TITLE

BACHELOR TERM PROJECT REPORT

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28th November, 2022

DECLARATION

I certify that

a. The work contained in this report has been done by me under the guidance of my supervisor.

b. The work has not been submitted to any other Institute for any degree or diploma.

c. I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.

d. Whenever I have used materials (data, theoretical analysis, figures, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.

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CERTIFICATE

This is to certify that the project report entitled "**Z-number quality index (ZQI) and its application in university laboratory Fire Safety Risk Assessment**" submitted by **Aryan Sinha (19MF3IM03)** to Indian Institute of Technology, Kharagpur towards partial fulfilment of requirements for the award of degree of Dual Bachelor of Technology (Hons.) in Mechanical Engineering is a record of bona fide work carried out by him under my supervision and guidance during Autumn Semester 2022-2023.

Date: 28/11/2022

Place: Kharagpur

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1 Introduction

There are various types of accidents that happens in a university laboratory, many of them involving multiple risks. With an intensive atmosphere of research, there should exist some proper form of management to optimize the service quality and comfortability of their laboratories. Therefore, risk assessment for unsafe behaviour is an important task in the management of university laboratories. To prevent the occurrence of these hazards, deep understanding of risks potential in a laboratory is a necessity. In this paper, we have mainly focused on fire risks and its assessment.

For e.g.- In the chemical laboratory, various risks were identified which could lead to fire in the laboratory. There are various reactions going out in the laboratory which involve flammable chemicals whose involvement could lead to fire. In the electrical laboratory, various components such as wires, resistors, circuit board, power source etc. possesses a threat to the laboratory. For ex. – open wires or wires cut at multiple points, damage components, circuit boards could lead to short circuit and fire. Many of them have been listed down in the questionnaire. Similarly, for laboratories involving flammable gas/oil cylinders, there is a risk involved for the broking of fire in the laboratory.

When characterising risks according to FMEA analysis, some of them have high frequency of occurring, some have high severity, while some have very low detectability. How can we find out which risks are overall more hazardous to us? For this purpose, our project aims at analysing multiple fire risks that occur in different kinds of laboratories and rank them according to the most hazardous one. The process involves Z number quality index values. Z numbers are fuzzy linguistic values consisting of two parts, opinion and reliability of that opinion which consists of values having fuzzy numbers. The opinion part consist of Trapezoidal fuzzy number values and reliability part has the triangular fuzzy number values. These types of numbers have been used to capture more information regarding the risk uncertainty.

2 Literature Review

FMEA methods have been generally used to solve the problems regarding evaluation failure modes. The traditional FMEA comprises of the following process: A group of experts identify various potential risks for some system. Then the frequency/probability of the failure (O), the severity of the consequences (S), and the chance/probability of the failure going undetected (D) is being calculated, followed by multiplying them together to calculate the risk priority number (RPN). Finally, these RPN are ranked and critical risks are identified. However, there are many shortcomings of the traditional FMEA method that are partially solved by some methods like introduction of factor weights into the RPN calculation, analysis of failure mode relationships and structures, and fuzzy expression and calculation of RPN factors and weights. However, many remaining problems require additional research. For example, the linguistic fuzziness of expert scoring has been extensively studied, but the sampling randomness of expert scoring has not been considered.

Sr No.	Title of the Research Paper	Issues Addressed
1	A pattern of fire risk assessment and emergency management in educational center laboratories	In the paper, we figured out the general fire risks involved in the laboratory and use it to prepare the questionnaire.
2	Application of Risk Identification, Risk Analysis, and Risk Assessment in the University Laboratory	This paper listed out some general risks which were involved in some laboratories and their Frequency, Severity and Detectability values. It helped us to figure out some general risks which could cause fire.
3	The Risk Priority Number Evaluation of FMEA Analysis Based on Random Uncertainty and Fuzzy Uncertainty	In the paper, we studied about RPN calculation. Fuzzy Beta-Binomial Approach has been followed for SOD Ranking evaluation. This method gave different results than traditional FMEA because it considered Fuzzy uncertainty and random uncertainty also while evaluating the O, S, D for each failure mode.
4	Ranking of Z-numbers Based on the Developed Golden Rule Representative Value	In the paper, we studied about Z-numbers, how to formulate fuzzy numbers in form of a Z-number and how to find fuzzy probability distributions for each Z-number
5	Fuzzy Numbers in Cost Range Estimating	In the paper, we studied about Fuzzy numbers, how to find the defuzzified value for them, their mean and variance for the corresponding probability

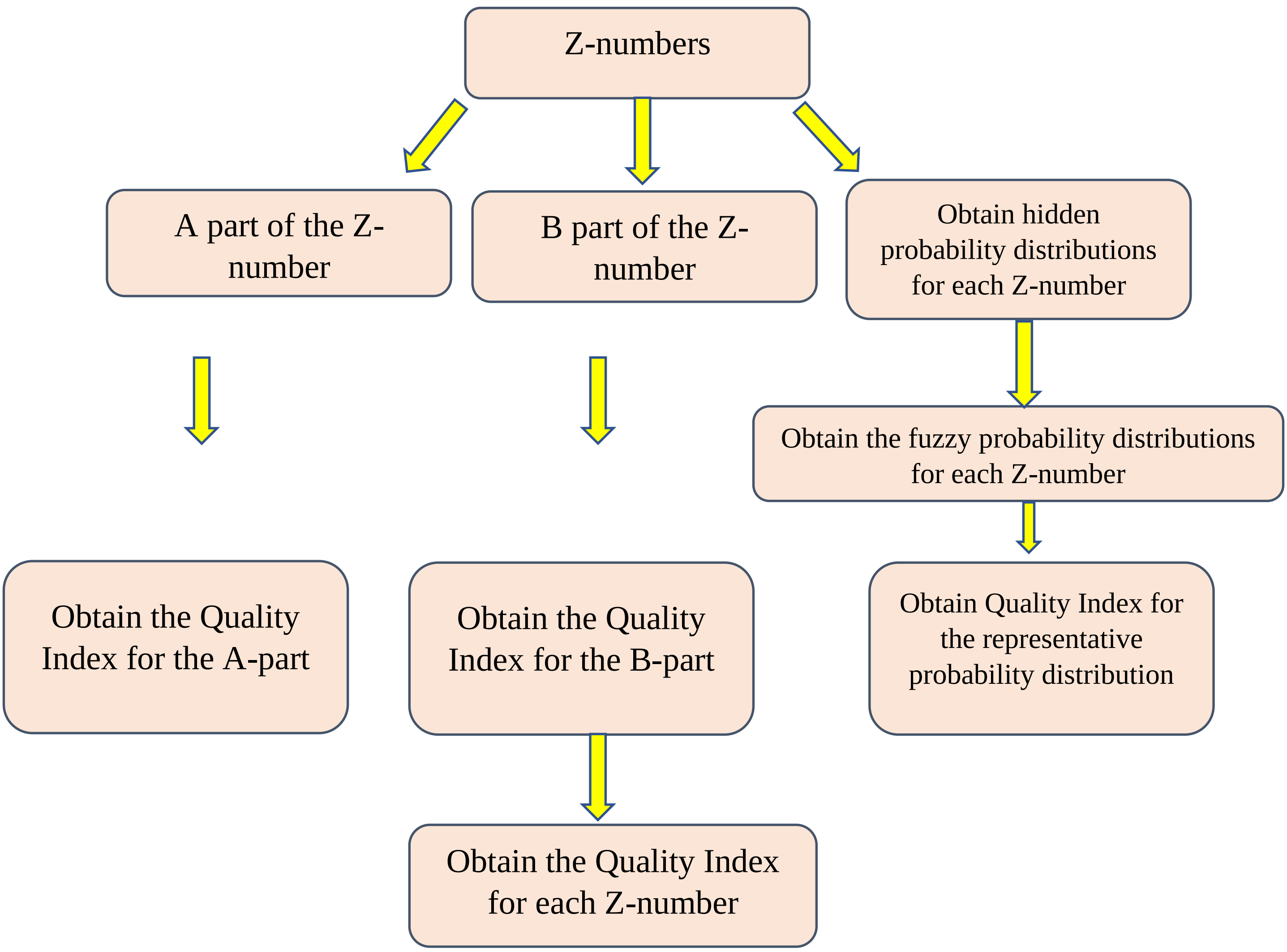
		distributions, Fuzziness and Ambiguity Measures and ultimately their fuzzy number quality Index.

3 Research Gaps

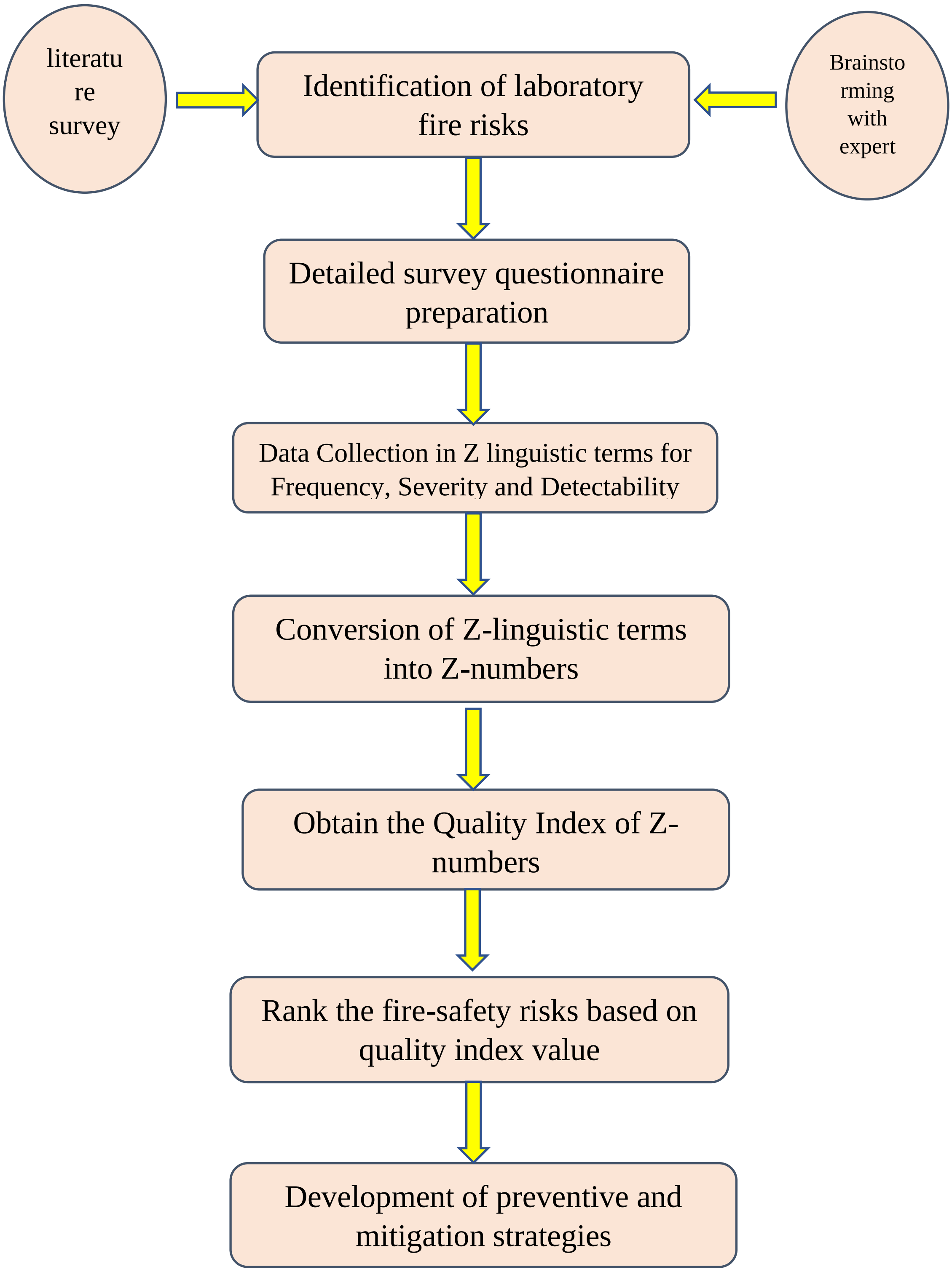
- All these papers do not take into account the random uncertainty and the fuzzy uncertainty.
- We calculated the fuzzy probability distribution to take into account of these.
- There is dearth of literature in university laboratory risk assessment in Indian context.
- Risk assessment information reliability has not been captured in university laboratory risk assessment.

4 Methodology

The methodology for developing Z-quality index is shown in Figure**.



Further, the overall methodology for fire safety risk evaluation is shown in Figure**.



4.1 Stepwise procedure

For collecting the data regarding the fire safety risks, a detailed questionnaire is prepared. From the questionnaire, we have our input data in the form of Z-number. The input data consists of Frequency(O), Severity(S) and Detectability(D) values of opinion(A) and confidence(B) for 25 failure modes. These particular values are of fuzzy number format. The opinion(A) column has values in the trapezoidal fuzzy number form while confidence(B) has triangular fuzzy number form. We have to find out the FNQI (fuzzy number quality index) of these numbers and the Quality Index for fuzzy probability distribution of the Z-numbers as the output. These fuzzy numbers for opinion (A) and confidence (B) are in general represented as a four element notation (a,b,c,d).

4.1.1 Fuzzy number quality index (FNQI)

The FNQI of a fuzzy number can be calculated as-

$$FNQI = [W_F F(A) + W_{AG} AG(A)] / [W_F + W_{AG}]$$

Where F(A) and AG(A) are the fuzziness and ambiguity measures of fuzzy number A respectively and W_F and W_{AG} are the weights of the fuzziness measure and ambiguity measure, respectively. In this paper, equal weights are assumed for both measures, so W_F and W_{AG} becomes equal, therefore the formula for FNQI reduces to –

$$FNQI = [F(A) + AG(A)] / 2$$

4.1.1.1 Fuzziness and ambiguity measures

Since for the calculation of FNQI, fuzziness(F(A)) and ambiguity measures (AG(A)) are required, the equations for calculating them are –

For a given fuzzy set Ax, the measure of fuzziness, FA, is obtained using the following equation:

$$F(A) = \sum_{x \in X} (1 - |2A(x) - 1|)$$

Upon simplification, for the given fuzzy numbers, it can be reduced to –

$$F(A) = (b + d - a - c) / 2$$

AG can be considered as a global spread of the fuzzy number, therefore for the ambiguity measure calculation, we use the following equations –

1. For a trapezoidal fuzzy number, A (a, b, c, d):
$$AG = (c - b)/2 + [(d - c) + (b - a)] /6$$
2. For a triangular fuzzy number, A (a, b, b, c):
$$AG = [(c - b) + (b - a)] /6$$

Hence, we can easily calculate the FNQI for any fuzzy number.

4.1.2 Z-number

A Z-number, Z = (A, B) is an ordered pair of fuzzy numbers related to the real-valued uncertainty variable X. These variables are frequency(O), severity(S) and detectability(D). 'A' is the fuzzy constraint on X, and 'B' is a measure of the reliability of A. We regard the following discrete Z-number as discrete analogues of continuous Z-number Z = (A, B).

$((\mu_A(x_1)/x_1 + \mu_A(x_2)/x_2 + ... + \mu_A(x_n)/x_n), (\mu_B(b_1)/b_1 + \mu_B(b_2)/b_2 + ... + \mu_B(b_m)/b_m))$

4.1.2.1 Hidden probability Distribution

To calculate the hidden probability distribution, we use a maximum entropy optimization model, which is shown below-

$$\text{Max } H(x) = -\sum p_X(x_i)\log_2 p_X(x_i)$$

$$\text{s.t-}$$

$$\sum \mu_A(x_i) \cdot p_X(x_i) = b_j$$

$$p_X(x_1) + p_X(x_2) + ... + p_X(x_n) = 1$$

$$0 \leq p_X(x_i) \leq 1$$

$$\sum x_i p_X(x_i) = \sum x_i \mu_A(x_i) / \sum \mu_A(x_i)$$

Through this optimisation model, we can plot the hidden probability distribution for each Z-number.

4.1.2.2 Fuzzy probability distribution

The fuzzy probability distribution of the Z-number is defined as the product of the membership function of the A component and the hidden probability distribution, as follows

$$FPD_j = \frac{\mu_A(x_1)p_X^j(x_1)}{x_1} + \frac{\mu_A(x_2)p_X^j(x_2)}{x_2} +, \dots, + \frac{\mu_A(x_n)p_X^j(x_n)}{x_n}$$

This represents the fuzzy probability distribution of a Z-number.

4.1.2.3 Quality Index for Fuzzy probability distribution

To calculate the Quality Index for Fuzzy probability distribution, we use the following algorithm-

Input: some probability distributions, $p_1, p_2, \cdots, p_n$

$$d(p_i, p_j) = \sqrt{\frac{1}{2}(\vec{p_i} - \vec{p_j})^T(\vec{p_i} - \vec{p_j})}$$

$$sim(p_i, p_j) = 1 - d(p_i, p_j)$$

$$sup(p_i) = \sum_{j=1, j\neq i}^{n} sim(p_i, p_j)$$

$$crd(p_i) = \frac{sup(p_i)}{\sum_{i=1}^{n} sup(p_i)}$$

$$||p_i||^2 = \sum_{j=1}^{n} (p_{ij})^2$$

$$Qu(p_i) = e^{crd(p_i) * ||p_i||^2}$$

Here, Qu represents the Quality Index for a probability distribution.

4.1.2.4 Quality Index of Z-number

The overall Quality Index for a Z-number can be calculated as-

$$QI = \frac{(\frac{QI(A) + Qu}{2}) + Q(B)}{2}$$

Where QI(A), QI(B) and Qu represents Quality Index of A part and B part of the Z-number and Qu represents the Quality Index of the probability distribution of that Z-number.

5 Case Study

To demonstrate the applicability of the proposed methodology, fire related risks from a leading industry is considered. A detailed questionnaire is prepared to collect data from a team of experts from the same industry. The screenshot of the data is shown below (see Table**).

Table**: Data collection for fire safety risks

	Fire Risks/ Failure modes	Causes	Effects	Frequency of occurrence (O)		Severity(S)		Detectability(D)	
				opinion	confidence	opinion	confidence	opinion	confidence
1	Absence of fire Extinguisher	Improper design of the laboratory	Fire control could not be possible	L	H	H	MH	VH	VH
2	No proper working of Fire Extinguisher	No proper maintenance of the laboratory	Fire control could not be possible	H	MH	VH	MH	VH	H
3	No Exhaust	Improper design of laboratory	No control on smoke due to fire leading to life threatening effects on people	VL	H	VH	VH	VH	VH
4	Working exhaust failure	The exhaust would be a defective piece	No control on smoke due to fire	H	MH	VH	M	VL	H
5	Blocked windows	No proper maintenance of the Laboratory	No control on smoke due to fire	ML	H	H	H	MH	H
6	Flammable Gas Cylinders' Pipes broken/blocked	No proper checking of the components laboratory	Blast in the lab causing fire	M	MH	H	ML	L	VH
7	Flammable Gas Cylinders' Pipes Leakage	No proper checking of the components laboratory	The leakage of gas from pipes can cause fire in the lab	H	MH	VH	ML	VH	VH
8	Flammable Oil tanks' pipelines broken/blocked	No proper checking of the components laboratory	Blast in the lab causing fire	M	MH	H	H	M	M
9	Flammable Oil tanks' pipelines Leakage	No proper checking of the components laboratory	The leakage of oil can cause fire in the lab	H	H	VH	H	VH	VH
10	Damaged Bunsen burner	No proper maintenance of the laboratory	Injury risk while using it	ML	MH	VH	MH	VL	H
11	Corroded pipeline of Bunsen burner	No proper maintenance of the laboratory	Gas leakage could take place that can cause fire in the lab	MH	H	VH	H	VH	VH
12	Improper storage of Flammable substance	Improper management system within the laboratory	These flammable substances can cause fire when in contact with ignition source	H	MH	H	M	H	MH
13	Release of Flammable chemical fumes	The reactions involving such chemicals were not taken place in a controlled environment	Release of flammable chemical fumes coming in contact with ignition source can cause fire	VL	VH	VH	MH	VH	VH
14	Runaway chemical chain Reaction	Experiment was done without proper precautionary measures	A runaway chemical reaction can cause damage to the people performing experiment	ML	MH	VH	MH	VL	H
15	Overuse of power-supply machines	Number of machines could be less than required	Machine can catch fire and blasts could also happen	VL	H	VH	MH	VH	VH

16	Using too old machines	Improper maintenance of the laboratory	The parts could easily catch fire and blasts could happen	H	VH	VH	MH	VL	H
17	Emergency exit locked	No proper maintenance of the laboratory	People can get trapped within the lab	H	H	H	H	MH	H
18	Emergency exit unavailable	Improper design of the fire-escape system during designing of the lab	No escape of people from the laboratory, could lead to life threatening results	M	MH	H	H	L	M
19	Emergency exit pathway already blocked	No proper maintenance of the laboratory	People would have no time to clear the way, leading to trapping within the lab	MH	MH	VH	H	VH	VH
20	Emergency exit direction-signage instructions not available	Improper design of the fire-escape system during designing of the lab	No information for the people about where to escape	L	MH	H	VH	L	M
21	Emergency alarm not working	No proper maintenance of the laboratory	People could not be aware that a fire had broken in the lab	H	VH	VH	H	VH	VH
22	Open Electric wires	No proper checking of the Laboratory components	While working in the electrical lab, short circuit may take place leading to fire	M	H	VH	MH	VL	H
23	Damaged circuit board	No proper maintenance of the Laboratory components	Short circuit may take place leading to fire in the lab	H	MH	VH	H	VH	VH
24	Proper data of electrical components not printed on them	No proper maintenance of the laboratory	The electrical equipment may get overheated and catch fire	H	MH	VL	M	H	MH
25	Delay in calling fire brigade	Irresponsible reaction to the initiation of fire in the lab	Spread of fire across whole lab leading to life-threatening effects	VL	VH	VH	H	VH	VH

Table**: The conversion table of Z linguistic terms to Z-numbers is shown above.

A (opinion)	
Linguistic variable	Trapezoidal Fuzzy number
Very Low (VL)	(0,0,1,2)
Low (L)	(1,2,2,3)
Medium Low (ML)	(2,3,4,5)
Moderate (M)	(4,5,5,6)
Medium High (MH)	(5,6,7,8)
High (H)	(7,8,8,9)
Very High (VH)	(8,9,10,10)

B (reliability component)	
Linguistic Variable	Triangular Fuzzy number
Very Low (VL)	(0,0,0.1)
Low (L)	(0,0.1,0.3)
Medium Low (ML)	(0.1,0.3,0.5)
Medium (M)	(0.3,0.5,0.7)
Medium High (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1)
Very High (VH)	(0.9,1,1)

There are 25 FMs whose Z linguistic terms are given for Frequency, Severity and Detectability. These linguistic terms are then converted to Z-numbers, having two fuzzy number's opinion(A), which has values in the trapezoidal fuzzy number form and reliability/confidence(B), which has triangular fuzzy number form.

From the data, the Quality Index is calculated for the A part and the B part of the Z -number by the process as mentioned above. The hidden probability distribution and the fuzzy probability distribution is also calculated. Finally, the overall quality index of a particular Z-number can be obtained using the process mentioned above. The quality index values for each FM are shown below in the table.

Quality Index		
Frequency	Severity	Detectability
0.966883621	0.947499008	0.295439463
0.947499008	0.795412242	0.628764673
0.996435835	0.295439463	0.295439463
0.947499008	0.79537225	0.996435835
0.944389644	0.7809011	0.866000137
0.996789442	0.94399087	0.634328085
0.947499008	0.792447244	0.295439463
0.95795795	0.7809011	0.957423029
0.7809011	0.628764673	0.295439463
0.910434162	0.795412242	0.996435835
0.866000137	0.628764673	0.295439463
0.947499008	0.947346419	0.947499008
0.665177374	0.795412242	0.295439463
0.910434162	0.795412242	0.996435835
0.996435835	0.795412242	0.295439463
0.44760204	0.795412242	0.996435835
0.7809011	0.7809011	0.866000137

0.95795795	0.7809011	0.929351296
0.932532424	0.628764673	0.295439463
0.932127447	0.44760204	0.929351296
0.44760204	0.628764673	0.295439463
0.891540431	0.795412242	0.996435835
0.947499008	0.628764673	0.295439463
0.947499008	0.942041609	0.947499008
0.665177374	0.628764673	0.295439463

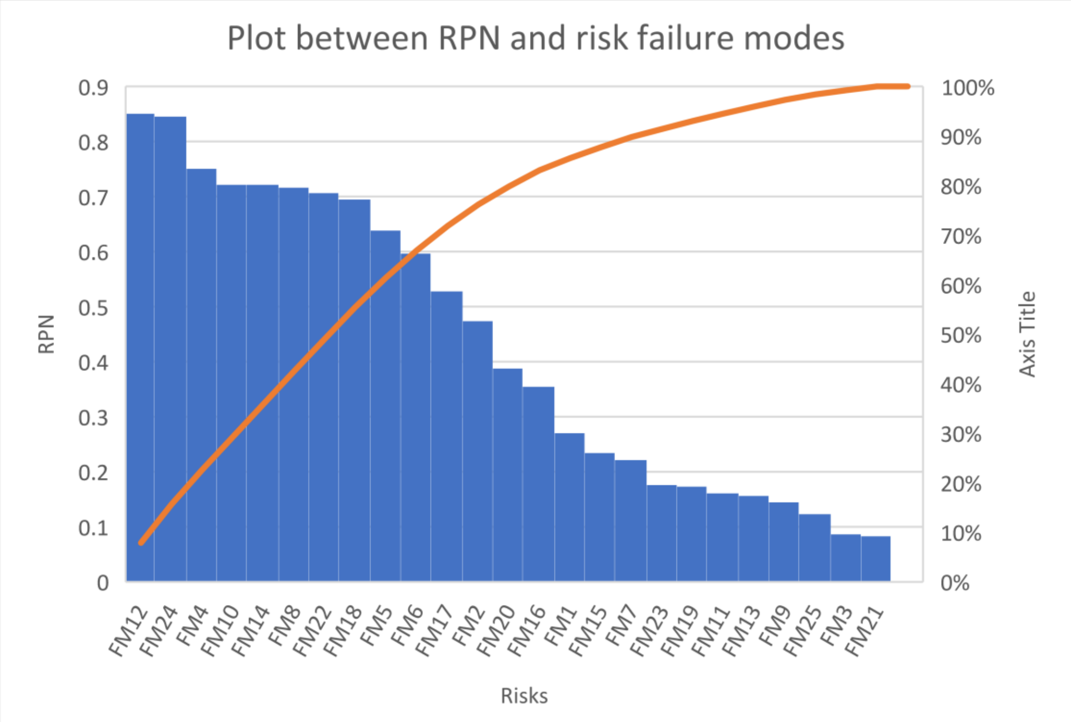
These quality index values for frequency, severity and delectability are combined together to obtain the RPN values for each FM. The final RPN values for each FM are shown below.

FMs	RPN
FM1	0.270658376
FM2	0.473869949
FM3	0.08697338
FM4	0.750928412
FM5	0.638653375
FM6	0.596877439
FM7	0.221828646
FM8	0.716219844
FM9	0.14506167
FM10	0.721589416
FM11	0.160869828
FM12	0.850484388
FM13	0.156314132
FM14	0.721589416
FM15	0.2341586
FM16	0.3547592
FM17	0.528092536
FM18	0.695220211
FM19	0.173228992
FM20	0.387745943
FM21	0.083147404
FM22	0.706614674
FM23	0.176009213
FM24	0.845721971
FM25	0.123564611

Finally, the ranking of the FM is obtained by the decreasing order of RPNs.

FM12 > FM24 > FM4 > FM10 > FM14 > FM8 > FM22 > FM18 > FM5 > FM6 > FM17 > FM2 > FM20 > FM16 > FM1 > FM15 > FM7 > FM23 > FM19 > FM11 > FM13 > FM9 > FM25 > FM3 > FM21

As shown below is the pareto chart of RPN and various risk failure modes.



6 Discussion

From the chart, 9 FMs among 25 FMs have RPN value above 0.6, they are FM12, FM24, FM4, FM10, FM14, FM8, FM22, FM18 and FM5 and had been categorized as important risks. The risk “Improper storage of Flammable substance” has topped the chart. It means according to the data derived from experts and the methodology used, among all the given risks, this particular risk has the most hazardous potential. This could be because the frequency, severity and detectability of this risk is high. For the prevention of these risk, mitigation strategies should be developed such as proper maintenance of laboratories should take place to control the risks of happening of any accidents.

7 Conclusion

For actually evaluation risk analysis process in the real world, there are at least two types of uncertainties, fuzzy uncertainty and random uncertainty. It is more beneficial to build a decision model by considering both uncertainties simultaneously for the improvement the validity of the evaluation results. From the traditional methods of FMEA analysis, their studies have not considered these factors. Although the traditional FMEA method has these types of shortcomings, the prioritization of failure risks by calculating RPN is the most common method in the industry because the RPN calculation is simpler and easier to understand than other methods.

This study proposes a method to introduce both random and fuzzy uncertainty into FMEA to calculate RPN. It can be seen from the literature review that scholars have extended FMEA studies by introducing fuzzy uncertainty or random uncertainty into traditional FMEA analysis to compensate for the shortcomings of the traditional approach, but these studies consider either fuzzy or random uncertainty separately and rarely consider both uncertainties simultaneously in a single model. This study also captures risk assessment information reliability by using the concept of Z-numbers that has not been captured in university laboratory risk assessment papers previously. Moreover, these data we consider in the study is obtained for university laboratory risk assessment in Indian context, which is not been considered before. There can be further development in this process. The weights of different criteria can be taken, expert's different weights can be taken. The three risk factors O, S, and D have been calculated on a discrete ordinal scale. However, the multiplication is not meaningful on the ordinal scale, to which MCDM methods such as TOPSIS and DEMATEL can be used. Further, Cost, quality, and other factors may also be added to improve the theoretical basis of the RPN evaluation.

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