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# Risk analysis of cutting system under intuitionistic fuzzy environment

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**ABSTRACT**

Failure Mode Effect Analysis (FMEA) is popular and versatile approach applicable to risk assessment and safety improvement of a repairable engineering system. This method encompasses various fields such as manufacturing, healthcare, paper mill, thermal power industry, software industry, services, security etc. in terms of its application. In general, FMEA is based on Risk Priority Number (RPN) score which is found by product of probability of Occurrence (O), Severity of failure (S) and Failure Detection (D). As human judgement is approximate in nature, the accuracy of data obtained from FMEA members depend on degree of subjectivity. The subjective knowledge of members not only contains uncertainty but hesitation too which in turn, affect the results. Fuzzy FMEA considers uncertainty and vagueness of the data/ information obtained from experts. In order to take into account, the hesitation of experts and vague concept, in the present work we propose integrated framework based on Intuitionistic Fuzzy- Failure Mode Effect Analysis (IF-FMEA) and IF-Technique for Order Preference by Similarity to Ideal Solution (IF-TOPSIS) techniques to rank the listed failure causes. Failure cause Fibrizer (FR) was found to be the most critical failure cause with RPN score 0.500. IF-TOPSIS has been implemented within IF-FMEA to compare and verify ranking results obtained by both the IF based approaches. The proposed method was presented with its application for examining the risk assessment of cutting system in sugar mill industry situated in western Uttar Pradesh province of India. The result would be useful for the plant maintenance manager to fix the best maintenance schedule for improving availability of cutting system.

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## 1. Introduction

FMEA is a trustworthiness management approch to find the potential mode of failures in process, product and services (Pillay & Wang, 2003). The goals of using FMEA are to detect the mode of failure in the system/subsystem, gauge effect of failure in overall performance of system, eliminating severity of occurrence (Lo and Liou, 2018). This technique is used to find and rank the potential failure modes by a numerical value known as RPN score. RPN is measure of degree of failure risk. So, it is applicable to rank the failures and decide the remedial action taken for the required failures. A highest value of RPN score indicates more critical failure and remedial action should be given to highest value score. As FMEA is a group-oriented technique and hence is impossible that information provided by the group of experts are exact. The information obtained by the experts contain vagueness/ uncertainties (Panchal et al. 2018). Fuzzy set theory defines a fuzzy subset $A$ of a set $X$ by its membership function value ($\mu_A$) as a mapping from the elements of $X$ to the closed interval [0, 1] (Zadeh, 1965). To handle the uncertainties fuzzy set (FS) concept was incorporated to FMEA by Pillay and Wang (2003). In the past, several other researchers also incorporated the FS theory based mathematical modelling for evaluation of risk analysis of industrial system such as Panchal and Kumar, (2017) exponded the application of IF-THEN rule base fuzzy FMEA approach for assessing the failure event in compressor unit of thermal power industry. Panchal et al. (2018) applied FMEA approach and grey relation analysis (GRA) technique for developing a new risk based integrated model. The results obtained were equated with approaches and subsequently the critical components of a urea fertilizer industry were identified. Xin et al. (2018) evaluated the risk associated with supercritical water gasification (SCWG) technology to ensure the removal and recovery of pollution created by sewage sludge treatment (SST) plant. A fusion of FMEA and multi-granular linguistic distribution evaluation was illustrated to find the criticality of aformentioned system. Panchal et al. (2019) again proposed a risk-based model for studying risk issues under uncertainity in a chlorine plant. Improved Fuzzy FMEA technique was based on relative weight values of experts and was highly useful in ranking the failure causes with high level of accurateness as it overcome the limmitations of IF-THEN rule base FMEA approach in an effective manner. So, it has been concluded from above work that, FS theory based FMEA has proved efficient in handling and managing uncertainties in vague data related to real and complex industrial system to some extent. It has also negated the several limitations of classical FMEA in an effective way but still the fuzzy set theory based existing FMEA approaches are not able to consider the hesitancy of experts during their feedback which raises a serious question on the correctness of the analyzed results. Furthermore, Intuitionistic Fuzzy Set (IFS) theory was seen as an extension of conventional fuzzy set by Attanassov (1986) which consist of membership and non- membership function and allows the researchers to consider the hesitancy effect of expert personnel of any industrial system. IFS was incorporated in FMEA to achieve more correct result of real-life problem which involves human judgement by several researchers. IF modelling-based risk assessment approaches using intuitionistic fuzzy numbers-based quality function deployment (QFD) and VIsekriterijumska optimizacija I KOmpromisno Resenje (VIKOR) technique was proposed by Efe (2019). A novel work relevant to IF based mathematical approach to deal with the uncertainty of data, IF Analytical Hierarchy Process (AHP) was presented (Yazdi et al. 2019) to consider the hesitancy effect involved in experts' feedback. Additionally, Liu et al. (2019) proposed the IF-FMEA approach to make advancement in the performance of method in term of its effectiveness of the results even further. The current approach was integrated by using interval-valued intuitionistic fuzzy sets (IVIFSs) and the multi-attributive border approximation area comparison (MABAC) method. Besides the risk analysis of industrial system, IF based FMEA has encompassed other filed also, Tooranloo et al. (2018) utilised FMEA technique in knowledge management failure factors in an IF environment to analyse the failure modes of oil and gas company. Chang and Cheng (2010) proposed a new approach, which combined the intuitionistic fuzzy set (IFS) and the decision-making trial and evaluation laboratory (DEMATEL) approach on risk analysis. Under this work, risk issues of etching process were assessed to illustrate the current methodology. Moreover, the IF based FMEA was applied in services sector to identify the risk of failures. The failure mode of internet banking services was examined and the quality of services were maintained by IF based FMEA tool was proposed (Tooranloo and Sadat, 2016).

From the above studied literature, it has been found that implementation of IF set theory-based FMEA approach has not yet been reported for studying the risk analysis of cutting system of a sugar mill industry situated in western Uttar Pradesh region of India. Therefore, to bridge this gap the application of IF-FMEA approach has been presented in the current work.

## 2. Proposed framework

The framework has been developed in two stages to carry out risk analysis of cutting system of a sugarmill industry.In first stage IF- FMEA approach was utilized to conduct the risk assessment of the above mentioned system.In this approach, feedback from industrial experts are obtained to design linguistic scale for three risk factors O, S and D.FMEA sheet consisting of subsystem/components, its function, mode of failure, its effect and cause of potential failures were listed for all failure causes. Critical causes are identified on the basis of fuzzy RPN score derived from IF- FMEA approach. In order to make a prudent decision, IF-TOPSIS has been implemented within IF- FMEA to compute the ranking results on basis of relative coefficient, and comparision of both approaches are compared in the later stage eventually. Propopsed integatred two-stage framework has been shown in fig. 1.

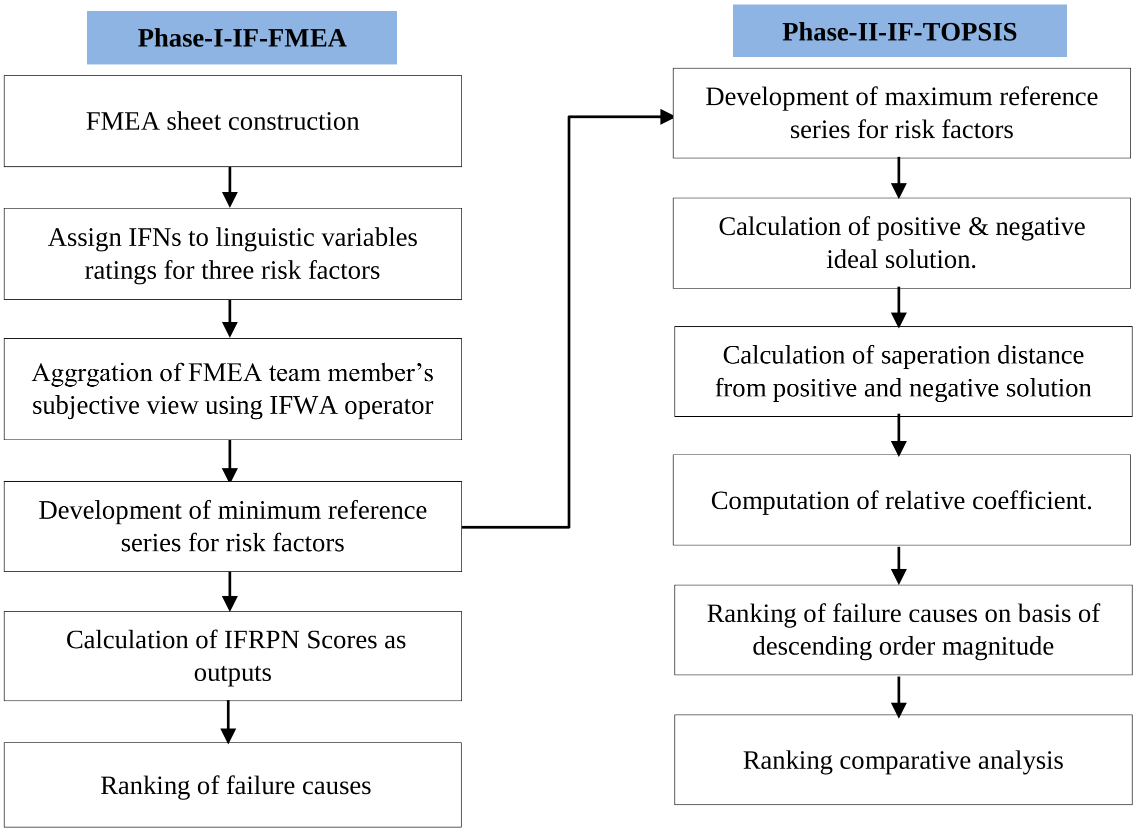

**Figure 1** A two-stage framework

## 3. Notions of Intuitionistic fuzzy set (IFS)

An IFS in a universal set S which is a set of three variables given by Eqn (1) as:

$$B = \left\{ < x, \mu_{B}^{-}(x), \nu_{B}^{-}(x) \,\middle|\, x \epsilon\, S \right\} \tag{1}$$

Where $\mu_{A}^{-}(x)$ is a membership function, $\nu_{A}^{-}(x)$ is a non-membership function which is given by Eqs. (2) and (3) respectively (Garg 2014)

$$\mu_{B}^{-}: S \rightarrow [0\ 1], x\epsilon\, X \rightarrow \mu_{B}^{-}(x) \rightarrow [\,0\ 1] \tag{2}$$

$$\vartheta_{B}^{-}: S \rightarrow [0\ 1], x\epsilon\, X \rightarrow \vartheta_{B}^{-}(x) \rightarrow [0\ 1] \tag{3}$$

The above two equations must satisfy condition to be eligible for an IFS

$$\mu_{B}^{-}(x) + \nu_{B}^{-}(x) = 1\, for\ all\ x \,\epsilon\, S.$$

In addition to membership $\mu_{A}^{-}(x)$ and non-membership function $\nu_{x}^{-}(x)$ Degree of Hesitation is defined as and is defined by Eqn (4) (Attanassov, 2012).

$$\pi_x = 1 - \mu_{B}^{-}(x) - \nu_{B}^{-}(x) \tag{4}$$

Intuitionistic Fuzzy Distance (IFD) between two Intuitionistic Fuzzy Number (IFN) is calculated by Eqn. (5)

Let $\beta_1 = (\mu_{1,}\vartheta_1)$ and $\beta_2 = (\mu_{2,}\vartheta_2)$ are two IFNs, the IFD between $\beta_1$ and $\beta_2$ is given as:

$$d_{IFD}(\beta_1, \beta_2) = |\beta_1 - \beta_2| = \frac{1}{2}(|\mu_1 - \mu_2| + |\vartheta_1 - \vartheta_2|) \quad (5)$$

For IFN $\beta_1 = (\mu_{1,}\vartheta_1)$ if the value $\mu_1$ gets bigger the value of $\vartheta_1$ will be smaller and the IFN will be bigger. Also, $\beta^+$ = (1,0) and $\beta^-$ = (0,1) are the largest and smallest IFNs respectively.

Score and accuracy are defined by Eqn. (6) as

$$P\ (a) = \mu_1 - \vartheta_1 \text{ and accuracy } Q(a) = \mu_1 + \vartheta_1 \quad (6)$$

# 4. Risk analysis approaches

## 4.1 IF- FMEA approach

FMEA serves as a proactive method in prioritising and determining the failure cause of the various repairable industrial systems by assigning RPN score (Adar et al. 2017). Score of RPN is used to determine the criticality of the system/subsystem. The higher the score, more critical is the system. In the past the FMEA technique has been applied by many scholars in vivid field like Sharma and Sharma (2012) proposed fuzzy based risk assessment of a paper mill industry. Panchal and Kumar (2016) utilised fuzzy based FMEA approach to carry out study of risk analysis of compressor house unit in a thermal power process industry. Several other researchers also conducted risk assessment in various fields - Offshore wind turbine (Kang et al. 2017); Gas turbine system (Ahn et al.,2017); Thermal power industry (Panchal and Kumar, 2017); Reliability and safety (Lo and Liou, 2018); Transmission system (Panchal et al. 2018); LHD machine (Balaraju et al. 2019); CNG dispensing system (Panchal and Srivastav, 2019); HDR brachytherapy (Su et al. 2020); Steam safety valve (Qin and Pedrycz, 2020). Due it limmitations related to consideration of hesistancy effect in the expert knowledge IF-FMEA approach gain streangh for delivering ranking results with high accuracy. The procedural steps of IF-FMEA technique are as follows:

Step-1 Assign the linguistic terms for the risk factor which is defined as IFN as shown in the table 1. It contains two numerical values one is membership and another non-membership.

**Table 1.** Linguistic variables rating for three risk factors under FMEA approach

| Linguistic Variables | (IFNs) |
|---|---|
| Very low (VL) | (0.25, 0.70) |
| Low (L) | (0.30, 0.60) |
| Medium Low (ML) | (0.40, 0.50) |
| Medium (M) | (0.50,0.50) |
| Medium High (MH) | (0.60,0.30) |
| High (H) | (0.70,0.20) |
| Very High (VH) | 0.75,0.20) |

**Step-2** Using Eqn. (7) aggregate the team members' subjective views obtained from experts for three risk factors namely O, S & D.

$$\text{IFWA}\ (\alpha_1, \alpha_2, , , , , , , , \alpha_n) = W_{1.}.\alpha_1 + W_2.\alpha_2 + \dots\dots\dots\dots + W_{n.}.\alpha_n$$

$$= \left(1 - \prod_{i=1}^{n}(1 - \mu_{\alpha i})^{w_i},\ \prod_{i=1}^{n}(\nu_{\alpha i})^{w_i}\right) \quad (7)$$

where $\left(W_{1,}W_{2,} \dots\dots W_n\right)^T$ is called the weight vector of $\alpha_i\ (i = 1,2,3, \dots\dots n)$, with $W_i \epsilon\ [0\ \ 1]$ and $\sum_{i=1}^{n} W_{i.} = 1$.

**Step- 3** Develop a reference series for risk factor smaller the score, less is the risk, so choose minimum value $\delta^- = (0,1)$ using Eqn. (8)

$$\tilde{\delta}_0 = \left[\delta_{01,}\delta_{02,\dots\dots\dots}\delta_{0n,}\right] = [\delta^-, \delta^-, \dots\dots.\delta^-] \quad (8)$$

**Step - 4** Calculate the Intuitionistic Fuzzy Risk Priority Number (IFRPN) score for all listed failure causes and rank them by using Eqn. (9).

$$IFRPN = dIFD(O) \times dIFD(S) \times\ dIFD(D) \quad (9)$$

**Step -5** Rank all the failure modes in descending order of the IF-FMEA approach output score as obtained.

### 4.2 IF- TOPSIS approach

TOPSIS was first proposed by Hwang and Yoon to deal with Multi Criteria Decision Making problems (Hwang and Yoon,1981). TOPSIS is a versatile multi-objective decision making approach in which the basis of TOPSIS laid on compromise principle for solving the multi criteria problem in confliction environment. According to the principle of TOPSIS the solution selected should be shortest distance from positive ideal solution and longest distance from negative ideal solution. In course of time TOPSIS has altered combined with various mathematical concept and widely applied accepted with modifications. The landmark change took place when classical TOPSIS combined with fuzzy concept which was proposed by Zadeh in the year 1965. The fuzzy TOPSIS came into picture to consider the uncertainties/ vagueness in the expert opinion. Subsequently, fuzzy TOPSIS have been implemented by several researchers. Chu, (2002) proposed fuzzy set theory-based TOPSIS approach for selection of plant location. Junior et al. (2014) implemented the application of fuzzy TOPSIS for supplier selection. Petrović et al. (2019) proposed comparison of three fuzzy based MCDM approaches for supplier selection. Yazdi et al. (2020) expounded the application of fuzzy concept in modified fuzzy AHP combined with fuzzy TOPSIS to carry out risk assessment specifically considering fire and explosion in a complex chemical process industry. Ali et al. (2020) utilised fuzzy based a hybrid MCDM technique i.e Full Consistency Fuzzy TOPSIS method for car selection. Zolfani et al. (2020) proposed logarithmic normalization based TOPSIS and VIKOR for re-evaluation of multi criteria decision making approach. Moreover, fuzzy TOPSIS has further been improved with the advent of IFS theory proposed by Attanassov. Several scholars implemented IFS based TOPSIS approach for decision making in vivid fields- Selection of wind power plants (Daneshvar Rouyendegh et al. 2018); Maritime industry (Senel et al. 2018); Complex and changeable bone transplant selections (Zhang and Yao 2020); Green supply selection (Ramakrishnan and Chakraborty 2020). The steps of FMEA presented in this work and of TOPSIS are same till steps 2 so, it is not repeated here again. The other steps of TOPSIS applied in the current work are presented. The procedural steps of IF-TOPSIS approach is given in following steps:

**Step-3** Develop a reference series for risk factor for minimum and maximum series using Eqs. (10 – (11). Smaller the score, less is the risk, so choose minimum value $\delta^- = (0,1)$.

Minimum series for non-benificial risk factors

$$\tilde{\delta}_{0-} = [\delta_{01,}\delta_{02,\dots\dots}\delta_{0n}] = [\delta^-, \delta^-, \dots\dots.\delta^-] \tag{10}$$

Maximum series for beneficial risk factors

$$\tilde{\delta}_{0+} = [\delta_{01,}\delta_{02,\dots\dots}\delta_{0n}] = [\delta^+, \delta^+, \dots\dots.\delta^+] \tag{11}$$

**Step-4** Calculate the positive ideal solution PIS and negative ideal solution NIS by using Eqs. (12) – (13).

$$PIS = \{(k^{max_{pij}}\ /j \in\ J), (i^{max_{pij}}\ /j \in j')\ for\ k =\ 1,2,3\dots m\} \tag{12}$$

$$NIS = \{(k^{min_{pij}}\ /j \in\ J), (i^{max_{pij}}\ /j \in j')\ for\ k =\ 1,2,3\dots m\} \tag{13}$$

**Step-5** Calculation of saperation distances from positive and negative solution using Eqs.14-15.

$$a_i^+ = \sqrt{\textstyle\sum_{j=1}^{n} pij - z)^2}\ k = 1,2,3\dots m \tag{14}$$

$$a_i^- = \sqrt{\textstyle\sum_{j=1}^{n} pij - z^-)^2}\ k = 1,2,3\dots m \tag{15}$$

**Step-6**. Using Eqn. (14) tabulate relative coefficient for each failure cause.

$$\kappa = \frac{a_i^-}{a_i^+ + a_i^-} \tag{16}$$

**Step-7** Rank all the listed failure mode in the order of decreasing values of relative coefficient.

## 5. Case study

To exemplify application of developed IF-FMEA approach for risk examination, cutting system (CS) of sugar mill industry situated in western part of Uttar Pradesh, India has been considered which is one of the important functionary unit of the considered Industry. The unit not only chops and cuts the sugar cane but also feed the tandem mill with small pieces of cane. Generally, CS is a complex subsystem consist of chopper, leveller, fibrizer and tandem mill or crusher and unloader which are arranged in series configuration. If function of any components of cutting system deviates, the supply of raw juice to other subsystem comes to halt. Also, the supply of bagasse (Fuel) to the boiler will be stopped. Both the supply of raw juice and bagasse shut the production of sugar. That is why, for maintaining high availability of CS it is crucial to study and analyse the failure risk related with its various subsystem/equipment/components.

### 5.1 Application of the proposed model for risk analysis

### *5.1.1 IF- FMEA application*

Selected FMEA team which consists of three team members of different in experience, age and educational qualification are asked to perform a brainstorming session related to list various failure causes related to different subsystem/component of cutting unit and FMEA sheet was developed as shown in table 2.

**Table 2**. FMEA Sheet

| Subsystem/components | Function | Mode of potential failure | Effect of potential failure | Cause of potential failure |
|---|---|---|---|---|
| Main cane career | To supply raw cane to the chopper. | Burning of motor armature | Stop the supply of sugar cane | Overloading of main track of conveyor (MC) |
| Chopper | It chops the cane into small pieces. | Wear and tear | Stop the supply of sugar cane | Blunt blade of the components (CH) |
| Leveller | It is used to level the cane. | Loosening of sleeve | Loss of production. | Blockage (LR) |
| Fibrizer | Hammer in the fibrizor further break the cane into partially crushed cane. | Jamming | Bursting of casing and cause accident. | Particle like stone, iron piece results in jamming (FR). |
| Rack Elevator | Transport the partially crushed cane from one mill to other. | Wearing of chain sprocket | Decrease in supply of partially crushed cane. | Improper lubrication (RE). |
| Roller/Crusher | Extract the juice from the cane. | Wearing of teeth | Low production of raw juice | Bearing failure (CR). |
| Imbibition Juice Pump | Pump the raw juice to the raw juice heater | Overheating | Stops supply of juice to clarification unit | Improper Lubrication. Faulty Priming (JP). |
| Impeller failure | Create pressure difference in pump | Choking | Stop functioning of pump | Dirt deposition (DP) |

| Subsystem/components | Function | Mode of potential failure | Effect of potential failure | Cause of potential failure |
|---|---|---|---|---|
| Unloader | To supply cane to main cane carrier | Hydraulic system failure | Stop supply of cane to mill house | Leakage of oil (UL) |
| Nozzle | To supply water to mill | Blockage due to deposition of dirt | Poor removal of baggase from mill | Chocking (NL) |
| Spray system | To sprinkle water | Blockage | Deposition of fine baggase | Leakage of nozzle pipe (LK) |
| Motor | To supply power to pump | Overheating | Stop supply of power to pump | Excessive current supply (EC) |
| Bearing | To support shaft of motor | Overload | Leads to stop of pump functioning | Poor lubrication (PL) |

The identified thirteen failure causes as shown in table 2 related to three risk factors O, S, D are rated by these experts on the basis of rating scale (table 1) and the ratings for the three risk factors are shown in table 3.

**Table 3**. Experts rating for three risk factors

| Failure causes | Occurrence (O) | | | Severity (S) | | | Detection (D) | | |
|---|---|---|---|---|---|---|---|---|---|
| | TM1 | TM2 | TM3 | TM1 | TM2 | TM3 | TM1 | TM2 | TM3 |
| MC | MH | M | M | ML | ML | ML | M | ML | L |
| CH | M | MH | H | MH | MH | ML | MH | H | MH |
| LR | ML | ML | L | M | L | ML | VH | M | M |
| FR | H | MH | M | VL | ML | L | H | M | H |
| RE | M | M | ML | M | M | M | L | M | H |
| CR | VH | MH | VH | VH | ML | ML | ML | ML | L |
| JP | L | M | L | M | ML | ML | MH | ML | M |
| DP | H | M | H | MH | M | M | ML | ML | ML |
| UL | L | M | VH | M | MH | H | MH | MH | ML |
| NL | VH | VH | VH | ML | ML | L | M | L | ML |
| LK | H | VH | VH | H | MH | M | VL | ML | ML |
| EC | L | M | L | M | M | ML | M | M | M |
| PL | ML | L | L | VH | MH | VH | VH | ML | ML |

Here, the risk factor O, S and D are considererd as non-benifical criteria. On the basis of experts feedback as per table 1, linguistic variables against each risk factors in table 3 are used to calculate the aggregated value of three team members with the relative weight assigned as $\Psi_k = 0.30, 0.45\ and\ 0.25$. The three team members selected from consider plant maintenance departments were assumed to be of different importance because of their practical knowledge, educational qualification and expertise. The aggregated information of all failure modes was calculated by using Eqn. (7) and is given in table-4.

**Table 4.** Aggregated IFNs of failure modes.

| Sr. No | Failure cause | Occurrence (O) | | Severity (S) | | Detection (D) | |
|---|---|---|---|---|---|---|---|
| 1 | MC | 0.5324 | 0.5710 | 0.5000 | 0.5000 | 0.4096 | 0.4767 |
| 2 | CH | 0.6020 | 0.6840 | 0.3565 | 0.6591 | 0.6486 | 0.7500 |
| 3 | LR | 0.3764 | 0.4767 | 0.5478 | 0.4572 | 0.5939 | 0.6202 |
| 4 | FR | 0.6120 | 0.6982 | 0.5710 | 0.4469 | 0.6225 | 0.6979 |
| 5 | RE | 0.4767 | 0.5000 | 0.5000 | 0.5000 | 0.5132 | 0.5800 |
| 6 | CR | 0.6911 | 0.7600 | 0.4243 | 0.6202 | 0.3764 | 0.4767 |
| 7 | JP | 0.3984 | 0.5510 | 0.5000 | 0.5000 | 0.4924 | 0.5710 |
| 8 | DP | 0.6225 | 0.6979 | 0.4469 | 0.5710 | 0.4000 | 0.5000 |
| 9 | UL | 0.5349 | 0.5800 | 0.3457 | 0.6840 | 0.5573 | 0.6591 |
| 10 | NL | 0.7500 | 0.8000 | 0.5271 | 0.4767 | 0.3911 | 0.4572 |
| 11 | LK | 0.7359 | 0.8000 | 0.3302 | 0.6982 | 0.3585 | 0.4469 |
| 12 | EC | 0.3984 | 0.4473 | 0.5000 | 0.5000 | 0.5000 | 0.5000 |
| 13 | PL | 0.3316 | 0.4319 | 0.2467 | 0.7600 | 0.5386 | 0.6202 |

After calculating the aggregated IFNs Eqn. (8) was used to calculate the distance of the two IFNs and are compared with reference series. (minimum) $\bar{A}_0 = [(0,1), (0,1), , , , , , (0,1)]$ and using Eqn. 9 IFRPN score were tabulated for the listed failure causes and the corresponding ranks are summarized in table 5.

**Table 5.** IFD (Minimum series), IFRPN score, relative coefficient and TOPSIS Rank

| Failure cause | O | S | D | IFRPN Score | FMEA Rank | Relative Coeff. | TOPSIS Rank |
|---|---|---|---|---|---|---|---|
| MC | 0.7469 | 0.7500 | 0.6713 | 0.3760 | 6 | 0.5701 | 6 |
| CH | 0.7600 | 0.5269 | 0.7736 | 0.3098 | 10 | 0.5064 | 10 |
| LR | 0.6381 | 0.8191 | 0.7838 | 0.4097 | 3 | 0.6170 | 3 |
| FR | 0.7629 | 0.8476 | 0.7735 | 0.5002 | 1 | 0.7373 | 1 |
| RE | 0.7267 | 0.7500 | 0.7232 | 0.3942 | 4 | 0.5899 | 4 |
| CR | 0.8111 | 0.6142 | 0.6381 | 0.3179 | 9 | 0.5081 | 9 |
| JP | 0.6228 | 0.7500 | 0.7069 | 0.3302 | 8 | 0.5176 | 8 |
| DP | 0.7735 | 0.6614 | 0.6500 | 0.3325 | 7 | 0.5206 | 7 |
| UL | 0.7449 | 0.5037 | 0.7278 | 0.2731 | 11 | 0.4575 | 11 |
| NL | 0.8500 | 0.7888 | 0.6625 | 0.4442 | 2 | 0.6609 | 2 |
| LK | 0.8359 | 0.4811 | 0.6350 | 0.2554 | 12 | 0.4429 | 12 |
| EC | 0.6747 | 0.7500 | 0.7500 | 0.3795 | 5 | 0.5741 | 5 |
| PL | 0.6157 | 0.3667 | 0.7285 | 0.1645 | 13 | 0.2583 | 13 |
| **PIS** | **0.8500** | **0.8476** | **0.7838** | | | | |
| **NIS** | **0.6157** | **0.3667** | **0.6350** | | | | |

### *5.1.2 IF-TOPSIS application*

As per the consideration of risk factor as non-benifial (same as under IF-FMEA), using equation 10, reference series for the set of linguistic terms was developed as shown in table 5. further, using equation 12-13 positive and negative ideal solution for each listed failure cause has been tabulated as shown in table 5. Separation distancefrom positive and negative solution values were computed using Eqn.14-15 as shown in table 6-7.

**Table 6.** Separation distance from positive solution

| Failure causes | O | S | D | $\sum O,S,D$ | $\sqrt{\sum O,S,D}$ |
|---|---|---|---|---|---|
| MC | 0.1031 | 0.0976 | 0.1125 | 0.3133 | 0.5597 |
| CH | 0.0900 | 0.3207 | 0.0102 | 0.4209 | 0.6488 |
| LR | 0.2119 | 0.0284 | 0.0000 | 0.2404 | 0.4903 |
| FR | 0.0871 | 0.0000 | 0.0103 | 0.0974 | 0.3120 |
| RE | 0.1233 | 0.0976 | 0.0606 | 0.2815 | 0.5306 |
| CR | 0.0389 | 0.2334 | 0.1457 | 0.4180 | 0.6465 |
| JP | 0.2272 | 0.0976 | 0.0769 | 0.4017 | 0.6338 |
| DP | 0.0765 | 0.1862 | 0.1338 | 0.3965 | 0.6297 |
| UL | 0.1051 | 0.3439 | 0.0560 | 0.5050 | 0.7106 |
| NL | 0.0000 | 0.0588 | 0.1213 | 0.1801 | 0.4244 |
| LK | 0.0141 | 0.3665 | 0.1488 | 0.5293 | 0.7276 |
| EC | 0.1753 | 0.0976 | 0.0338 | 0.3067 | 0.5538 |
| PL | 0.2343 | 0.4809 | 0.0553 | 0.7705 | 0.8778 |

**Table 7.** Separation distance from negative solution.

| Failure causes | O | S | D | $\sum O,S,D$ | $\sqrt{\sum O,S,D}$ |
|---|---|---|---|---|---|
| MC | 0.1312 | 0.3833 | 0.0363 | 0.5508 | 0.7421 |
| CH | 0.1443 | 0.1602 | 0.1385 | 0.4431 | 0.6656 |
| LR | 0.0224 | 0.4525 | 0.1488 | 0.6237 | 0.7897 |
| FR | 0.1473 | 0.4809 | 0.1385 | 0.7667 | 0.8756 |
| RE | 0.1110 | 0.3833 | 0.0882 | 0.5825 | 0.7632 |
| CR | 0.1955 | 0.2475 | 0.0031 | 0.4461 | 0.6679 |
| JP | 0.0072 | 0.3833 | 0.0719 | 0.4624 | 0.6800 |
| DP | 0.1578 | 0.2947 | 0.0150 | 0.4675 | 0.6838 |
| UL | 0.1292 | 0.1370 | 0.0927 | 0.3590 | 0.5992 |
| NL | 0.2343 | 0.4221 | 0.0275 | 0.6839 | 0.8270 |
| LK | 0.2203 | 0.1144 | 0.0000 | 0.3347 | 0.5785 |
| EC | 0.0591 | 0.3833 | 0.1150 | 0.5574 | 0.7466 |
| PL | 0.0000 | 0.0000 | 0.0935 | 0.0935 | 0.3058 |

Using tabulated sepration values as per Eqn.16, the values of relative coefficient for all listed failure causes were calculated and the ranking of failure causes was done in descending order as shown in table 5.

## 6. Compartive result discussion

From table 5, it has been found that failure cause FR with IFRPN and Relative Coefficient outputs 0.500 & 0.7373 has been prioritized as the most critical one with rank 1st. So, extra care is required for this cause for maintaining system in operation continuously. On the other hand, failure cause (PL) has been ranked as 13th so less care is required for this failure causes in order to avoid system failure. Other failure causes such as MC, CH, LR, RE, CR, JP, DP, UL, NL, LK and EC with their corresponding IFRPN score 0.376, 0.310, 0.410, 0.394, 0.318, 0.330, 0.333,0.273, 0.444, 0.255, 0.380, 0.164 were ranked 6th, 10th, 3rd, 4th, 9th, 8th, 7th,11th, 2nd, 12th, 5th respectively. But with implementation of IF based TOPSIS approach all the ranking of failure causes were found to be same which established the compatibility of both the IF based approaches. FR with relative coefficient 0.7373 was ranked 1st whereas PL with relative coefficient 0.2583 was ranked 13th. Relative coefficient values of failure cause of same order as of IF- FMEA were 0.5701, 0.5064, 0.6170, 0.5899, 0.5081, 0.5176, 0.5206, 0.4575, 0.6609, 0.4429, 0.5741.

As the overlapping of ranking is not there here with the implementation of IF-FMEA approach which consider the hesitancy effect also so it is a useful and effective approach to be proposed for carrying out risk analysis of different complex industrial system also.

## 7. Conclusions

The risk analysis of cutting system has been illustrated by IF - FMEA approach based integrated framework and the failure cause FR has been priortised as the most critical one. The merits of the said approach lie in the fact that it takes into consideration membership and non-membership function. Also, another merit was the aggregation of team member's subjective opinion which has been done by IFWA, to take care of the average effect of different views. IFRPN score and the rank of the considered system was calculated which facilitates system analysts to detect critical component of the system and hence to carry out the risk analysis. When IF-TOPSIS was implemented the ranking of all the listed failure causes were same as that of IF- FMEA approach which laid the foundation of strong correlation among both aforementioned techniques. As, all ranking obtained from both IF based techniques were same as represented in table 5, this verified the consistency of the proposed model. Apart from that merits of current approach can also be extended using the objective weight of risk factors which has not been considered in the present work. Also, this work can be extended to other subsystems of sugar mill industry to conduct out risk assesment under intuitionistic fuzzy environment. Moreover, ranking results could be further compared with other IF based MCDM approaches such as COPRAS, WAPAS and CODAS also.

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