



Research Article

A Quantitative-Fuzzy FMEA Approach for Failure Mode Analysis in Narrow Fabric Manufacturing

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KEYWORDS

Narrow fabric; FMEA;
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ABSTRACT

In the garment industry, narrow fabric plays a significant role, as it accounts for a large portion of trims and accessories, which are essential elements of a garment. Due to conventional production philosophy and poor managerial decision-making, Bangladesh's narrow fabric industry, both local and export-oriented, faces inefficiencies comprising quality deviation, rework, scrap, and lead time delays in its production. These factors increase overall production cost, which in turn lowers profitability. In this context, this study identifies, ranks, and categorizes the major failure modes that cause the production inefficiencies in narrow fabric production. Regarding this analysis, the study employs an approach that integrates the conventional Failure Mode and Effect Analysis (FMEA) with Interval Valued Pythagorean Fuzzy Decision-Making Trial and Evaluation Laboratory (IVPF-DEMATEL). The findings of this study suggest the critical failure modes are 'communication barriers among stakeholders,' 'technical data misinterpretation, and 'operator turnover,' with the impact scores 2.718, 2.015, and 2.002, respectively. This study is novel in that it combines FMEA with IVPF-DEMATEL to examine failure modes in narrow fabric manufacturing, which had not previously been investigated. The study will provide managers and policymakers with insights into how to examine fundamental challenges in the production process in a proactive manner for decision-making, and how to apply the concept to remedy critical issues to enhance productivity in narrow fabric and other manufacturing settings.

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1. Introduction

The textile and garment industry, particularly in emerging economies, is a driver of economic growth and employment. Among these economies, Bangladesh has emerged as a leading garment exporter [1]. The textile and ready-made garments (RMG) industry of Bangladesh accounts for more than 80% of total export revenues [2]. However, sustaining this development requires streamlined production systems, resilient supply chains, and proactive quality management practices that reduce production losses and ensure product consistency [3]. Within the garment production ecosystem, narrow fabrics, such as elastic tapes, plain elastics, drawstrings, webbings, and woven labels, are an import-

ant category of trimmings and accessories [4]. Figure 1 shows some of the narrow fabrics. Narrow fabrics ensure the functional and aesthetic qualities of the finished garments. The consistent strength, flexibility, and color homogeneity of narrow fabrics have a direct impact on stitching performance, garment fit, and durability. As a result, any quality mistake in narrow fabric production might spread across the garment assembly line, requiring rework and waste. In Bangladesh, there is a strong demand for good-quality narrow fabrics, much of them are imported from China due to China's superior production efficiency, consistent quality, and cost competitiveness [5]. Though the

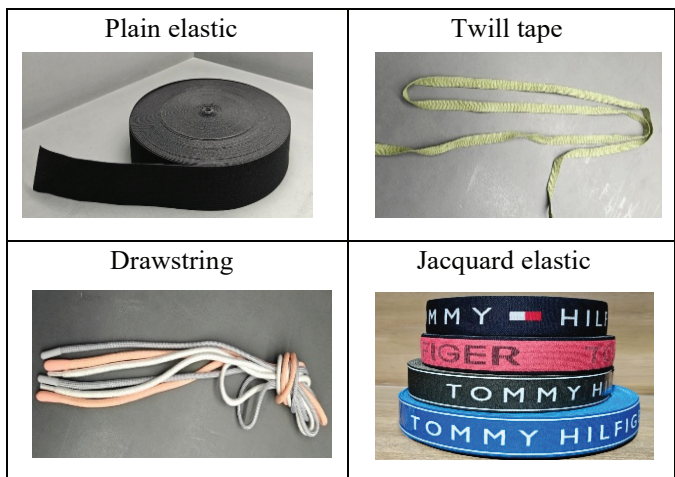


Figure 1. Different types of narrow fabrics are used as garment accessories

local narrow fabric sector in Bangladesh has grown in volume, it continues to face inefficiencies, waste, and inconsistent quality as a result of frequent process stoppages, equipment malfunctions, low first-pass yield, machine setup errors, yarn tension inconsistencies, operator inexperience, maintenance delays, and insufficient inspection protocols [6]. These inefficiencies not only raise manufacturing costs, but they also jeopardize the industry's ability to fulfill international buyers' specific lead-time and quality standards [7]. To overcome these difficulties, this sector relies heavily on traditional, reactive problem-solving methodologies rather than proactive process improvement frameworks. The reactive management style, which addresses problems after they occur, has slowed the sector's technical growth. To increase productivity and remain competitive in today's global context, it is critical to develop a systematic, proactive data-driven approach for failure detection, prioritization, and mitigation [8]. Failure Mode and Effect Analysis (FMEA) is one of the most used methodologies for structured risk assessment and quality improvement in manufacturing [9]. It systematically identifies and ranks probable failure modes using the risk priority number (RPN), which is calculated from the severity (S), occurrence (O), and detection (D) ratings [10]. However, the typical FMEA has significant shortcomings. The method is primarily reliant on subjective expert judgments and cannot address the unpredictability and ambiguity of human decision making, resulting in variability, inconsistency in risk rating, and the inability to identify interrelationships among failure modes [11]. To address these issues, a hybrid framework combining FMEA with sophisticated multi-criteria decision-making (MCDM) and fuzzy logic techniques is needed [12]. This study integrates FMEA with an advanced MCDM tool, the Interval-Valued Pythagorean Fuzzy Decision-Making Trial and Evaluation Laboratory (IVPF-DEMATEL) [13]. Compared to other prominent techniques such as AHP, ANP, TOPSIS, and VIKOR, DEMATEL allows for the illustration of causal relationships, quantification of interdependencies, and identification of influential failure modes that cause

inefficiencies. Again, IVPF sets offer a broader decision space than intuitionistic fuzzy sets (IFS) and grey fuzzy sets (GFS), allowing experts to express greater degrees of ambiguity, particularly in the narrow fabric section, where there are various hidden interactions among the failure modes [14]. As narrow fabric manufacturing faces substantial uncertainty because of tension variation, operator skill variation, raw material variation, and other machine parameter variations, making it difficult to accurately analyze failure modes. In certain cases, IVPF sets offer a more comprehensive depiction of uncertainty than traditional FMEA or other fuzzy sets. Therefore, by combining these tools FMEA and IVPF-DEMATEL, this study will identify, categorize, and interrelate failure modes, allowing policymakers and production stakeholders to understand proactively which failure modes are the primary causes of inefficiencies in narrow fabric production. The study's innovation is that it uses contemporary tools to examine the reasons for failure in the narrow fabric production process, which has not been explored before. **Section 1.1** will provide a more detailed gap analysis to highlight the study's uniqueness.

1.1 Related Works and Research Gaps

Numerous studies have applied FMEA and its variants to improve reliability, quality performance and efficiency across manufacturing industries. Akhtar et al. developed a Cloud Model Theory–DEMATEL–FMEA framework to identify dominant failures in cigarette production, highlighting machine-specific bottlenecks such as drum jamming [15]. Tsai et al. prioritized design and process-planning defects in photovoltaic cell manufacturing through an integrated DEMATEL–FMEA method [16]. Similar prioritization-focused approaches can be seen in Reda and Dvivedi, who utilized VSM, FMEA, and fuzzy QFD to address waste in shoe manufacturing [17], and in Gui and Ak, who applied an interval-valued spherical fuzzy TOPSIS-based FMEA to detect maintenance failures in the marble industry [18]. Other studies extended hybrid FMEA models in various sectors, including furniture manufacturing using fuzzy TOPSIS, fuzzy AHP, and fuzzy WINGS [19], textile production using fuzzy TOPSIS–AHP–FMEA [20], and garment manufacturing using fuzzy TOPSIS–AHP–FMEA to quantify lean waste drivers [21]. More recent data-driven FMEA methodologies, such as the M-CRITIC–ABAC approach in the food industry [22] and coherence-enhancing causal models in the semiconductor sector [23], improved objectivity and documentation consistency but remain sector-specific and fail to capture the operator-dependent uncertainties inherent in textile production. Zhu et al. also used FMEA to analyze supply chain-related product deletion risks but focused on broader manufacturing risks rather than process-level failures [24]. Across all reviewed studies, no researchers have employed Pythagorean fuzzy sets, which provide a higher degree of freedom in expressing uncertainty and hesitation—an essen-

tial requirement in narrow fabric manufacturing where machine variability, inconsistent maintenance logs, and subjective operator experience make precise judgments difficult. Additionally, no existing work integrates interval valued Pythagorean fuzzy DEMATEL with FMEA to jointly model cause–effect relationships and prioritize failures under uncertainty within the unique operational constraints of the narrow fabric sector. Given that processes such as beam overloading, pinion misalignment, variable tension, inadequate starching parameters, and needle breakage are strongly interdependent, traditional or fuzzy ranking-based FMEA models remain insufficient.

Addressing these gaps, the present study proposes an integrated FMEA with interval valued Pythagorean fuzzy DEMATEL framework to analyze and prioritize critical failure modes while explicitly modeling their causal structures, providing a more reliable, uncertainty-tolerant, and context-specific decision-support tool for enhancing operational efficiency in narrow fabric manufacturing.

2. Methodology

The process of survey design and data collection was carried out in subsequent stages, following the overall methodological framework illustrated in **Figure 2**.



Figure 2. The step-by-step methodological framework of the study

In the first stage, failure modes were identified by direct field investigation in Bangladesh's narrow-fabric manufacturing industry. In this industry, we only have access to the plain elastic production line. This production line includes the important phases such as covering, warping, bobbin winding, crochet weaving, and starching. On-site observations, informal technical discussions with production team, and a thorough assessment of operations yielded an initial list of failure modes. The preliminary list of failure modes was subsequently sent to seven experts, including senior production engineers, quality-control officials, planners, and maintenance specialists who are directly involved and have extensive experience in this production area. Table 1 highlights the details of the expert's panel. The experts validated the preliminary list of failure modes without inclusion or exclusion. Then, the validated failure modes were evaluated by the same experts using the Severity (S), Occurrence (O), and Detection (D) scoring system of classical FMEA. Experts assigned S–O–D values based on standardized scoring guidelines (given in Appendix B, Table

Table 1. Details of the expert's panel

Expert name	Designation and domain of expertise	Working experience in the relevant field
Expert 1	Assistant General Manager, Production	12
Expert 2	Executive, Production	8
Expert 3	Assistant Manager, Quality Control	10
Expert 4	Senior Executive, Quality Control	5
Expert 5	Assistant Manager, Industrial Engineering	9
Expert 6	Assistant Manager, Planning	7
Expert 7	Deputy Manager, Maintenance	13

B1 of supplementary materials), with evaluation values ranging from 1 to 10. Scores of three factors for risk- S, O, D is multiplied to calculate the RPN, as depicted in

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

The validated failure modes, including the scores of RPN, are given in Table 2. These failure modes have the vital contribution for the defects or wastes, such as elastic width deviation, shrinkage, dust and oil contamination, etc., in the plain narrow elastic production floor.

The last stage of the survey focused on seeking expert feedback to proceed with the study, accounting for the failure modes' prominence and causal analysis through IVPF-DMATEL.

Table 2. Finalized failure modes' list following expert validation with assigned RPN scores

Code	Failure Modes	Severity (S)	Occurrence (O)	Detectability (D)	RPN= S*O*D
FM1	Technical data misinterpretation	9	5	3	135
FM2	Wrong raw material selection	8	8	3	192
FM3	Communication barriers among stakeholders	9	5	6	270
FM4	Absence of inline quality inspector	7	7	2	98
FM5	Disobeying quality guidelines by operator	8	7	3	168
FM6	Operator turnover	9	4	1	36
FM7	Lack of machine maintenance	9	6	4	216
FM8	Use of outdated measuring tools	9	6	3	162
FM9	Documentation error during the sample development	8	6	6	288
FM10	Incorrect heat and speed settings in the starching process	8	5	2	80
FM11	Improper tension & speed in the yarn warping process	8	7	5	280
FM12	Exceeding beam capacity in the warping process	7	5	5	175
FM13	Wrong pinion setup in the loom	8	5	6	240
FM14	Needle breakage in the loom	7	5	1	35
FM15	Wrong speed & heat setup in the loom	8	5	6	240
FM16	Mismeasurement during packaging	6	6	3	108

2.1 IVPF-DEMATEL Method

1. Interval-Valued Pythagorean Fuzzy Set Theory

Definition 1: Let F be a PFS, an object having form, and let M be a fixed set [25].

$$F = \{ \langle x, \mu_F(x), \nu_F(x) \rangle ; x \in X \} \quad (1)$$

Where the degree of membership is defined by the function $\mu_F(m): M \rightarrow [0,1]$, and $\nu_F(m)$: The degree of non-membership of an element $m \in M$ to F is defined by $M \rightarrow [0, 1]$, and for any $m \in M$, the following is true:

$$0 \leq \mu_F(x)^2 + \nu_F(m)^2 \leq 1 \quad (2)$$

The degree of hesitancy condition in this case may be written as follows:

$$\pi_F(x) = \sqrt{1 - \mu_F(m)^2 - \nu_F(m)^2} \quad (3)$$

Definition 2: Given an IVPFS be F^* defined over M , it can be expressed as [26],

$$P^* = \{ \langle x, \mu_{F^*}(m), \nu_{F^*}(m) \rangle ; m \in M \} \quad (4)$$

where the degrees of membership and non-membership of the element $m \in M$ to F^* are defined, respectively, by the variables $\mu_{F^*}: M \rightarrow [0,1]$ and $\nu_{F^*}: M \rightarrow [0,1]$. The closed intervals $\mu_{F^*}(m)$ and $\nu_{F^*}(m)$ are represented by the equations $\mu_{F^*}(m) = [\mu_{FL}^*(m), \mu_{FU}^*(m)]$ and $\nu_{F^*}(m) = [\nu_{FL}^*(m), \nu_{FU}^*(m)]$. As a

result, F^* may also be written like this:

$$F^* = \{ \langle m, [\mu_{FL}^*(m), \mu_{FU}^*(m)], [\nu_{FL}^*(m), \nu_{FU}^*(m)] \rangle ; m \in M \} \quad (5)$$

In line with PFS, the degree of hesitancy of each element $m \in M$ with respect to F^* is expressed as follows:

$$\pi_{F^*}(m) = \pi_{FL}^*(m) + \pi_{FU}^*(m) = [\sqrt{1 - (\mu_{FL}^*(m))^2 - (\nu_{FU}^*(m))^2}, \sqrt{1 - (\mu_{FU}^*(m))^2 - (\nu_{FL}^*(m))^2}] \quad (6)$$

Definition 3: A PFS is represented by Set P . The notation for the crispification operator is $E_\lambda: [0,1] \times [0,1] \rightarrow Z$ [27]. There are two stages to this approach, which are:

- Create the fuzzy set (standard) from P .
- By using a defuzzification approach, the standard fuzzy set can be calculated.

The following is the term for crispification:

$$S^*(m) = [(\mu_{FU}^*(m))^2 + (\mu_{FL}^*(m))^2 - (\nu_{FU}^*(m))^2 - (\nu_{FL}^*(m))^2] / 2 \quad (7)$$

The following formula is used to determine the final crisp value:

$$S(m) = 1/2 [S^*(m) + 1] \quad (8)$$

2. DEMATEL

Step 1: The direct connection matrix (DCM) Q , described by the equation q_{ij} , which shows the impact of factor i on j , is created by taking into consideration the expert opinions [28].

$$Q = \begin{bmatrix} 0 & \cdots & q_{1n} \\ \vdots & \ddots & \vdots \\ q_{n1} & \cdots & 0 \end{bmatrix} \quad (9)$$

A group of N experts generates a pairwise comparison. For pairwise comparison, let's assume that there are F items. The z th expert's DCM is followed by

$$Q^z = (q_{ij}^z)_{F \times F} \quad \text{where, } q_{ij}, \text{ the impact of factor } i \text{ on } j.$$

The amalgamation of DCM, Q , Q_m where $z = 1, 2, \dots, N$ and $\xi_m \in R$ is regarded as the importance of the z^{th} expert. Therefore, Q may be expressed as follows:

$$Q = (q_{ij})_{F \times F} = \left(\frac{\sum_{z=1}^N \xi_m q_{ij}^z}{\sum_{z=1}^N \xi_m} \right)_{F \times F} \quad (10)$$

Step 2: The following formula can be used to compute the normalized matrix (V). V_{ij} can obtain a value between 0 and 1 via this operation [29].

$$V = \frac{Q}{\max \sum_{j=1}^n q_{ij}} \quad (11)$$

Step 3: The complete relation matrix (L) is obtained from the following equation. The identity matrix is defined by [30],

$$L = [L_{ij}]_{n \times n} = V(I - V)^{-1} \quad (12)$$

Step 4: The totals of all vector rows (D) and columns (R) are computed using the following formula [31].

$$D = [L_i]_{n \times 1} = \left[\sum_{j=1}^n L_{ij} \right]_{n \times 1} \quad (13)$$

$$R = [L_j]_{n \times 1} = \left[\sum_{i=1}^n L_{ij} \right]_{1 \times n} \quad (14)$$

Step 5: The causal network is constructed using the vertical axis ($D - R$) and the horizontal axis ($D + R$). 'Prominence' is the horizontal axis that displays the factor's importance, while 'Relation' is the vertical axis that shows the impact's magnitude. If the ($D - R$) axis is positive, then the factor is in the cause group. The factor is situated in the effect group when the ($D - R$) axis is negative [32].

The fundamental steps of IVPF-DEMATEL are outlined in **Figure 3**.

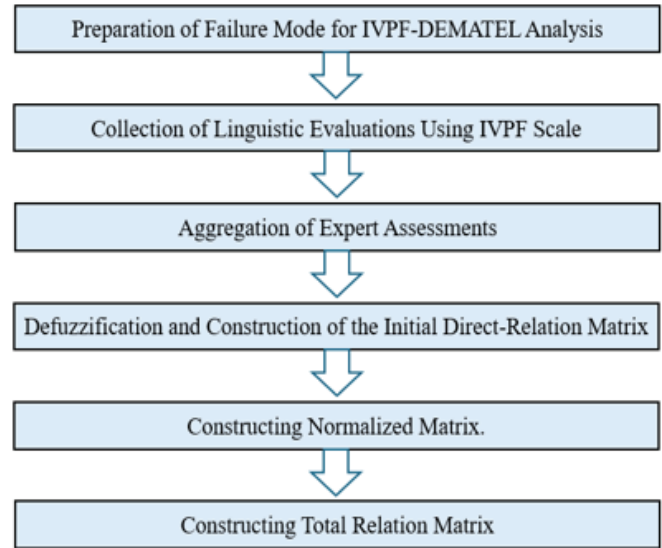


Figure 3. Steps of IVPF-DEMATEL framework

A detail description of IVPF-DEMATEL is given below.

Step 01: Preparation of Failure Mode Set for Causal Evaluation

Following the expert validation process, the finalized list of failure modes (**Table 2**) served as the basis for the causal assessment.

Step 02: Collection of Linguistic Evaluations Using IVPF Scale

The failure modes are assessed on the linguistic scale given in Table 3 and replaced with corresponding IVPF numbers to reach the expert findings.

The findings of seven experts are given in **Table A1, Appendix A of supplementary materials**.

Table 3: Linguistic scale of IVPF for evaluating the failure modes [33]

Linguistic	Abbreviation	μ	μ	ν	ν	Crisp
No influence	N	0.000	0.000	1.000	1.000	0.000
Very low influence	VL	0.120	0.250	0.500	0.780	0.314
Low influence	L	0.210	0.340	0.560	0.690	0.366
High influence	H	0.560	0.690	0.210	0.340	0.634
Very high influence	VH	0.650	0.780	0.120	0.250	0.711

Step 03: Aggregation of Expert Assessments

Seven experts were involved in this analysis however; their decisions were combined. Therefore, no aggregation was required.

Step 4: Defuzzification and Construction of the Initial Direct-Relation Matrix (DRM)

The IVPF values were converted into crisp influence scores using Equation (7). The resulting crisp direct-relation matrix (DRM) is provided in Table A2 in Appendix A of the *supplementary materials*.

Step 5: Constructing Normalized Matrix.

We normalized the original DRM by using Equation (11). Each element of the Table A2 was divided by the most significant value of the entire row and column. Table A3 in Appendix A of the supplementary materials contains the normalized matrix result.

Step 6: Constructing the TRM.

The TRM were obtained by applying Equation (12) to the normalized DCM. Table A4 in Appendix A of the supplemental material displays the TRM. The $(D_i + R_j)$ and $(D_i - R_j)$ values are obtained from Equations (13) and (14), which calculate the D_i and R_j values. The classification of the cause-and-effect group and the prominent ranking of the driving variables are based on $(D_i + R_j, D_i - R_j)$.

3. Results and Discussion

Figure 4 depicts failure modes based on risk priority numbers. In regard to this investigation, the top failure modes are FM9, FM11, FM3, FM13, and FM15, which play a critical role in waste or inefficiency on the narrow elastic production floor because of their higher risk priority number in terms of severity, detectability, and occurrences.

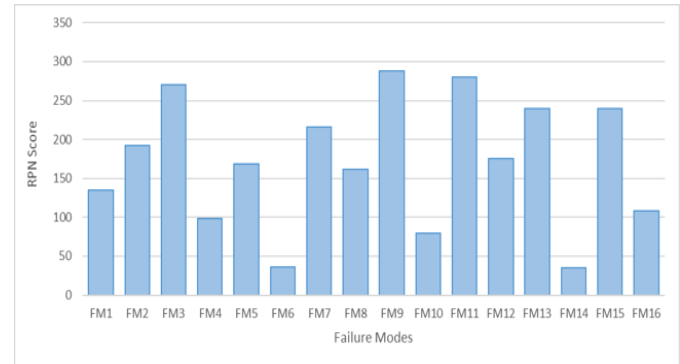


Figure 4. RPN scores of different failure modes

Following the RPN results to determine the prominence and cause and effect evaluation for the failure modes, the IVPF-DEMATEL analysis was carried out to discover which failure modes are critical in the context of impact behavior, and which failure modes have a greater impact on others or are influenced by others.

Table 4. Prominence and causal ranking of the failure modes

Code	Failure modes	D+R	D-R	Prominence Ranking	Causal Ranking	Factor Type
FM1	Technical data misinterpretation	2.015	0.012	6	8	Cause
FM2	Wrong raw material selection	1.689	0.097	10	7	
FM3	Communication barriers among stakeholders	2.718	0.257	1	6	
FM4	Absence of inline quality inspector	1.497	1.200	12	2	
FM5	Disobeying quality guidelines by operator	1.734	0.813	9	3	
FM6	Operator turnover	2.002	1.705	7	1	
FM7	Lack of machine maintenance	1.296	0.437	13	5	
FM8	Use of outdated measuring tools	1.576	0.741	11	4	
FM9	Documentation error during the sample development	2.303	-0.096	2	9	Effect
FM10	Incorrect heat and speed settings in the starching process	1.860	-1.358	8	16	
FM11	Improper tension & speed in the yarn warping process	2.083	-0.235	5	10	
FM12	Exceeding beam capacity in the warping process	1.078	-0.505	14	11	
FM13	Wrong pinion setup in the loom	2.122	-0.874	4	14	
FM14	Needle breakage in the loom	0.814	-0.550	16	12	
FM15	Wrong speed & heat setup in the loom	2.125	-0.876	3	15	
FM16	Mismeasurement during packaging	0.881	-0.768	15	13	

Table 4 displays the prominent rating and causative ranking of failure modes in the plain elastic section. The failure types are ranked according to their impact level ($D+R$) as follows: FM3 > FM9 > FM15 > FM13 > FM11 > FM1 > FM6 > FM10 > FM5 > FM2 > FM8 > FM4 > FM7 > FM12 > FM16 > FM14.

Table 4 also presents the causal ranking of the failure modes. The failure modes are divided into two categories based on the causal ranking: the cause group and the effect group. Among the 16 barriers, eight are causal ($D+R>0$) and eight are effect groups ($D-R<0$). The failure modes in the cause group are ordered as follows: FM6 > FM4 > FM5 > FM8 > FM7 > FM3 > FM2 > FM1. The FMs in the effect group are rated as follows: FM9 > FM11 > FM12 > FM14 > FM16 > FM13 > FM15 > FM10.

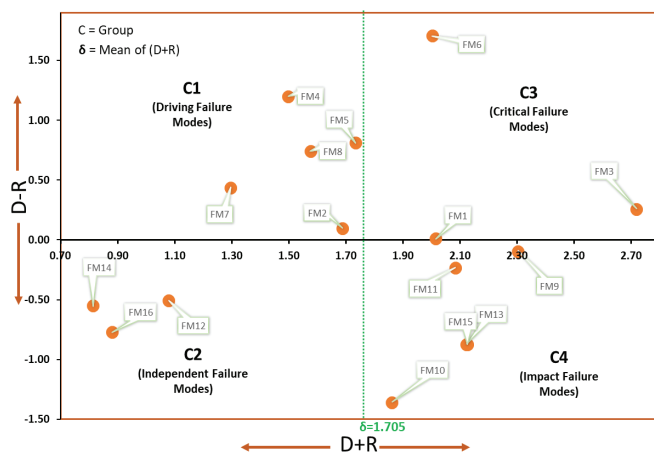


Figure 5. Representation of the cause-and-effect group of the failure modes

The cause-and-effect diagram of the failure modes generated by Table 4 illustrated in Figure 5. The cause-and-effect diagram was drawn, keeping $D-R$ in the Y-axis and $D+R$ in the X-axis on the Cartesian Plane. The failure modes are classified into driving (C1), independent (C2), critical (C3), and impact (C4) clusters. The cause group includes the driving (C1) and critical (C3) failure modes. On the other hand, both the impact (C4) and independent failure modes (C2) belong to the effect group.

Through the results of the conventional FMEA, five factors were identified to significantly influence the inefficiencies in the elastic production based on their RPNs. In sequential descending order, they are FM 9, FM11, FM3, FM13, FM15. This conventional FMEA method can have inconsistency in risk evaluation and cannot show causal analysis for the failure modes.

Further study of IVPF-DEMATEL, Table 4 and Figure 5 reveals that the most critical failure modes are FM1, FM3, and FM6, which are located in the C3 group, as these failure modes have a high influence ($D+R$) and operate as cause factors ($D+R>0$) that affect other failure modes. Again, FM2, FM4, FM5, FM7, and FM8 are in the C1 group, which is the driving cluster. These factors have a low influence but a high causal score, indicating that they affect other failure modes. Both C1 and C3 failure modes are causal failure modes, with the greatest causal score among these factors being 'Operator turnover (FM6)'. As skilled operators have a higher potential to make fewer mistakes, such as incorrect machine setup and material selection, resulting in fewer defects and wastes in the process, the narrow fabric industry should provide proper incentives and motivation to reduce operator turnover, which will ultimately reduce the impact of other failure modes and defect generation, since this factor has the greatest influence on other failure modes [34].

The second predominant causal failure mode is the 'Absence of inline quality inspector (FM4)'. To ensure consistent quality products, the presence of an in-line quality specialist is essential. By providing an adequate number of quality inspectors, as well as training and lessons to teach them about their responsibilities and importance in the narrow fabric production process, this industry can reduce waste [35]. The third and fourth causal failure modes are 'Disobeying quality guidelines by operator (FM5)' and 'Use of outdated measuring tools (FM8)', respectively. Neglecting to maintain quality standards, as well as the use of expired or non-calibrated measuring tools, both result in challenges caused by incorrect RPM, heat, pinion setup, and mismeasurement during packaging [36]. Thus, adequate calibration and maintenance of measuring tools, as well as proper training for operators to follow quality guidelines, can help reduce process waste in the narrow fabric manufacturing environment [37]. To increase operational efficiency in the narrow plain elastic production process, policymakers in the narrow fabric manufacturing sector should resolve important failure modes in the C3 group, followed by the C1 group, as both serve as cause factors. Conversely, C4 contains FM9, FM10, FM11, FM13, and FM15, which have a large impact yet work as effect factors, implying that these failure modes are affected by both C3 and C1. C4 can be handled by resolving C1 and C3, as C4 is influenced by these factors. For example, 'Documentation error during sample development (FM9)' and 'Improper tension & speed in the yarn warping process (FM11)' are both in the C4 group with causal ranks of 9th and 10th, respectively. They are affected by the causal factors

'Technical data misinterpretation (FM1)' and 'Technical data misinterpretation (FM3)'. When technical specifications—such as yarn parameters, machine settings, or process instructions—are misunderstood, problems spread to subsequent phases [38]. This results in inaccurate sample information recording in FM9 and improper machine parameter settings in FM11, causing tension imbalance and speed fluctuation. Thus, fixing FM1 and FM3 failure modes can help resolve effect factors like FM9 and FM11. Finally, the FM12, FM14, and FM16 are independent failure modes with little or no impact on others. The study's findings differ from previous studies [15-21] in that it evaluates, ranks, and correlates significant failure modes for the narrow fabric production process using the IVPF-DEMATEL framework.

So, the study will assist managers and practitioners in identifying the true causes of process failure and the optimal order by combining FMEA and IVPF-DEMATEL to solve various failure problems, thereby effectively resolving process problems and increasing production yield in narrow fabric production settings.

4. Conclusion

FMEA is a preventative analysis tool used in product design and process planning to assist users in identifying flaws and potential defects, thereby preventing the recurrence of problems, reducing their effects, improving product quality and reliability, saving costs, and increasing competitiveness. FMEA solves problems by addressing individual elements and prioritizing those that can be used to develop solutions. When numerous failure modes are functioning or interact with one another, analysis becomes difficult, such that FMEA will incorrectly identify the influence factors and factors being influenced. As a result, key issues may stay unaddressed. This study integrated FMEA with IVPF-DEMATEL to address FMEA's shortcomings and improve its effectiveness. As a consequence, FMEA was used first to identify issues that needed to be improved, followed by IVPF-DEMATEL to investigate the causality and level of influence of the indicated issues. Finally, priority for resolving the core problems was suggested for the narrow fabric manufacturing. In addition to contributing to academia, the method proposed in the present study can be implemented in industrial practice. Future academics may investigate a broader range of sectors or use alternative evaluation methodologies for analysis and comparison.

Conflicts of Interest

There is no conflict of interest.

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Supplementary Materials

Appendix A

Table A1. Influence Matrix of failure modes

	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FM9	FM10	FM11	FM12	FM13	FM14	FM15	FM16
FM1	0	H	VH	N	VL	N	N	N	N	H	H	L	VH	N	VH	N
FM2	N	0	L	N	N	N	N	N	H	H	VH	H	H	N	VH	N
FM3	VH	H	0	L	H	L	VL	VL	N	VH	H	L	VH	N	H	H
FM4	H	H	H	0	N	N	L	H	N	H	H	L	H	N	VH	H
FM5	L	H	L	N	0	N	H	VH	N	H	H	L	H	N	H	H
FM6	H	VH	H	N	H	0	VH	H	VH	VH	H	VH	VH	N	VH	VH
FM7	N	N	N	N	N	N	0	N	H	VH	VH	L	VH	VH	VH	N
FM8	H	N	H	N	N	N	VL	0	H	VH	VH	N	H	N	H	H
FM9	H	H	VH	N	L	N	N	N	0	H	H	N	VH	N	H	N
FM10	N	N	N	N	N	N	N	N	H	0	N	N	N	N	N	L
FM11	N	N	H	N	N	N	N	N	VH	H	0	VH	VH	H	H	N
FM12	N	N	N	N	N	N	N	N	N	N	N	0	H	L	L	N
FM13	L	N	H	N	N	N	N	N	H	L	N	N	0	L	VL	N
FM14	N	N	N	N	N	N	N	N	N	N	N	N	N	0	N	H
FM15	H	N	L	N	N	N	N	N	H	H	N	N	N	H	0	N
FM16	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	0

Table A2. IVPF values corresponding to the expert findings

	FM1				FM2				FM3				FM4			
FM1	0.00	0.00	0.00	0.00	0.56	0.69	0.21	0.34	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00
FM2	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.21	0.34	0.56	0.69	0.00	0.00	1.00	1.00
FM3	0.65	0.78	0.12	0.25	0.56	0.69	0.21	0.34	0.00	0.00	0.00	0.00	0.21	0.34	0.56	0.69
FM4	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.00	0.00	0.00	0.00
FM5	0.21	0.34	0.56	0.69	0.56	0.69	0.21	0.34	0.21	0.34	0.56	0.69	0.00	0.00	1.00	1.00
FM6	0.56	0.69	0.21	0.34	0.65	0.78	0.12	0.25	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00
FM7	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM8	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00
FM9	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00
FM10	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM11	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00
FM12	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM13	0.21	0.34	0.56	0.69	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00
FM14	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM15	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00	0.21	0.34	0.56	0.69	0.00	0.00	1.00	1.00
FM16	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00

	FM5				FM6				FM7				FM8			
FM1	0.12	0.25	0.50	0.78	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM2	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM3	0.56	0.69	0.21	0.34	0.21	0.34	0.56	0.69	0.12	0.25	0.50	0.78	0.12	0.25	0.50	0.78
FM4	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.21	0.34	0.56	0.69	0.56	0.69	0.21	0.34
FM5	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.65	0.78	0.12	0.25
FM6	0.56	0.69	0.21	0.34	0.00	0.00	0.00	0.00	0.65	0.78	0.12	0.25	0.56	0.69	0.21	0.34
FM7	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
FM8	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.12	0.25	0.50	0.78	0.00	0.00	0.00	0.00
FM9	0.21	0.34	0.56	0.69	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM10	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM11	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM12	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM13	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM14	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM15	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM16	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00

	FM9				FM10				FM11				FM12			
FM1	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.21	0.34	0.56	0.69
FM2	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.65	0.78	0.12	0.25	0.56	0.69	0.21	0.34
FM3	0.00	0.00	1.00	1.00	0.65	0.78	0.12	0.25	0.56	0.69	0.21	0.34	0.21	0.34	0.56	0.69
FM4	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.21	0.34	0.56	0.69
FM5	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.21	0.34	0.56	0.69
FM6	0.65	0.78	0.12	0.25	0.65	0.78	0.12	0.25	0.56	0.69	0.21	0.34	0.65	0.78	0.12	0.25
FM7	0.56	0.69	0.21	0.34	0.65	0.78	0.12	0.25	0.65	0.78	0.12	0.25	0.21	0.34	0.56	0.69
FM8	0.56	0.69	0.21	0.34	0.65	0.78	0.12	0.25	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00
FM9	0.00	0.00	0.00	0.00	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00
FM10	0.56	0.69	0.21	0.34	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM11	0.65	0.78	0.12	0.25	0.56	0.69	0.21	0.34	0.00	0.00	0.00	0.00	0.65	0.78	0.12	0.25
FM12	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
FM13	0.56	0.69	0.21	0.34	0.21	0.34	0.56	0.69	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM14	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM15	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00
FM16	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00

	FM13				FM14				FM15				FM16			
FM1	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00
FM2	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00
FM3	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34
FM4	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00	0.65	0.78	0.12	0.25	0.56	0.69	0.21	0.34
FM5	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34
FM6	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00	0.65	0.78	0.12	0.25	0.65	0.78	0.12	0.25
FM7	0.65	0.78	0.12	0.25	0.65	0.78	0.12	0.25	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00
FM8	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34
FM9	0.65	0.78	0.12	0.25	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00
FM10	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.21	0.34	0.56	0.69
FM11	0.65	0.78	0.12	0.25	0.56	0.69	0.21	0.34	0.56	0.69	0.21	0.34	0.00	0.00	1.00	1.00
FM12	0.56	0.69	0.21	0.34	0.21	0.34	0.56	0.69	0.21	0.34	0.56	0.69	0.00	0.00	1.00	1.00
FM13	0.00	0.00	0.00	0.00	0.21	0.34	0.56	0.69	0.12	0.25	0.50	0.78	0.00	0.00	1.00	1.00
FM14	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34
FM15	0.00	0.00	1.00	1.00	0.56	0.69	0.21	0.34	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00
FM16	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00

Table A3. The crisp direct relation matrix

	FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9	FM 10	FM 11	FM 12	FM 13	FM 14	FM 15	FM 16	Sum
FM1	0.50	0.63	0.71	0.00	0.31	0.00	0.00	0.00	0.00	0.63	0.63	0.37	0.71	0.00	0.71	0.00	5.22
FM2	0.00	0.50	0.37	0.00	0.00	0.00	0.00	0.00	0.63	0.63	0.71	0.63	0.63	0.00	0.71	0.00	4.82
FM3	0.71	0.63	0.50	0.37	0.63	0.37	0.31	0.31	0.00	0.71	0.63	0.37	0.71	0.00	0.63	0.63	7.53
FM4	0.63	0.63	0.63	0.50	0.00	0.00	0.37	0.63	0.00	0.63	0.63	0.37	0.63	0.00	0.71	0.63	7.02
FM5	0.37	0.63	0.37	0.00	0.50	0.00	0.63	0.71	0.00	0.63	0.63	0.37	0.63	0.00	0.63	0.63	6.75
FM6	0.63	0.71	0.63	0.00	0.63	0.50	0.71	0.63	0.71	0.71	0.63	0.71	0.71	0.00	0.71	0.71	9.36
FM7	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.63	0.71	0.71	0.37	0.71	0.71	0.71	0.00	5.05
FM8	0.63	0.00	0.63	0.00	0.00	0.00	0.31	0.50	0.63	0.71	0.71	0.00	0.63	0.00	0.63	0.63	6.04
FM9	0.63	0.63	0.71	0.00	0.37	0.00	0.00	0.00	0.50	0.63	0.63	0.00	0.71	0.00	0.63	0.00	5.46
FM10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.50	0.00	0.00	0.00	0.00	0.00	0.37	1.50
FM11	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.71	0.63	0.50	0.71	0.71	0.63	0.63	0.00	5.17
FM12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.63	0.37	0.37	0.00	1.87
FM13	0.37	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.63	0.37	0.00	0.00	0.50	0.37	0.31	0.00	3.18
FM14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.63	1.13
FM15	0.63	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.63	0.63	0.00	0.00	0.00	0.63	0.50	0.00	3.40
FM16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.50

Table A4. Normalized matrix

	FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9	FM 10	FM 11	FM 12	FM 13	FM 14	FM 15	FM 16
FM1	0.05	0.07	0.08	0.00	0.03	0.00	0.00	0.00	0.00	0.07	0.07	0.04	0.08	0.00	0.08	0.00
FM2	0.00	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.08	0.07	0.07	0.00	0.08	0.00
FM3	0.08	0.07	0.05	0.04	0.07	0.04	0.03	0.03	0.00	0.08	0.07	0.04	0.08	0.00	0.07	0.07
FM4	0.07	0.07	0.07	0.05	0.00	0.00	0.04	0.07	0.00	0.07	0.07	0.04	0.07	0.00	0.08	0.07
FM5	0.04	0.07	0.04	0.00	0.05	0.00	0.07	0.08	0.00	0.07	0.07	0.04	0.07	0.00	0.07	0.07
FM6	0.07	0.08	0.07	0.00	0.07	0.05	0.08	0.07	0.08	0.08	0.07	0.08	0.08	0.00	0.08	0.08
FM7	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.07	0.08	0.08	0.04	0.08	0.08	0.08	0.00
FM8	0.07	0.00	0.07	0.00	0.00	0.00	0.03	0.05	0.07	0.08	0.08	0.00	0.07	0.00	0.07	0.07
FM9	0.07	0.07	0.08	0.00	0.04	0.00	0.00	0.00	0.05	0.07	0.07	0.00	0.08	0.00	0.07	0.00
FM10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.05	0.00	0.00	0.00	0.00	0.00	0.04
FM11	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.08	0.07	0.05	0.08	0.08	0.07	0.07	0.00
FM12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.04	0.04	0.00
FM13	0.04	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.07	0.04	0.00	0.00	0.05	0.04	0.03	0.00
FM14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.07
FM15	0.07	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.00	0.00	0.00	0.07	0.05	0.00
FM16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05

Table A5. Total relation matrix

	FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8	FM 9	FM 10	FM 11	FM 12	FM 13	FM 14	FM 15	FM 16	D
FM1	0.09	0.09	0.12	0	0.05	0	0.01	0.01	0.04	0.12	0.1	0.07	0.13	0.03	0.13	0.02	1.01
FM2	0.03	0.07	0.08	0	0.01	0	0	0	0.11	0.12	0.1	0.09	0.11	0.02	0.12	0.01	0.89
FM3	0.12	0.11	0.12	0.05	0.09	0.05	0.05	0.05	0.06	0.16	0.12	0.08	0.15	0.03	0.14	0.11	1.49
FM4	0.11	0.1	0.12	0.06	0.02	0.01	0.05	0.08	0.06	0.14	0.12	0.07	0.13	0.03	0.14	0.1	1.35
FM5	0.08	0.09	0.09	0	0.07	0	0.08	0.09	0.06	0.14	0.11	0.07	0.13	0.03	0.13	0.1	1.27
FM6	0.13	0.12	0.14	0.01	0.1	0.06	0.1	0.09	0.16	0.18	0.14	0.12	0.17	0.04	0.17	0.12	1.85
FM7	0.02	0.01	0.03	0	0.01	0	0.06	0	0.11	0.12	0.1	0.06	0.11	0.11	0.11	0.02	0.87
FM8	0.11	0.03	0.12	0	0.02	0	0.04	0.06	0.12	0.14	0.12	0.02	0.12	0.03	0.12	0.09	1.16
FM9	0.11	0.1	0.13	0.01	0.06	0.01	0.01	0.01	0.1	0.13	0.11	0.03	0.13	0.02	0.13	0.02	1.1
FM10	0.01	0.01	0.01	0	0	0	0	0	0.08	0.07	0.01	0	0.01	0	0.01	0.05	0.25
FM11	0.03	0.02	0.1	0	0.01	0	0.01	0.01	0.11	0.11	0.08	0.09	0.12	0.09	0.11	0.02	0.92
FM12	0.01	0	0.01	0	0	0	0	0	0.01	0.01	0	0.06	0.08	0.05	0.05	0	0.29
FM13	0.07	0.02	0.1	0	0.01	0	0.01	0.01	0.09	0.07	0.02	0.01	0.08	0.05	0.06	0.02	0.62
FM14	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0	0.08	0.13
FM15	0.09	0.02	0.06	0	0.01	0	0	0	0.09	0.1	0.02	0.01	0.03	0.08	0.08	0.02	0.62
FM16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06	0.06
R	1	0.8	1.23	0.15	0.46	0.15	0.43	0.42	1.2	1.61	1.16	0.79	1.5	0.68	1.5	0.82	

Appendix B

Table B1. SOD guidelines for RPN scoring

Score	Severity (S)	Occurrence (O)	Detection (D)
1	No effect	Extremely unlikely	Almost certain to detect
2	Very minor effect	Very low probability	Very high chance to detect
3	Minor effect	Low probability	High chance to detect
4	Moderate effect	Occasional	Moderate chance to detect
5	Significant effect	Moderate probability	Detection inconsistent
6	Serious effect	High probability	Low chance to detect
7	Very serious effect	Very high probability	Very low chance to detect
8	Major impact	Extremely high probability	Detection unlikely
9	Severe effect; safety risk	Near-certain	Almost impossible to detect
10	Catastrophic effect	Certain	No detection