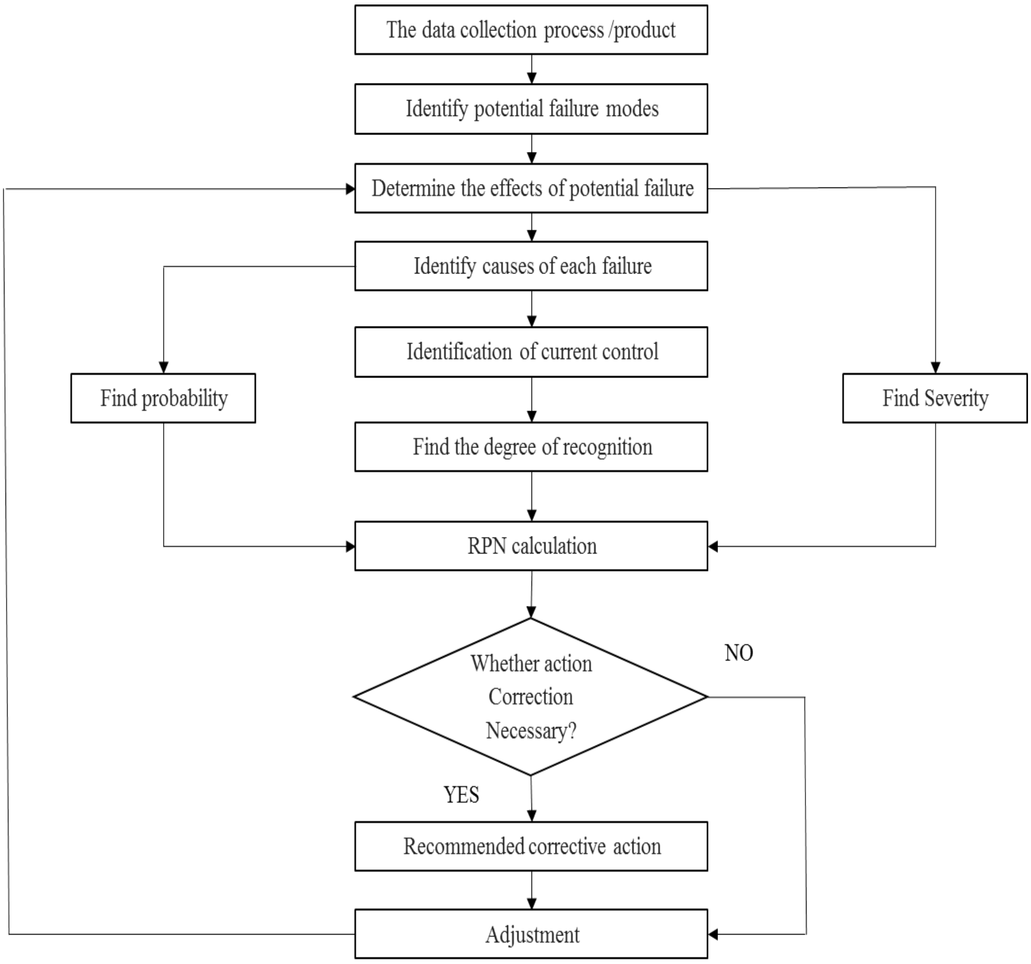


Figure 1: FMEA Flowchart: Steps to Analysing Potential System Failure an Effects. Derry et al.,2011

In these ten steps, as shown in the figure 1, after collecting information and identifying failure modes, its potential effects are identified, and in the most important step, the RPN method is used to rank the options, and finally the necessary measures are taken to correct the operations.

3.2. Grey Number theory

In some cases, grey numbers are perceived as extensions of fuzzy numbers (Khuman and Yang, 2014). A fuzzy number is a generalization of a regular, real number in the sense that it does not refer to one single value but rather to a connected set of possible values, where each possible value has its own weight between 0 and 1. This weight is called the membership function (Dijkman et al., 1983). Nonetheless, there is a major difference between both numbers. Although a grey number has vague values, the intervals between these values are known (Zakeri and Keramati, 2015). Grey numbers are similar to fuzzy numbers, but the fundamental difference between grey numbers and fuzzy numbers is that in grey numbers the exact value of the numbers is unknown, but the range that the value of that numbers contains is known. However, in a fuzzy number, while the number is defined as an interval, the exact value of the left and right sides of the number is not known and follows a membership function. Moreover grey theory is uncomplicated to apply and flexible while dealing with obscurity, which is its advantage over fuzzy sets hypothesis (Chalekaee et al., 2019). Grey can be defined as a numerical value with uncertain information. For instance, the positioning rules in a choice that can be communicated as phonetic factors with mathematical spans expressed._The numerical ranges were uncertain information. In other words, the number of grey to the exact number is unclear, but refers to the amount of time that it takes much known.

In the issue associated with the future, run instability, restricted data or information loss are present, grey numbers system is an effective instrument confronting comparative circumstances. The numbers are categorized into three sorts, based on data uncertainty: white number, grey number, and black number (Chalekaee et al., 2019). When the data is totally clear, the system is called a white system. When the data is incomplete it is called a grey system. When the data is unknown it is called a black system (Jui- Chen Huang, 2011).

If ⊗∈ [a, b] be considered as a grey figure, the structure can be seen as Figure 2 shows.

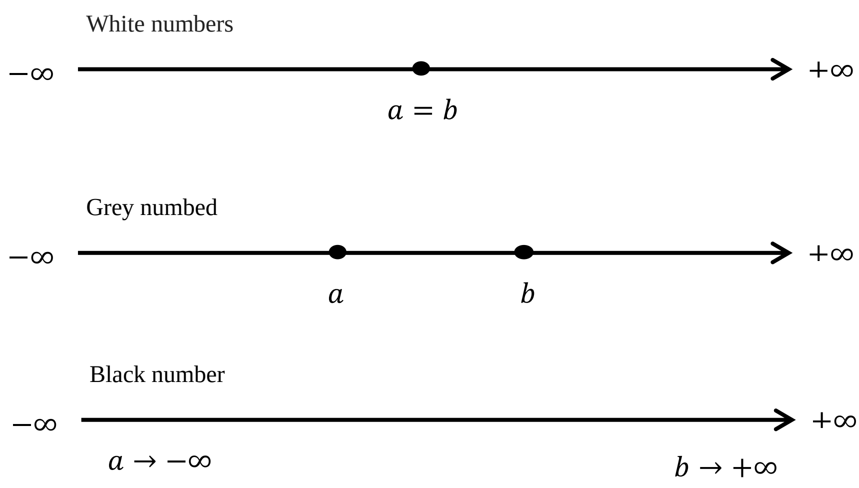


Figure 2: Numbers of grey. Wang & Wu (2008)

3.3. Relations between Grey numbers

A grey number can be related to (1) define:

$$\otimes \in [a, b] \tag{1}$$

If two grey $\otimes_1$, $\otimes_2$then have given (Moor, 1966).

$$\otimes_1 \in [a, b] \;,\quad \otimes_2 \in [c, d] \tag{2}$$

$$\otimes_1 + \otimes_2 \in [a + c, b + d] \tag{3}$$

$$\otimes_1 - \otimes_2 = \otimes_1 + (-\otimes_2) \tag{4}$$

$$-\otimes = [-b, -a] \tag{5}$$

$$\otimes^{-1} \in \left[\frac{1}{b}, \frac{1}{a}\right] \tag{6}$$

$$\otimes_1 \times \otimes_2 \in [min\{ac, ad, bc, bd\}, max\{ac, ab, bc, bd\}] \tag{7}$$

$$\frac{\otimes_1}{\otimes_2} = \otimes_1 \times (\otimes_2)^{-1} \tag{8}$$

$$\frac{\otimes_1}{\otimes_2} \in \left[min\left\{\frac{a}{c}, \frac{a}{d}, \frac{b}{c}, \frac{b}{d}\right\}, max\left\{\frac{a}{c}, \frac{a}{b}, \frac{b}{c}, \frac{b}{d}\right\}\right]; cd > 0 \tag{9}$$

$$k \times \otimes_1 \in [ka, kb];\; k \in R^+ \tag{10}$$

3.4. Comparing Grey Numbers

Since the data values are grey numbers and we need to choose the best and worst option in the proposed model to calculate the VIKOR index, we must compare the grey numbers. This process is as follows (Shi et al., 2005).

If $\otimes_1 \in$ [a, b], a <b and $\otimes_2 \in$ [c, d], c <d have two grey, grey possibility degree $\otimes_1 \leq \otimes_2$ defined as follows:

$$\mathrm{p}(\otimes_1 \leq \otimes_2) = \frac{\max(0, \mathrm{l}^* - \max(0, \mathrm{b} - \mathrm{c}))}{\mathrm{l}^*} \tag{11}$$

$$\mathrm{l}^* = \mathrm{l}(\otimes_1) + \mathrm{l}(\otimes_2) \tag{12}$$

In relation to (12) L length grey number $\otimes \in [a, b]$ and the equation (13) is calculated as:

$$l(\otimes) = b - a \tag{13}$$

The following four relationship between the positions of the two grey $\otimes_1$, $\otimes_2$ criteria:

A) If b = d, a = c, the two are equal and can be written grey $\otimes_1 = \otimes_2$ In this case, we have:

$$p(\otimes_1 < \otimes_2) = 0.5 \tag{14}$$

B) If c> b, then $\otimes_1 < \otimes_2$ and in this case we have:

$$p(\otimes_1 < \otimes_2) = 1 \tag{15}$$

C) If d <a , then $\otimes_1 > \otimes_2$ and in this case we have:

$$p(\otimes_1 \leq \otimes_2) = 0 \tag{16}$$

D) If the interference between them, then if p $(\otimes_1 \leq \otimes_2) > 0.5$ then it can be

Said $\otimes_1 < \otimes_2$ and if p $(\otimes_1 < \otimes_2) < 0.5$, the result $\otimes_1 > \otimes_2$ is.

3.5. Evaluation of the analysis of failure modes using the techniques in the grey VIKOR:

Suppose that an MCDM of k (k = 1, 2, ..., k), and m different options A_1, A_2, A_3, ..., A_m each option evaluated by the n criteria is and to evaluate the option of i to j-th measure as a number of grey in a decision matrix G_{ij} specified.

Then, to solve using VIKOR, we follow these steps:

The first step: using the views of decision makers, grey scales and a total weight rating of grey and obtains options. We will make the decision matrix grey (Taghavifard & Malek, 2011).

$$D \otimes = \begin{bmatrix} G_{11\otimes} & \cdots & G_{1n\otimes} \\ \vdots & \cdots & \vdots \\ G_{m1\otimes} & \cdots & G_{mn\otimes} \end{bmatrix} \tag{17}$$

$$W \otimes = [W_1 \otimes, W_2 \otimes, \ldots, W_2 \otimes] \tag{18}$$

$\otimes G_{ij}$, ranked A_i option to j-th and $\otimes W_j$, the importance weights j.

3.6. Set benchmarks and weight

Suppose $\otimes W = \{\otimes W_1, \otimes W_2, \ldots, \otimes W_m\}$ is the vector of weighted criteria. In this study, the weight criteria using linguistic variables expressed and to increase the level of accuracy and judgment of experts in close to reality, to the Table (2) linguistic variables in a Likert scale and the use of "grey numbers," said. In this study, the weight of the importance of risk factors and failure modes ranked according to each risk factor to consider is the number of grey.

Table 2: Scale to determine the weighting of criteria (Taghavifard & Malek, 2011)

Scale	Very High	High	Med High	Medium	Med Low	Low	Very Low
	VH	H	MH	M	ML	L	VL
⊗ **w**	[0.9 1]	[0.7 0.9]	[0.6 0.7]	[0.4 0.6]	[0.3 0.4]	[0.1 0.3]	[0 0.1]

If the decision makers (DMs) including k, the standard weight of Q_i through the equation (19) is obtained.

$$\otimes W_j = \frac{1}{k}\{\otimes W_j{}^1 + \otimes W_j{}^2 + \cdots + \otimes W_j{}^k\}$$
(19)

Where $\otimes_{Wj}{}^{k}$ (j = 1, 2,..., n) j-th standard weight, the k th decision by grey numbers to the equation (20) is shown.

$$\otimes W_j^k = \left[W\_{}_j^k, \bar{W}_j^k\right]$$
(20)

3.7. Assessing and ranking the options

Options can be weighted in determining the priority of the range [0,10], with grey numbers on a scale of seven bulls, In this case, the choice is very poor grey corresponding number,[0, 1], and an option that is very good with grey numbers[9,10] in the Table (3) is defined.

Table 3: Scale for the Assessment of Options

scale	Very High	high	Med High	Medium	Med Low	Low	Very Low
	VH	H	MH	M	ML	L	VL
⊗ **G**	[9 10]	[7 9]	[6 7]	[4 6]	[3 4]	[1 3]	[0 1]

Taghvifard & Malek (2011)

Preferred option of the i to j-th criterion of the relationship (21) is calculated.

$$\otimes G_{ij} = \frac{1}{k}\left\{\otimes {G_{ij}}^{1} + \otimes {G_{ij}}^{2} + \cdots + \otimes {G_{ij}}^{k}\right\}$$

(21)

In this regard $\otimes G_{ij}$ (i = 1,2, ..., m, j = 1,2, ..., n), the decision-maker to assess the k th i th option than to j-th criteria and can be in the form of relation (22), respectively.

$$\otimes G_{ij}^{k} = \left[G_{-}{}_{ij}^{k}, \bar{G}_{ij}^{k}\right]$$

(22)

Step Two: The criteria for ranking the best and worst standards by the relationships we choose

(Opricovic & Tzeng, 2007).

$$f_j^{+} = \begin{cases} max_i \quad G_{ij} & \text{To measure profits} \\ min_i \quad G_{ij} & \text{For cost criteria} \end{cases}$$

(23)

$$f_j^{-} = \begin{cases} min_i \quad G_{ij} & \text{To measure profits} \\ max_i \quad G_{ij} & \text{For cost criteria} \end{cases} \qquad (24)$$

Step Three: index S_i and R_i, utility and non-utility options, with about 25 and 26 are calculated (Opricovic & Tzeng, 2007).

$$S_i = \sum_{j=1}^{n} \left(w_j \times \frac{\left(G_j^{+} - G_{ij}\right)}{\left(G_j^{+} - G_j^{-}\right)} \right) \qquad S_i \in [0,1] \tag{25}$$

$$R_i = max_j \left(w_j \times \frac{\left(G_j^{+} - G_{ij}\right)}{\left(G_j^{+} - G_j^{-}\right)} \right) \tag{26}$$

Step Four: Index Q_i (i = 1,2, ..., m) from the equation (27) obtains.(Opricovic & Tzeng, 2007).

$$Q_i = \frac{V\left(S_i - S^{+}\right)}{\left(S^{-} - S^{+}\right)} + \frac{(1-V)\left(R_i - R^{+}\right)}{\left(R^{-} - R^{+}\right)} \tag{27}$$

In relation to the above, we have:

$$\begin{cases} S^{-} = max_i \ S_i \\ S^{+} = min_i \ S_i \end{cases} \tag{28}$$

$$\begin{cases} R^{-} = max_i \ R_i \\ R^{+} = min_i \ R_i \end{cases} \tag{29}$$

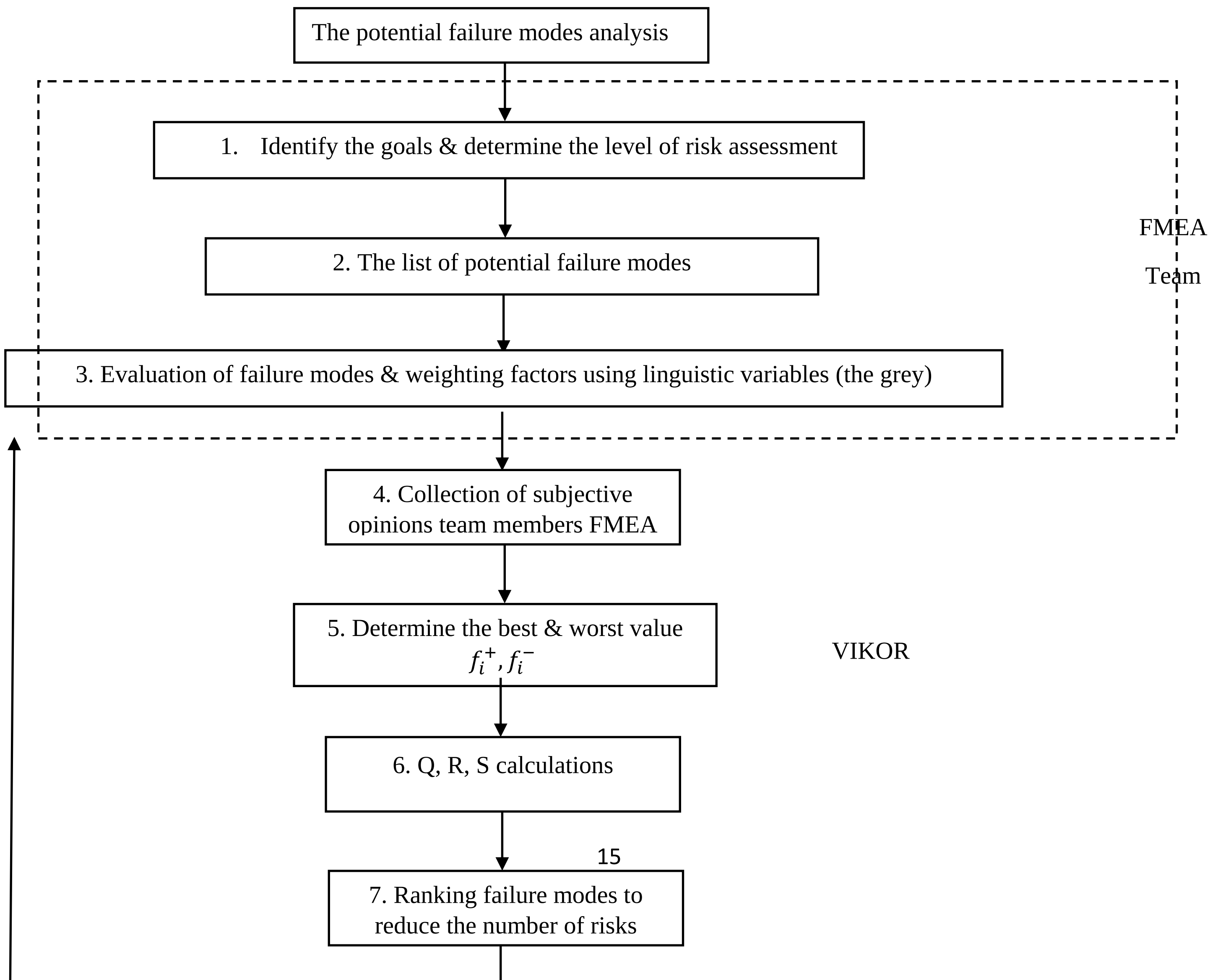
Weight strategy (the majority of the criteria) or maximum utility group which has a fixed value is 0.5. When v is larger than 0.5, the index Q_i is the maximum utility and when v is smaller than 0.5, indicating that the maximum non-utility. In general, if the value of v is equal to 0.5, means the group is in agreement (Liu et al., 2012).

Step Five: options based on our rating Q_i.

Q_i can be ranked based on the value options. Q_i much more options that they be placed at a higher priority, and smaller amounts of Q_i means the lower ranks (Liu et al., 2012).

3.8. Proposed method

With respect to the previous model, integrated flowchart is shown in Figure 3. Based on the material described before, evaluation of failure modes and weighting factors are used by linguistic variables of grey theory. in the grey FMEA method, after identifying the working process in the fire extinguisher, investigation of the performance of its components as well as all failure modes of the fire extinguisher and its effects were investigated. Definitive data were then obtained using linguistic expressions and the opinions of experts who had high empirical and scientific competence in relation to the product. for ranking, the definite values were converted to grey numbers. In order to identify and prioritize product parts for improvement or replacement, the FMEA approach index was used. The framework used in this research is based on a multi-criteria decision model. Then, using VIKOR decision method to rank failure modes and finally, taking corrective actions where are required.



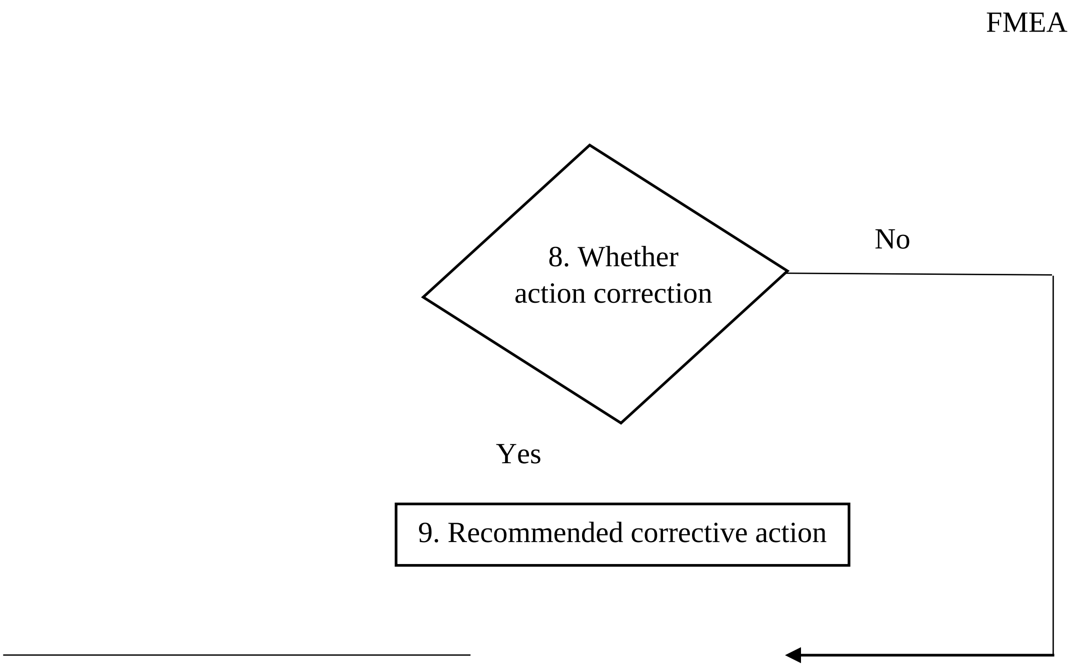


Figure 3: Developed framework of research

4. Results

Since fire is possible everywhere the use of fire extinguishers device is inevitable. Therefore, many studies have been conducted on the fire extinguisher as a case study of this research. A team included five employees gathered to work in the process FMEA. In order to identify and prioritize product parts for improvement or replacement. the FMEA, including design engineers, production supervisors, technicians, quality, purchasing manager and director of marketing and sales. The most logical failure includes: Broken pipe, casing and charging indicator. The team on each of the components, brainstorming for all potential failures did. For example, for pipes, potential failure of cracks, holes and was blocked. The bodies of failures were to crush the body and the other body on the label is not attached properly. Potential causes of the process and abbreviations were used for each component separately in Tables (4), (5) and (6).

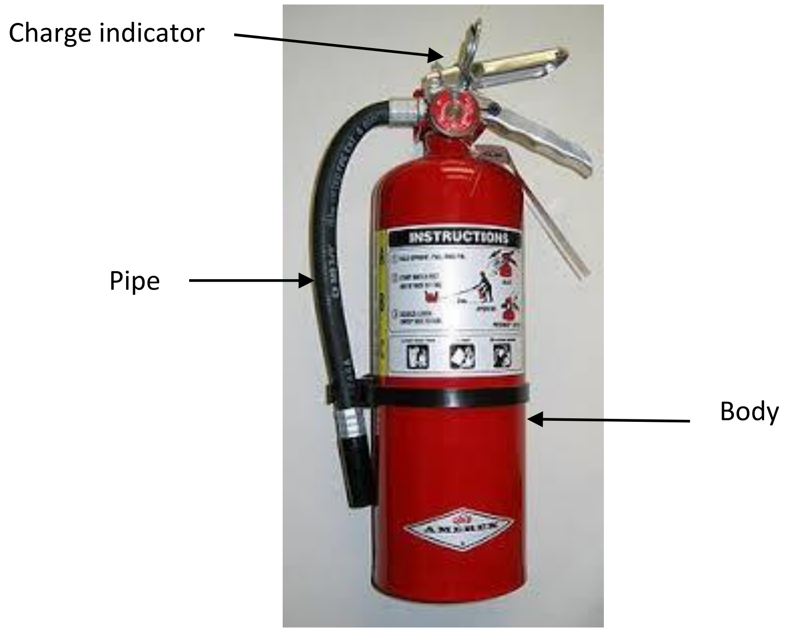


Table 4: symbols of" Pipe damage" in the production fire extinguisher

Components & role		cause of failure	severity	occurrence	detection	RPN
Pipe damage (cracks, holes, blockages) (A)	A_1	Excessive heat or cold	10	5	6	300
	A_2	Damage to the Pipe during the operation	10	6	5	300
	A_3	Foreign material in the pipe	10	6	3	180

Table 5: Symbols of "Body damage" in the production of fire extinguishers.

Components & role		Potential cause of failure	severity	occurrence	Detection	RPN
	B_1	Lack of color	10	6	2	120

Body damage (color, label) (B)	B_2	Paint spray nozzle relatively involved	10	9	4	360
	B_3	The label is wrong or bad.	5	7	2	70
	B_4	Excessive humidity	7	5	2	70

Table 6: Symbols of "Charge degree" in the production of fire extinguishers.

Components & role		**Potential cause of failure**	**severity**	**occurrence**	**detection**	**RPN**
Charge degree:	C_1	Degree is not calibrated correctly	10	7	5	350
remaining	C_2	No glass heat treatment	8	3	4	96
determined (C)	C_3	Crystal hit a sharp object	8	8	9	432

More experts in the FMEA (five) on weight factors, S, O and D is evaluated by the number of grey separately.

4.1. Ranking among the potential cause of failure "Pipe damage".

Weight and risk factors for the damage Pipe in the Table (7) is shown and in the following Table (2) these values are converted to grey numbers and results in the Table (8) is given.

To obtain the weight of the factors, since the problem has three indicators, three pairwise comparisons must be made. To obtain the weight of the indicators, a pairwise comparison questionnaire was used, which includes a table in which decision makers use the five variables to compare the indicators with each other and compare the preferences of the indicators.

Table 7: Weight factors S, O and D using a grey scale for "damage pipe"

Weight

	Decision maker1	Decision maker2	Decision maker3	Decision maker4	Decision maker5
S	H	VH	VH	H	H
O	ML	L	ML	ML	ML
D	L	L	ML	ML	L

Table 8: weight conversion factors, S, O and D "damage pipe" grey numbers.

	Weight				
	Decision maker1	Decision maker2	Decision maker3	Decision maker4	Decision maker5
S	[0.7 0.9]	[0.9 1]	[0.9 1]	[0.7 0.9]	[0.7 0.9]
O	[0.3 0.4]	[0.1 0.3]	[0.3 0.4]	[0.3 0.4]	[0.3 0.4]
D	[0.1 0.3]	[0.1 0.3]	[0.3 0.4]	[0/3 0.4]	[0.1 0.3]

Risk factors grey scale values by using the comments of the FMEA, for "damage pipe" in the Table (9) is expressed. According to the Table (2) amounts factors grey "grey values" has become in the Table (10) results are shown.

Table 9: Factors grey values S, O and D "damage pipe"

	Severity (S)				
	Decision maker1	Decision maker2	Decision maker3	Decision maker4	Decision maker5
A_1	VH	VH	H	VH	VH
A_2	VH	H	H	VH	H
A_3	VH	VH	VH	H	H
					Occurrence(O)
A_1	M	M	ML	M	M
A_2	M	MH	M	M	M
A_3	M	M	MH	MH	M
					(D)Detection
A_1	MH	MH	MH	M	MH
A_2	M	M	ML	M	M

A_3	ML	ML	ML	L	ML

Table 10: Conversion factor values S, O and D grey numbers for "damage pipe"

	Severity (S)				
	Decision maker1	Decision maker2	Decision maker3	Decision maker4	Decision maker5
A_1	[9 10]	[9 10]	[7 9]	[9 10]	[9 10]
A_2	[9 10]	[7 9]	[7 9]	[9 10]	[7 9]
A_3	[9 10]	[9 10]	[9 10]	[7 9]	[7 9]
Occurrence(O)					
A_1	[4 6]	[4 6]	[3 4]	[4 6]	[4 6]
A_2	[4 6]	[4 6]	[4 6]	[4 6]	[4 6]
A_3	[4 6]	[4 6]	[6 7]	[6 7]	[4 6]
Detection (D)					
A_1	[6 7]	[6 7]	[6 7]	[4 6]	[6 7]
A_2	[4 6]	[4 6]	[3 4]	[4 6]	[4 6]
A_3	[3 4]	[3 4]	[3 4]	[1 3]	[3 4]

Table 11 shows the decision matrix. After solved by VIKOR, ranking in grey in the Table (12) is.

Table 11: The decision matrix for "damage pipe"

	S	**O**	**D**
$\mathbf{A_1}$	[8.6 9.6]	[3.8 5.6]	[5.6 6.8]
$\mathbf{A_2}$	[7.8 9.4]	[4.4 6.2]	[3.8 5.6]
$\mathbf{A_3}$	[8.2 9.8]	[4.8 6.2]	[2.6 3.8]
Weight	[0.78 0.94]	[0.26 0.38]	[0.18 0.34]

Table 12: rank potential causes of damage "damage pipe"

	$\mathbf{A_1}$	$\mathbf{A_2}$	$\mathbf{A_3}$
S	[-3.11 2.47]	[-3.2 2.96]	[-4.18 2.39]

R	[0.09 0.68]	[0 0.51]	[-0.6 0.6]
Q	[-3.11 2.47]	[0.55 4.4]	[0.8 5.11]
Ranking	**1**	**2**	**3**

4.2. Ranking potential causes of failure "body damage"

In this part, all the steps needed to rank potential causes of damage "damage pipe" was carried out, in order to do so. Weight factors S, O and D for "body damage" Table (13) states. Table 14 shows the grey scale values of the risk factors. And the solution, according to the model, grey Ranking Table (15) is shown.

Table 13: Weight factors S, O and D using a grey scale for "body damage"

	Weight				
	Decision maker1	Decision maker2	Decision maker3	Decision maker4	Decision maker5
S	M	MH	MH	M	M
O	ML	M	ML	ML	ML
D	ML	L	L	L	L

Table 14: Factors grey values S, O and D "body damage"

	Severity (S)				
	Decision maker1	Decision maker2	Decision maker3	Decision maker4	Decision maker5
B_1	VH	VH	VH	H	VH
B_2	VH	VH	H	H	VH
B_3	H	H	VH	H	H
B_4	H	H	H	MH	H
	Occurrence (O)				
B_1	MH	MH	M	M	MH
B_2	VH	H	VH	VH	H
B_3	MH	MH	H	MH	H
B_4	M	M	M	ML	M
	Detection (D)				
B_1	L	ML	L	L	L

B_2	M	ML	ML	M	M
B_3	L	ML	L	L	L
B_4	L	L	VL	L	L

Table 15: rank potential causes of damage "body damage"

	B_1	**B_2**	**B3**	**B_4**
S	[-19.95 1.95]	[-17.71 5.73]	[-16.48 9.4]	[-13 13.1]
R	[-0.07 0.54]	[0.03 1.41]	[-0.38 0.77]	[-0.57 0.57]
Q	[-1.33 1.33]	[-2.3 0.88]	[-1.81 1.52]	[-1.73 1.59]
Ranking	**2**	**1**	**3**	**4**

4.3. Ranking potential causes of damage "charge degree"

In this part, all the steps needed to rank potential causes of damage "damage pipe" was carried out, in order to do so. Weight factors S, O and D for "charge degree" Table (16) states. Table

(17) Shows the grey scale values of the risk factors, and the solution, according to the model, grey Ranking Table (18) is shown.

Table 16: Weight factors S, O and D using a grey scale for "charge degree"

	Weight				
	Decision maker1	Decision maker2	Decision maker3	Decision maker4	Decision maker5
S	MH	M	MH	MH	M
O	ML	L	L	ML	L
D	L	ML	ML	L	L

Table 17: Factors grey values S, O and D “charge degree"

	Severity (S)				
	Decision maker1	Decision maker2	Decision maker3	Decision maker4	Decision maker5
C_1	VH	H	VH	VH	VH
C_2	H	MH	H	H	H
C_3	H	H	MH	H	MH

	Occurrence (O)				
C_1	MH	MH	H	MH	MH
C_2	ML	ML	L	ML	ML
C_3	H	H	MH	H	H
	Detection (D)				
C_1	M	M	M	ML	M
C_2	ML	ML	M	M	ML
C_3	H	VH	H	VH	H

Table 18: rank potential causes of damage "charge degree"

	C_1	**C_2**	**C3**
S	[-0.45 6.01]	[-2.55 3.54]	[-2.45 3.92]
R	[0.065 5.28]	[-2.31 3.3]	[0.09 0.68]
Q	[-5.25 1]	[-3.35 3.17]	[-6.26 1.23]
Ranking	**2**	**3**	**1**

5. Discussion: Comparison of the results of the model proposed and traditional FMEA

The purpose of this study is to present a model for risk assessment and ranking using FMEA and VIKOR method in grey environment. To determine the difference between the traditional FMEA method and the grey FMEA. Table (19) presents the results of the ranking compiled by solving the proposed model and traditional method. As can be seen in the new model, the following results were obtained: identify high-risk factor is more pronounced. This model can solve the problems of traditional Risk Priority Number. As could be observed, in the role of "Damage pipe" excessive heat or cold shows the greatest failure in solving both. FMEA methodology traditional two cause’s damage to the pipes during the operation of foreign material in the pipe is placed in the second, while the proposed model the damage to the tube during the operation and after foreign material in the pipe presents the most important factors in causing the failure. That corrective measure can be taken to resolve failures. In the role of "body damage", the model shows a more accurate ranking. According to the Table (19), in the traditional FMEA wrong or bad label and excessive humidity was ranked third. However, the proposed model could distinguish apart ranking these factors, so that mistakes or poor quality label, ranking third and fourth place were excessive humidity. In the role of the charge level as well, as can be seen both of them for potential causes of damage rating is the same and this is indicative of the model is correct.

According to the table (19), by comparing the three columns related to “RPN traditional”, “classic ranking” and “proposed ranking model”, it is clear that by using the proposed ranking model, we were able to provide a more accurate ranking than the traditional mode.

Table 19: Comparison of the results of the proposed model and traditional FMEA

Comparison of the proposed model and traditional FMEA					
Pipe damage (cracks, holes, blockages)					
Row	Potential cause of failure	RPN traditional	Ranking classic	proposed model	Ranking
1	Excessive heat or cold	300	1	1	
2	Damage to the Pipe during the operation	300	1	2	
3	Foreign material in the pipe	180	2	3	
Body damage (color, label)					
1	Lack of color	120	2	2	
2	Paint spray nozzle relatively involved	360	1	1	
3	The label is wrong or bad.	70	3	3	
4	Excessive humidity	70	3	4	
Charge degree: (remaining determined)					
1	Degree is not calibrated correctly	350	2	2	
2	No glass heat treatment	96	3	3	
3	Crystal hit a sharp object	432	1	1	

6.Conclusion

Th preceding discussions acknowledge that FMEA is an efficient tool for managers and experts, as it provides a model for proactive risk identification, assessment and management in processes, and systems. This invariably enhances customer satisfaction by improving the quality of products being manufactured and identifying key processes and problems prior to production and sales. The FMEA is currently adopted in different organizations and industries worldwide. It is based on group work that requires knowledge, awareness, and interest of a group of experts and their ability to carry out activities in a working group. New grey FMEA based on the theory of grey sets and VIKOR method proposed to deal with risk assessment problems in FMEA. The present case study demonstrates the ability of the proposed FMEA model to manage crisis analysis clearly and easily. That is to say, to rank the failure modes in the interval of uncertainty although the values of S, O, and D are known to classify failure states in the uncertainty interval, the numbers themselves are unknown. Because real-world information is often inadequate, applications need to be developed from white-number-based methods to grey-number-based methods. For this reason, the grey method was used in this study. Then VIKOR method for ranking the risk factors in the analysis of potential failure modes was used.

According to Section 4, the proposed model has a more precise ranking compared to the traditional FMEA case. This new model can be considered in corrective actions to resolve the failure. In the proposed model, the ranking is done more accurately. As shown in Table 19, in the traditional case, "Damage to the Pipe during the operation" was ranked first, while in the grey case, this risk dropped to second place and "Excessive heat or cold" is the biggest risk for Pipe damage because it has the first rank. Also, "Excessive humidity", which was traditionally in the third place, dropped to the fourth place in the grey state, which indicates the lowest risk for body damage. The rest of the modes remained unchanged.

It is worth mentioning that, in conducting this research, there were limitations in which the information about the failure of the devices was expressed in general, and this information was not recorded anywhere, and the information of the expert had to be sufficient.

According to the results of this study can be related suggestions for future research and analysis of failure modes provided. You can use other methods such as SAW and TOPSIS to combined Ranking ANP in the grey area, because of the interaction of different factors and failure to gain weight for the parameters of uncertainty is noteworthy. In addition, in the field of aerospace, the proposed model can be used to rank risk factors for appropriate corrective action.

6. References

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