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Fuzzy FMEA Model: A Case Study to Identify Rejection and Losses in Fibre Industry

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Abstract

The growing competition between fibre producing industry and the standards to which, it requires high quality standards. ABC company's procurement department data shows N of number of defects in cellulose pulp sheet uncurl every month. Cellulose sheet is an important raw material in the fibre (Staple) producing industry. Quality tools such as Failure Mode and Effects Analysis (FMEA) applied to admeasure the risk of potential miscarriages. This study aims to determine the most dominant activity as the cause of rejection and losses of cellulose sheets and evince improvements that can be made by using the fuzzy FMEA model. Data collection techniques in the study are using the method of observations, interviews as well as assessment of experts to identity it. This study is based on the four criterion which dominates the defect of cellulose pulp sheet vis. Processing activities, acceptance, examination and delivery. Solicitation for overcoming these problems is presented.

Keywords: Fibre industry, Quality, FMEA, Fuzzy FMEA, Cellulose pulp.

1 | Introduction

In recent years, fibre manufacturing companies have faced an increasing number of competitive environments. With the enlargement of competitors in the market forces industries are constantly improve their processes and forces them to adopt innovative strategies for enlarging their product range and offer more and more personalised product. One of the main raw materials that focused in the fulfilment of quality is the quality of the cellulose pulp sheet raw material. Generally, the cellulose pulp sheet is made of hardwood, the wood chips go through a process of purification and separation in series of steps with require steam and chemicals (sodium hydroxide, sulphur dioxide) [1]. The role and function of cellulose sheet as one of the key raw materials in the staple fibre manufacturing industry makes the fulfilment of the quality and quantity of cellulose sheet as per the need. It is always said that the quality always proportional to productivity [2].

Risk management is the primordial part of the any organizations' strategy in which they propound the risks associated with the processes in order to achieve benefits.

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The main objective of the risk management is to maximize the sustainable value to all the activities, by enhancing the likelihood of their success and alleviating the likelihood of failures and uncertainties in conjunction with fulfilling or not fulfilling the objectives. One of the important tools for the risk management, is the FMEA [3].

FMEA is the method used to identify and analyse the possible failure modes of the process [4] and [5]. It is risk management methodology used for identification of the root causes. It is basically preventive method, by which risk will eliminate at the minimum level. FMEA can be used stand alone as well as part of the any quality management technique [6].

Company gets cellulose pulp sheet with its subsidiary industry. The use of cellulose pulp sheet a day is around 50-150tons & if consider a per month usage can be reaches up to 1500-4500tons. Hereby cellulose pulp sheet becomes an essential component in fibre manufacturing industry. On the basis of studies, we conducted research to identify cardinal cause of failure in achieving the quality and quantity of cellulose pulp sheet by using FMEA, Fuzzy FMEA methods. All these tools are very powerful methods for measuring the reliability of product and processes. These methods are helpful in identifying us to which risk has more concern and so that the action to prevent the loss before its arrival, hence reduces the loss of money and time of the industry [7] and [8]. In this paper, the critical failure mode factors are examined by using the FMEA in the fuzzy environment with the trapezoidal and triangular membership functions. The Fuzzy FMEA approach is applied to identifying, prioritizing and tracking the key potential failure effect, causes and controlling factors. This research is done for the fibre manufacturing industry for its raw material i.e., cellulose sheet which is come from the outside industry. The main motivation behind this research paper is to reduce the failures during handling with cellulose sheet and improve the process of handling by the reduction in the losses of the industry. The final results of this case study were to determine the most dominant activity for the cause of rejection and losses in the cellulose pulp sheet.

2 | Literature Review

Many studies indicate to use FMEA for the risk management. In 2004, Carbone and Tippett [29] put an application of project risk management by evaluating the risk score and RPN value to identify the most critical risk events which needs immediate risk responses. As per the management view, the sequential RPN calculations are very easy to realize the outcomes o the results. But we talk about the technical perspective, there are number of writers who hold concerns related to apply the traditional FMEA approach for the calculation of the Risk Priority Number (RPN). Exemplification of the Bowles and Peláez [23] and Puente et al. [30] focused number of loop holes in both the ways in which the calculations are made and the processes in which the results should have interpreted. By illustrating, with the different failure mode with assessment of severity say (8), occurrence say (6) and detection say (4), may have lower RPN (192) than that of with the high severity, high occurrence and moderate level of detection (say 7,7 and 5 achieves a RPN of 245). So far, the management point of view, the for most failure instigates higher priority for corrective action. The fuzzy model is first introduced by Zadeh [28], gives flexibility and expressive way to reach the risk associated with the substantive failure modes. The recent work within the cellulose pulp sheet is seen in apparent inspections in the fibre manufacturing industry, the usage of the fuzzy FMEA is shown in many varied sectors of the activity. The fuzzy FMEA is the improvement over the classical FMEA, in an ordinary method that is to be used as to fuzzing the risk parameters with appropriate holding functions. Many studies proposed the implementation of the Fuzzy FMEA to improve the efficiency of FMEA and overcome its limitations [9] and [10].

Fuzzy FMEA has been implemented to many distinct industries for different types of applications. A risk based fuzzy evidential outlook is tendering in by employing interval based Dempster- Shafer theory and fuzzy axiomatic design in order the analyse the risk of failure modes with fuzzy logic structures [11]. The competency of the proposed model investigated by the researchers by putting example and the results when they compared with riskless evaluations. An FMEA risk management outlook is proposed

in [12] by fuzzy approach-based interface system with the intention of curtailing the failures of Load, Haul, Dump (LHD) Machine. An extended FMEA approach by catch hold of fuzzy best-worst method and multi-objective optimization by ratio analysis based on Z-number theory (Z-MOORA) method [13]. These methods are used to overcoming of the various traditional RPN pitfalls. Riaz and Hashmi [14] established new extension of fuzzy sets to the Linear Diophantine Fuzzy Set (LDFS) for efficient and flexible structure to deal with uncertainties. They presented geometrical properties of LDFS to compare the fuzzy sets. In [15], they created Spherical Linear Diophantine Fuzzy Set (SLDFS) which is more efficient to address various uncertainties in a parametric view. Spherical linear Diophantine fuzzy information includes additional features of reference or control parameters. They defined operations on picture fuzzy numbers and smooth aggregation operators. Riaz et al. [16] extended the conventional orthopair fuzzy sets to the q-Rung Orthopair Fuzzy Sets (q-ROFSs) so that their can analyse wider membership function which will help decision makers to put rational perception. Khan et al. [17] defined the linear Diophantine fuzzy numbers, they find ranking function for triangular linear Diophantine fuzzy number with no such limitations take grades generally in q-ROFS, Pythagorean Fuzzy Sets (PFS). The problems allied with healthcare are prioritize with the implementation of the fuzzy FMEA system [10]. They used FMEA along with linguistic variables and fuzzy system. Inputs like S & O were explained according the five linguistic conditions and trapezoidal function. Enabler D and output RPN ere explained by trapezoidal, linguistic terms and triangular functions. Considering the vast modes of failure comes in healthcare institutions, their prioritization is need of an hour. FMEA is best suited for identifying the potential failures. Nevertheless, the implementation of the fuzzy FMEA technique vindicated to be the more flexible alternative of evaluation by providing the image of the uncertainty associated with the variables [18].

The risk assessment model in the green supply chain applying the fuzzy approach to FMEA is focused in [19] and being implemented in Indian plastic industries. In different areas of application in management failure factors were examined through an intuitionistic fuzzy environment as a case study of Iran oil and gas service [20]. The outcomes of this study have shown are lacking behind the leadership and management commitments of the company. In a fuzzy number method for FMEA proposes to cater the drawbacks of concise FMEA and fuzzy based FMEA methods. A specific methodology is developed that combines with the similarities of fuzzy numbers and possibility doctrine. All these above studies have visualized those copulations of previous studies were not exceptionally important but applying the fuzzy FMEA is seen to be lackadaisical. Thereby, due to the contribution of fuzzy logics, it is probabilistic to improve the understanding of complex dynamic problems by considering the subjective and inappropriate information. This approach helps to all possible accurate risk and overcomes the limitations of FMEA. The fuzzy rule-based system was applied widely for as much that put distinct advantages. As compared to the traditional methods of FMEA, the fuzzy FMEA system provided following advantages [21], [22] and [23].

I. Helps the researcher to use linguistic terms in criticality assessment for assessing directly the failure modes associated with it.
II. Haziness of data or information not explicitly present, could be used in the assessment and management in a well organised way.
III. The more flexibility of the structural combination of Severity (S), Occurrence (O) and Detection (D).

3 | Methodology

The fuzzy FMEA system follows a basic structure of the fuzzy FMEA epitome system consists of three chief modules: input module, knowledge base module and output interface model, as shown in *Fig. 1* [22]. As it can be observing that in *Fig. 1*, the inputs variables concur to the parameters of S, O and D [24]. The output variables equal to the RPN. S, O and D have to fuzzified by using the membership functions to identify the degree of membership among each input classes. The resulting fuzzy inputs will be evaluated in the fuzzy environment, which uses a well-defined rule base. These rules are fall under the "IF- THEN" type and together with fuzzy logic operations are used to identify the level of risk of failure. The fuzzy conclusion is then defuzzified to get RPN. The higher the value of the RPN, the greater the risk and vice versa.

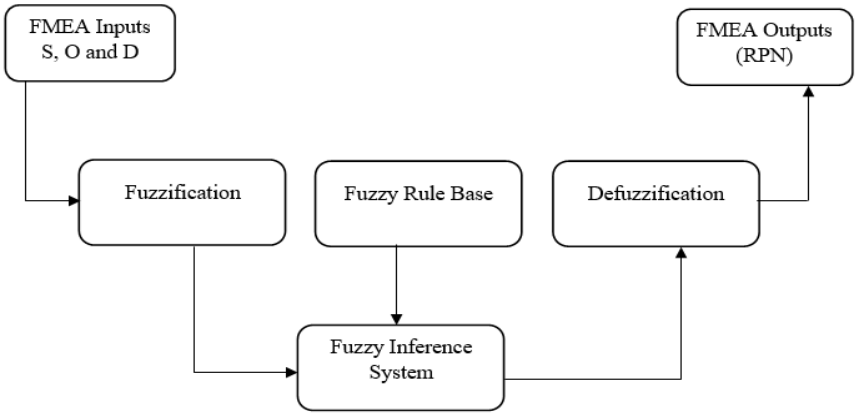

Fig. 1. Fuzzy inference system.

Fuzzy FMEA is legitimate technique which is employed to evaluate the output response from the input data. There are multiply reasons for using the Fuzzy FMEA are beneficial that's why the business commentators suggest the Fuzzy FMEA, these being, among others [25].

The fuzzy FMEA logic concept is very easy to understand. The fundamentals of mathematics are also less complicated in the fuzzy interface environment.

I. This is flexible and can endure the data if any undue error exists in the databases.
II. This technique has potential to model complex non-linear functions in the very short span of time.
III. This approach can also form the experience of specialists in absentia for the need of surplus training.
IV. This technique doesn't require an advance language, it works on the basis of simple language.

FMEA was used as a conjugation method with the other quality tools for alienating the potential risk and fabricate confidence in the system. Besides, the FMEA implementation used the RPN for visualizing the result of the assessment. The implementation process of the FMEA has to cast the correct evaluation of RPN was important because it was an intimation of the stiff severity to take appropriate actions to reduce or eliminate the risk that might occur. When FMEA used in the operable work was found., the RPN methods exhibited some drawbacks. Hereof, there are many researchers proposed FMEA implementation to step up its efficiency as a way to fix above mentioned drawbacks pertinent in real work [26].

3.1 | Fuzzification of the Inputs and Outputs

In this process, the S, O and D variables are modified into the linguistic terms and membership functions [27]. Several experts with varying degrees of competence are used to create the membership functions [22]. In this case, S, O and D are assigned to linguistic terms, rooted on FMEA's scales [24]. In FMEA, S, O and D are ceded in the values from 1 to 10. RPN will computed by the equation:

$$RPN = S \times O \times D.$$

As per the above mathematical expression, the minimum and maximum values which will be computed for RPN is 1 to 1000, respectively. Since the for the fuzzy FMEA will based on the traditional FMEA data, we were adopting the same values to define the universal for each variable. Hence, it is considered a universal value from 1 to 10 for S, O and D; and from 1 to 1000 for RPN. Then membership functions were designed in pursuance of the weight of the every FMEA classification. The data collection techniques in this study were using the method of observations, interviews and group discussion as well as the evaluation of the experts to identify it. Tables represent below the linguistic variables and membership functions of S, O, D and RPN.

Table 1. Linguistic variables and membership function for severity (S).

Input	Severity (S)
None	[0, 1, 2, 3]
Low	[2, 3, 4, 5]
Average	[4, 5, 6, 7]
High	[6, 7, 8, 9]
dangerous	[7, 8, 9, 10]

Table 2. Linguistic variables and membership function for Occurrence (O) event.

Input	Occurrence (O)
Nearly Impossible	[0, 1.5, 2.5]
Low	[1.5, 3, 4.5]
Average	[3.5, 4.5, 5.5]
High	[6.5, 7, 8.5]
Almost Few	[7.5, 8.5, 10]

Table 3. Linguistic variables and membership function for detection (D).

Input	Detection (D)
Almost Few	[0, 1.5, 2.5]
High	[1.5, 3, 4.5]
Average	[3, 4.5, 6]
Low	[4.5, 5.5, 7]
Nearly Impossible	[7, 8,10]

Table 4. Linguistic variables and membership function for RPN.

Input	RPN
No Important	[0, 100, 200]
Very Few Important	[150, 250, 400]
Few Important	[300, 450, 600]
Average important	[400, 550, 700]
Important	[600, 750, 900]
Very Important	[800, 950, 1000]

For defining the functions of variable S came to the less concern that the lowest values of S have for the process, and the way this is the reason that's why the trapezoidal functions with large belonging intervals were used. For above the values of average, we tried to redefine the criterion by using triangular function for the term "high". Thus, greater importance is obtained with the help of greater variability.

The O variable is represented with a set of symmetric functions, highlighten the terms "low" and "High", to define them precisely. This reflects the context in which the model is applied, since it is understand that the greatest variability should exist in the intervals that both terms represented.

The variable D emphasis for the "High" and "Average" terms, with the assignment of triangular functions. Because it is in the value range of these two functions are most concentrated, hence it deserves to be more accurately defined.

The output variable four triangular and two trapezoidal membership functions were selected. The range for the output variable defined by the set of [0, 1000], thus permitting in a more advance phase, comparing the output obtained by the implementation of Fuzzy RPN model with one obtained by basic FMEA RPN.

3.2 | Fuzzy Inference Process

In this paper, minimum inference engine used with the help of MATLAB to combine the fuzzy IF-THEN rules in the fuzzy rule base and being implication the fuzzy conclusions. The minimum inference engine uses:

I. Min operator for "AND" in the IF part of rules and rules and max operator for the "OR" in the IF part rules.
II. The prime combination to aggregate the consequences of the individual rules.

An example is offered to explain the process of minimum inference engine.

There are multiple defuzzification algorithms have been developed. In this paper the centre of gravity method defuzzification will be adopted. For determining the defuzzification value an expression is:

$$COG = \frac{\sum \mu_i(x) \times x_i}{\sum \mu_i(x)}.$$

Where; x_i= The membership function reaches maximum value and $\mu_i(x)$= degree of membership function.

Trapezoidal Membership Function. The trapezoidal membership function is used in the Severity (S) for expressing the vagueness of the information which in generally caused due to linguistic assessments through the transformation into the numerical variables.

$$\mu_i(x) = \begin{cases} 0 & \text{if} \quad x < a \\ \dfrac{(x-a)}{(b-a)} & \text{if} \quad a \le x \le b \\ 1 & \text{if} \quad b \le x \le c \\ \dfrac{(d-x)}{(d-c)} & \text{if} \quad c \le x \le d \\ 0 & \text{if} \quad x > d \end{cases}.$$

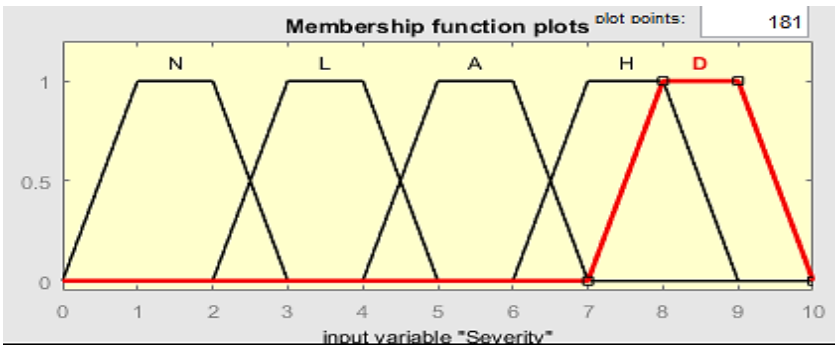

Fig. 2. Trapezoidal membership function for severity (S).

Triangular Membership Function. The Triangular Membership Function is used in the sets except in the Severity (S). It is elaborated by the three parameters (a, b, c) where for every value of x the membership function $\mu_i(x)$ is described in the *Fig. 3* and *Fig. 4*.

$$\mu_i(x) = \begin{cases} 0 & \text{if} \quad x < a \\ \dfrac{(x-a)}{(b-a)} & \text{if} \quad a \le x \le b \\ \dfrac{(c-x)}{(c-b)} & \text{if} \quad b \le x \le c \\ 0 & \text{if} \quad x > c \end{cases}.$$

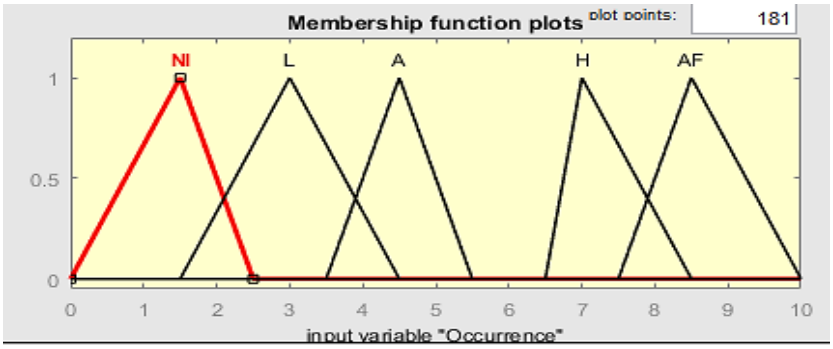

Fig. 3. Triangular membership function for occurrence (O).

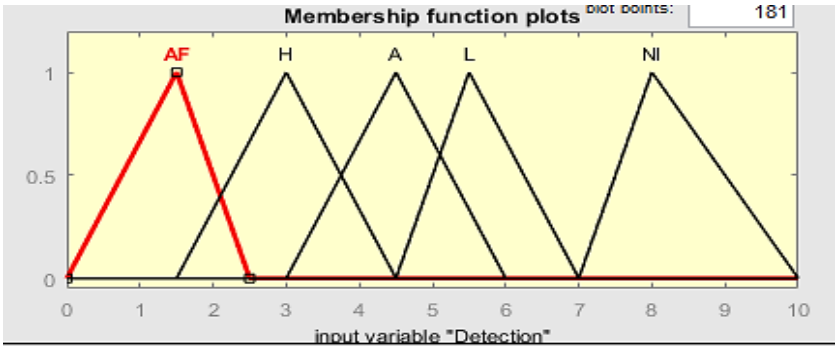

Fig. 4. Triangular membership function for detection (D).

If we compare the trapezoidal membership function is slightly complex to the triangular membership function. It needs more memory size for variable. Furthermore, it is complex process, the performance of trapezoidal function is better than that of triangular membership function. Severity plays an important role in this research paper so, for widening the spectrum of severity we choose trapezoidal function and others are operated at triangular membership function.

4 | Results and Discussion

4.1 | Identification of the Ordering Business Process for Cellulose Pulp Sheet

Fig. 5 gives a descriptive understanding of the activities for ordering supply chain to use of the cellulose pulp sheet. Few activities are carried out by the company and suppliers. But number of the activities can be identified by the type of failure and potential failure modes that can be occur.

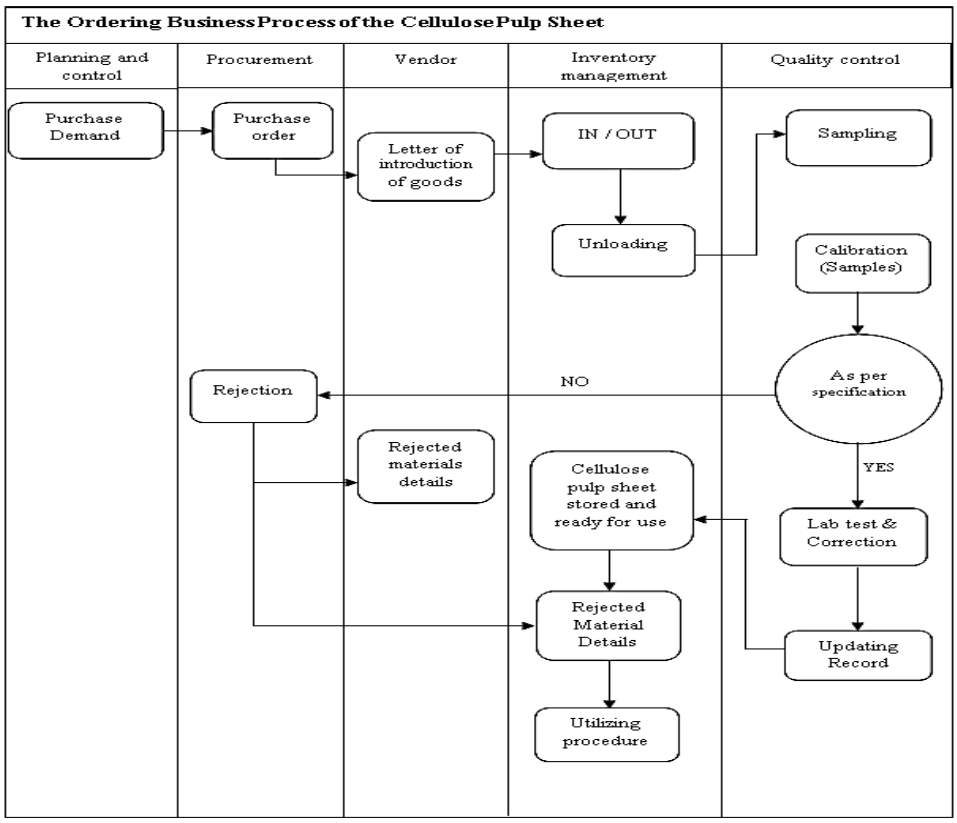

Fig. 5. Identification of the ordering business process in respect of cellulose pulp sheet.

4.2 | Identification of Failure Modes

The identification of failure modes was completed by using the analysis of previous years data and based on the interviews and group discussions with the procurement department engineers responsible for the management of the raw material handling processes. The potential failure for the cellulose pulp sheet rejections and losses are shown below in *Table 5*.

Table 5. Failure modes for the improvement.

Activity	Failure Mode	Notation	Causes	Impact	Control
Processing	Cellulose pulp sheet Spoilage	E1	Processing techniques not up to the mark	Reduction in the weight of sheet	Identify the specification, sample testing,
	Unfavourable quality grid	E2	Human error	Alleviated cellulose sheet quality because of during processing higher chemical content	Data accuracy
Shipping	Incorrect unloading location instruction	E3	Human error	Multiple handling	By establishing coordination between unloading & inventory workers
	Sheet becomes wet	E4	Rainy weather or moist climate at the delivery time	Affects the weight of the sheet	Cover properly with tarpaulins
	Truck number is not correct	E5	By the inability of suppliers to provide the truck	Latency for the fulfilment of supplies	Identify the standard of the minimum number of the trucks will be used, deliveries deadline

Table 5. (Continued).

Activity	Failure mode	Notation	Causes	Impact	Control
Compliance	Test results of the sample from the supplier and the actual sheet test by the company as a whole	E6	Spoof by supplier that holds a good sample but in reality, sheet is of low-quality wood	Getting cellulose sheet with low quality and incurred financial losses	Quality checks of the cellulose sheet prior to unloading cellulose sheet into the truck
Inspection	Take specimen for error finding	E7	Shortage of tools and knowledge about the correct specimen	Wrongly identified quality of cellulose sheet	Updation of tools that can be used by the whole team and train the team for reducing the error while inspecting activities
Stockpiles	Limited storage area	E8	Storage techniques are less precise for sheets	Limited capacity of company	Improved by engineered practices for pile up
	Nasty Drainage stockpile	E9	Influx of water does not drain	The water in sheets increases	Periodic maintenance of warehouses
	Sheets spilled during loading	E10	Overburdened carrying capacity	The road becomes sludgy by the sheets	Loading techniques improved

By the identification of the failure modes, the next process is weighing which conducted by expert. In this study, the researcher determines the expert who came from the procurement department of ABC company. Expert with his experience and will examine the severity occurrence and detection on the failure mode that has been identified in failure modes table. After that, the expert will examine the RPN and the Fuzzy RPN with the help of MATLAB software.

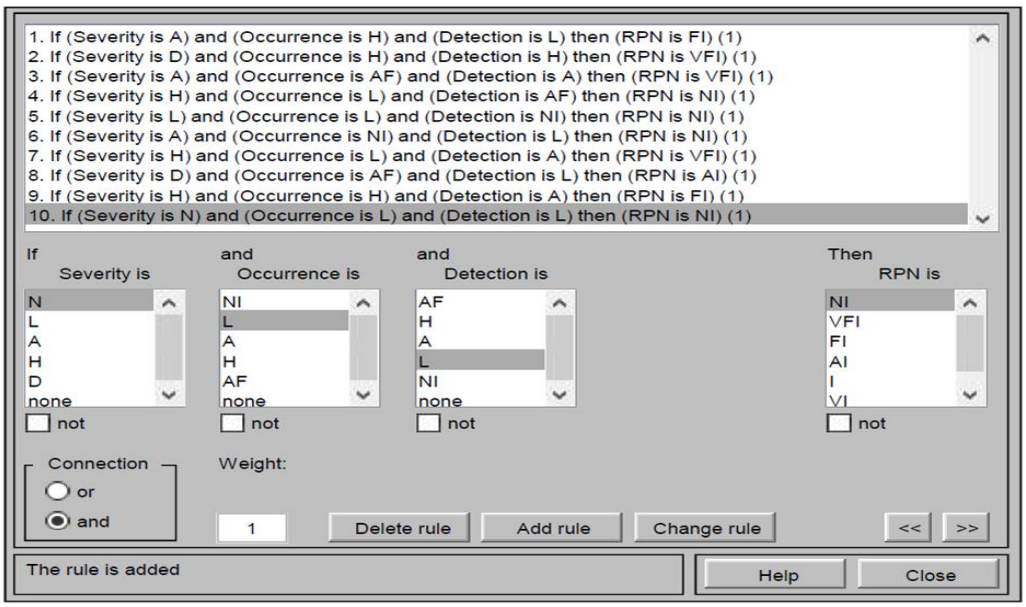

Fig. 6. Fuzzy rules in MATLAB software.

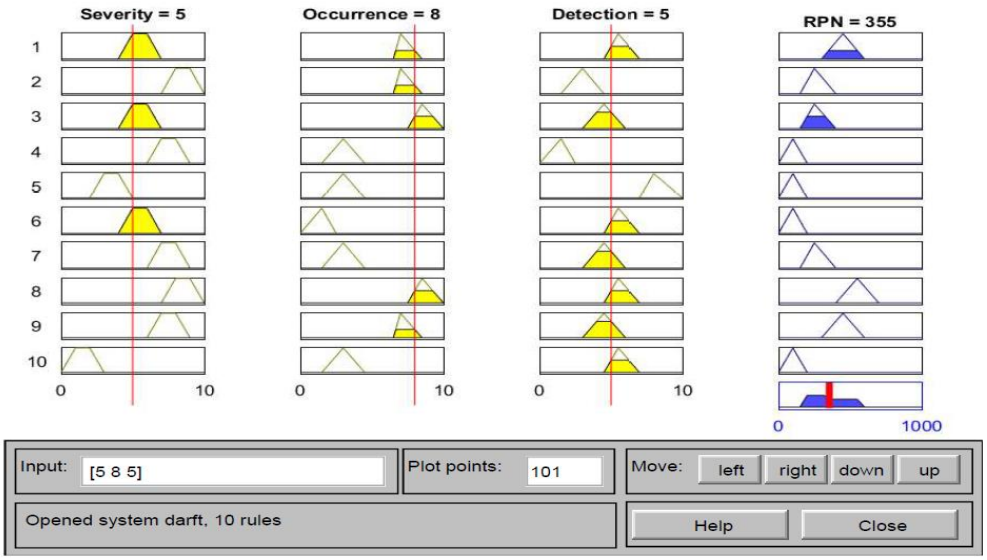

Fig. 7. RPN's input and output illustration.

Table 6. Comparison between FMEA and Fuzzy FMEA.

Failure Mode	Severity (S)	Occurrence (O)	Detection (D)	RPN	(FUZZY) RPN	RPN Ranking	(Fuzzy) RPN Ranking
E1	7	8	7	392	500	1st	4th
E2	8	8	5	192	510	5th	2nd
E3	5	8	5	200	355	4th	5th
E4	9	4	2	72	473	8th	3rd
E5	3	3	8	72	100	8th	4th
E6	4	2	5	40	500	9th	4th
E7	8	3	6	144	500	6th	4th
E8	8	9	5	360	550	2nd	1st
E9	7	7	6	294	500	3rd	4th
E10	3	4	7	84	500	7th	4th

All the above values are taken with help of interview and these values are analysed by the MATLAB software. The results of the assessment based on the table can be illustrated as the comparable results of 10 different types of fundamental RPN and Fuzzy RPN failures of which dominant most seen below in *Table 7*.

Table 7. Ranks for FMEA and fuzzy FMEA.

Rank	Potential Failure (RPN)	Potential Failure (Fuzzy RPN)
1st	Cellulose pulp sheet Spoilage(E1)	Limited storage area(E8)
2nd	Limited storage area(E8)	Unfavourable quality grid(E2)
3rd	Nasty Drainage stockpile(E9)	Sheet becomes wet(E4)

Juxtaposing the results for the traditional FMEA and with the Fuzzy FMEA, the disparities between them are clearly mentioned in *Table 7*. The failure modes E4 and E5 have the same RPN of 72 and have same priority. But the fuzzy FMEA RPN in those cases are different and it would be advantageous for stabilize priority on those components. Considering the failure modes E4 and E5 where their RPN is 72. The value of Severity (S), Occurrence (O) and Detection (D) ratings are 9, 4, 2 and 3, 3, 8 for the E4 and E5 respectively. Notwithstanding the RPN for both failure modes are same and the risk levels are subsequently different. The ranks of E4 and E5 in fuzzy environment are 3 and 4 and the failure mode E4 has greater RPN than E5. Hence, the traditional method FMEA may differ the results. In addition,

the ranking presented by the proposed system doesn't segregate the failure modes which has proximate ratings. If the both failure modes bear the same value and have proximate ratings, it will give same RPN to the both components. Nevertheless, the traditional FMEA methods creates the resulting different RPN.

The analysis of the outcomes produced by the traditional FMEA and Fuzzy FMEA methods show much accurate and reasonable results of the ranking which can be accomplish by adopting Fuzzy FMEA. Other finding can be done in the same manner. In addition, the Fuzzy FMEA can also be updated or amended when more information of a product or process is available. So, we can say that the proposed evaluation method can be continuously elevated.

5 | Conclusion

In this study, a failure mode and effect analysis based on the fuzzy logic approach is put forth and a model of the risk evaluation system for expert is developed. The analysis of a cellulose pulp sheet is presents to demonstrate the fuzzy FMEA. The cellulose sheet spoilage is the primary failure as per the classical FMEA approach, the results reflect in the fuzzy logic in FMEA as limited storage area. we identified that fuzzy logic environment gives more satisfactory results due to linguistic function. The subjective discretion was stated in the natural form which was sometimes vague, imperfect and tottered. In applying FMEA by assigning the Severity, Occurrence and Detection rating system in natural form produced and insubstantial and puddled impressions. As per the results, the RPN developed by these three ratings overlooked the proportional importance amongst the parameters and resulted in misunderstanding. The usage of linguistic terms permits the experts to confer a more reasonable and meaningful information for three parameters. Fuzzy based rules allow experts to create the more realistic and logical rule bases. By applying the fuzzy set and the membership functions, the inaccurate information is improved to show the real scenarios. By applying fuzzy IF – THEN, the collected rules from the experts, expert's intellect and experience are incorporated in the risk assessment tools. It is more handy to differentiate the risk representations among the same RPN. Although by constructing the knowledge and estimates are prevented efficiently. Furthermore, the information of each and every failure is updated by the experts. The proposed model for assessment is continuously improved. The major disadvantage of the tradition FMEA is the various combinations of three parameter ratings that produce an identical value for RPN. Notwithstanding, the risk represents a thoroughly differences. In this paper, fuzzy rules-based assessment was executed for the case study to meditate the difficulties grown up in conducting the traditional FMEA technique.

Future research intends to the introduction of the Multi- Criteria Decision Making (MCDM) process along with LDFS analysis with some more data sets. We look forward to that our results of research will be beneficial for researchers in the field of industrial raw material losses, reduction of wastage and many manufacturing industries losses.

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