

The Use of Grey Failure Mode and Effect Analysis (FMEA) to Improve Production Quality in Textile Company (Case Study: PT. ABC)

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Abstract

Product quality is a vital issue in the company. Therefore, it is essential to analyze the causes and risks of product failure. One of the methods used to identify this problem is the Failure Mode and Effect Analysis (FMEA) method. The traditional FMEA is based on the Risk Priority Number (RPN) value that has some weaknesses, and for example, while the number of the RPN is the same, it is possible to have different risks. This research uses the Grey Failure Mode and Effect Analysis (GFMEA) method. This method integrates traditional FMEA and Grey Theory through the Fuzzy Analytical Hierarchy Process (FAHP) to strengthen the FMEA method and increase the accuracy of RPN value by considering the failure factor weight. This research highlights a problem in a textile company, the Spinning V division. A continuous production process in a textile company needs to be minimized because failure in the previous process becomes an obstacle to the following process. This study aims to identify potential critical failures in the production process using the GFMEA method and provide suggestions for improvement. Data was obtained through observation and interviews with the company. The data processing with GFMEA obtained 50 potential failures that ten failures are critical and need to be prioritized. There were thick thin sliver drawing, deviated uster drawing, deviated ne drawing, deflated speed, neps carding, deflated ring, dirty winding, thick thin ring, web hole carding, and broken sliver carding with GRPN value 0.404084; 0.406152; 0.408895; 0.417443; 0.426736; 0.431085; 0.439939; 0.441411; 0.450704; 0.469499.

Keywords

FMEA, Grey Theory, FAHP, GFMEA, RPN

1. Introduction

Defective products in the production process will increase costs. The companies should have a procedure and plan to reduce and minimize the number of faulty products in the future (Agustin, 2017). Maintaining product quality is vital for the sustainability of company development because consumers will ensure that the products are free from errors and exceed the value generated by competitors when making transactions (Laroche, 2001). This is intended to maintain the quality of a product by the company and obtain optimal benefits (Hoe, 2018). In improving product quality, a company needs a process-based quality control program (Encomienda, 2018).

PT. ABC is a textile company located in Central Java Province that produces yarn, grey cloth, finished fabric, and finished products. In this study, the object of the research is regular yarn of various types, vis. 25s, 30s, and 60s, in Spinning V division. Based on the observations and interviews with the head of the production division, the head of quality control, and the operators, it is difficult to trace the cause of failure products. A continuous production process in this division causes difficulty in identifying and detect the root cause of failure. Therefore, it is necessary to carry out an in-depth analysis of causes and risks, to minimize company losses and to produce quality products.

Based on these facts, a method can solve these quality problems, Failure Mode and Effect Analysis (FMEA). FMEA is a method for determining, identifying, and eliminating defects in production problems, including potential system problems (Görener, 2013).

Although FMEA, which we called traditional FMEA, can detect the potential problems of failure, it has weaknesses (Chang, 2013). The main criticism of the traditional FMEA method is obtaining the same RPN value but having a different risk of failure (Mansur, 2015). The Grey Failure Mode and Effect Analysis (GFMEA) method covers this traditional FMEA weakness. GFMEA integrates conventional FMEA and grey theory through the Fuzzy Analytical Hierarchy Process (FAHP) bridge. FAHP helps to calculate the weight of importance between criteria, enlarge the range of the decision-making process and improve the accuracy of determining the RPN. The GFMEA determines the level of significance for each failure rate. Therefore, this study focuses on the most dominant failure to identify the causes and risks of loss in the normal yarn production process using the GFMEA method.

1.1 Objectives

Based on the background and the problems, this research has some objectives.

- a. Analysis of possible failures in the production process of regular yarn products
- b. Identification causes and effects resulted from the failure of the production process of regular yarn products based on FTA and cause-effect diagrams.
- c. Identifies the main problems that cause defects in common yarn products in Spinning Unit V based on the GFMEA method.
- d. Provide some suggestions based on the priority of the RPN value by the GFMEA method.

2. Literature Review

2.1 Failure Modes and Effect Analysis (FMEA)

FMEA is a tool for determining, identifying, and eliminating potential errors or problems in a system, design, or process before the product reaches the consumer (Omdahl, 1988). FMEA method is used for failure in a system, design, process, or service (Sharma, 2018). Identifying potential failures is attempted by providing a score for the failure mode based on the occurrence, severity, and detection (Stamatis, 1995). In general, there are two types of FMEA: the FMEA in design and the FMEA in process. The FMEA design is used after the system design is determined, whereas the FMEA process will evaluate each stage's fault or failure mode in the manufacture and assembly of the product (Sharma, 2018). The method applied in this research is the FMEA process because it focused on the production process only (Nurwulan, 2020). The purpose of implementing this approach is to minimize the possibility of defects (Zaman, 2017).

RPN number can be determined by multiply three factors, severity, occurrence, and detection.

- a. Severity
Severity indicates how serious the defect is caused by the occurrence of a failure process/product. Table 1. shows the proportion of the severity rating scale.
- b. Occurrence
Occurrence is a possible cause that may happen and create failure of product. Occurrence indicates the rating value adjusted for the estimated frequency and/or a cumulative number of failures.
- c. Detection
Detection indicates the level of control that can be a plan to detect the failures. Table 1 shows the weighted scale for detection.

Table 1. Rating Scale of Three Factors

Severity Rating Scale	
Grade	Criteria
1	No effect
2,3	Poor
4,5,6	Moderate
7,8	High
9,10	Very high

Occurrence Rating Scale	
Grade	Criteria
1	Nothing happens, with a probability of 1 / 10,000
2,3	Low occurrence, with a probability of 1/5000 to 1/500
4,5,6	Moderate occurrence, with a probability of 1/2000 to 1/200
7,8	High occurrence, with a probability of 1/100 to 1/20
9,10	Very high occurrence, with a probability of 1/10
Detection Rating Scale	
Grade	Criteria
1	The failure detection is elementary
2	The detection is relatively easy
3	Easy detection
4,5,6	Difficult detection
7,8	Very difficult detection
9,10	Failure has the possibility undetected

d. Risk Priority Number (RPN)

The RPN number is obtained by multiplying the severity, occurrence, and detection values to assign priority. This number is used to categorizing a failure as a risk or not. The formula is:

$$RPN = severity \times occurrence \times detection$$

2.2 Analytical Hierarchy Process (AHP)

AHP is one of the decision-making techniques used in solving the developed selection, sorting, and classification problems (Saaty, 2008).

The steps for preparing the AHP are as follows:

1. Identified problems and objectives
2. Determined decision-making criteria and alternatives
3. Create a hierarchical structure
4. Each criterion was created a pairwise comparison matrix for numerical analysis with the equations:

$$a_{ij} = \frac{w_i}{w_j} \quad i, j = 1, 2, 3, \dots, n$$

n is the number of criteria, w_i is the weight of all criteria, i and a_{ij} is the ratio of the weights of all criteria i and j .

Numeric criteria are based on an expert or a decision-maker, and the range value is between 1 to 9.

5. Normalize the column by dividing each value in the j -column and the y -column by the number of values in the i -column

$$a_{ij} = \frac{a_{ij}}{\sum a_i}$$

6. Determines the priority of each condition (w) by dividing each value by the specified requirements.
7. Calculate the consistency value with the following steps:

- a. The pairwise comparison matrix is multiplied by the weighting of each criterion (A_w).
- b. Calculating the *eigenvalue* (λ_{max}) obtained from the average value of A_w
- c. Calculating the *Consistency Index* (CI)

Calculate consistency for calculating the deviation from the consistency value with the equation:

$$CI = \frac{\lambda_{max} - n}{n - 1}; \quad n \text{ is the order of the paired matrix.}$$

- d. Calculating the *Consistency Ratio* (CR) with the equation:

$$CR = \frac{CI}{RI}$$

RI is a ratio index. The value of RI shows in Table 4 (Saaty and Vargas, 1984).

Table 2. Value of Ratio Index

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

If the pairwise comparison matrix has CR <0.1 then the inaccuracy of the expert's judgment is still acceptable.

2.3 Fuzzy Analytic Hierarchy Process (FAHP)

The FAHP method is a combination of AHP and fuzzy logic. FAHP is used for the uncertain condition in selecting objects (Mikaeil, 2009). The difference between AHP and FAHP lies in the application of pairwise comparison weights in the comparison matrix, which is represented by three variables (a, b, c) or (l, m, u) called fuzzy triangular numbers (TFN). In AHP, this method considers subjective factors such as perception, preference, experience, intuition and uses a mathematical-based process to evaluate criteria. Although the AHP method has been widely used to assist decision-making, the AHP method is still widely criticized because it is considered unbalanced in the pairwise comparison rating scale (Deng, 1999). The AHP scale, expressed in the form of crisp numbers, is considered less able to handle the problem of uncertainty. Therefore, the AHP scale is integrated with other methods, namely fuzzy logic. Fuzzy logic has an ambiguous value between two values. The fuzzy method, especially the AHP scale TFN method, is expected to minimize uncertainty so that the results obtained are expected to be more accurate.

After changing the pairwise comparison matrix to the TFN form, the following steps after changing the pairwise comparison matrix into TFN, we determine the weight using the FAHP.

- 1) Calculate the fuzzy synthetic extent values

Determine the fuzzy synthetic extent with the following formula:

$$S_i = \sum_{j=1}^m \sum_{i=1}^j x \frac{1}{\sum_{i=1}^n \sum_{j=1}^m M_i^j}$$

$$\sum_{j=1}^m M_{j=1}^m = \sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j$$

While

$$\frac{1}{\sum_{j=1}^n \sum_{j=1}^m M_i^j} = \frac{1}{\sum_{i=1}^n u_i \sum_{i=1}^n m_i \sum_{i=1}^n l_i}$$

- 2) Comparing the fuzzy synthetic extent values ($S_i \geq S_k$)

If the results are obtained for each matrix fuzzy $M_2 \geq M_1$ ($M_2 = (l_2, m_2, u_2)$ dan $M_1 = (l_1, m_1, u_1)$), If the results are obtained for each fuzzy matrix $M_2 \geq M_1$ ($M_2 = (l_2, m_2, u_2)$ and $M_1 = (l_1, m_1, u_1)$), then the vector values that can be formulated are as follows:

$$V(M_2 \geq M_1) = \sup [\min (\mu_{M_1}(x), \min (\mu_{M_2}(y)))]$$

Or the same as the chart below:

$$V(M_2 \geq M_1) = \begin{cases} 1, & \text{jika } M_2 \geq M_1 \\ 0, & \text{jika } l_1 \geq \mu_2 \\ \frac{l_1 - \mu_2}{(m_2 - \mu_2)(m_1 - l_1)} & \text{other} \end{cases}$$

- 3) Taking the minimum value from the comparison of the value of the fuzzy synthetic extent ($S_i \geq S_k$) for each criterion is expressed by:

$$d'(A_i) = \min V(S_i \geq S_k)$$

A_i is the decision element

- 4) Calculating the normalization of the fuzzy weight vector (w) Calculating the vector weight value as follows:

$$W' = (d'(A_1), d'(A_2) \dots d'(A_n))^T$$

And the value of fuzzy vector weight normalization (W) with the following equation:

$$W = (d(A_1), d(A_2) \dots d(A_n))^T$$

W is a nonfuzzy number

2.4 Grey Theory

Julong Deng introduced grey theory in 1982. This method focuses on problems with few samples or minimum information. Grey theory is a mathematical method for dealing with decisions characterized by incomplete data and explores the behavior of relational analysis systems use and model construction (Chang et al., 2001). Based on Chang et al. (2001), the grey theory provides a measure for analyzing the relationship between quantitative and qualitative discrete sequences. All components in the circuit must have the characteristics of existence, countable, exten-

sible, and independent. The one advantage of integrating grey theory and FMEA is determining different weights because each factor does not require a utility function in another form (Chang et al., 2001).

Gray theory is used to overcome the weaknesses of FMEA in determining risk priorities.. An acceptable approach to determining RPN easily and simply, without the need for utility functions.

The steps to calculating RPN with the grey theory, according to Chang et al. (2001) are as follows:

- a. Create a comparison line

$$X_j = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ \vdots \\ X_n \end{bmatrix} \begin{bmatrix} X_1(1) & X_1(2) & X_1(3) & \cdots & X_1(k) \\ X_2(1) & X_2(2) & X_2(3) & \cdots & X_2(k) \\ X_3(1) & X_3(2) & X_3(3) & \cdots & X_3(k) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ X_n(1) & X_n(2) & X_n(3) & \cdots & X_n(k) \end{bmatrix}$$

- b. Create standard lines

$$X_0 = X_0(1), X_0(2), X_0(3), \dots X_0(k)$$

- c. Calculates the difference between standard and comparison rows

$$D_0 = \begin{bmatrix} \Delta_1(1) & \Delta_1(2) & \Delta_1(3) & \cdots & \Delta_1(k) \\ \Delta_2(1) & \Delta_2(2) & \Delta_2(3) & \cdots & \Delta_2(k) \\ \Delta_3(1) & \Delta_3(2) & \Delta_3(3) & \cdots & \Delta_3(k) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \Delta_n(1) & \Delta_n(2) & \Delta_n(3) & \cdots & \Delta_n(k) \end{bmatrix}$$

$$\text{where, } \Delta_{0j}(k) = \|X_0(k) - X_j(k)\|$$

- d. Calculates the grey relational coefficient

$$\gamma_{0i}(k) = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta_{0j}(k) + \zeta \Delta_{max}}$$

Where ζ is an identification that only affects the relative risk value without changing the priority ζ is usually 0.5 (Ching, 2001).

- e. Determine the degree of relationship

$$\Gamma_{0i}(k) = \frac{1}{n} \sum_{k=1}^3 \gamma_{0i}(k)$$

- f. Sorting the level of risk based on the value of the degree of the relationship or grey RPN (GRPN)

The method that can overcome these problems is the Grey Failure Mode and Effect Analysis (GFMEA) method. This method is an integration method of traditional FMEA and grey theory through the help of the Fuzzy Analytic Hierarchy Process (FAHP) method. GFMEA calculate the weight of the interests between the criteria and the benefits of making decisions. GFMEA is broader than the Analytic Hierarchy Process (AHP) and can increase the accuracy of determining the RPN. GFMEA determines the level of importance for each level of failure.

3. Methods

3.1 Research respondents

Research respondents are determined based on sufficient knowledge and experience about the problem to help researchers follow the situation under study. The researcher defines the research respondents based on the problem related to the failure of the production process of ordinary yarn products. Thus, the research respondents are the head of the production department, quality control supervisor, supervisor of all operations and operators who are employees there, and the object of research being researched in the form of ordinary yarn.

3.2 Data

The data used are data on the identification of potential failures in the production process of regular yarn products, data on causes and effects of failure in the production process of everyday yarn products, data on the severity, occurrence, and detection of potential errors in the production process of regular yarn products, data on the weight assessment of failure factors.

3.3 Flow chart of research method

Figure 1. shows the flow chart of this research method.

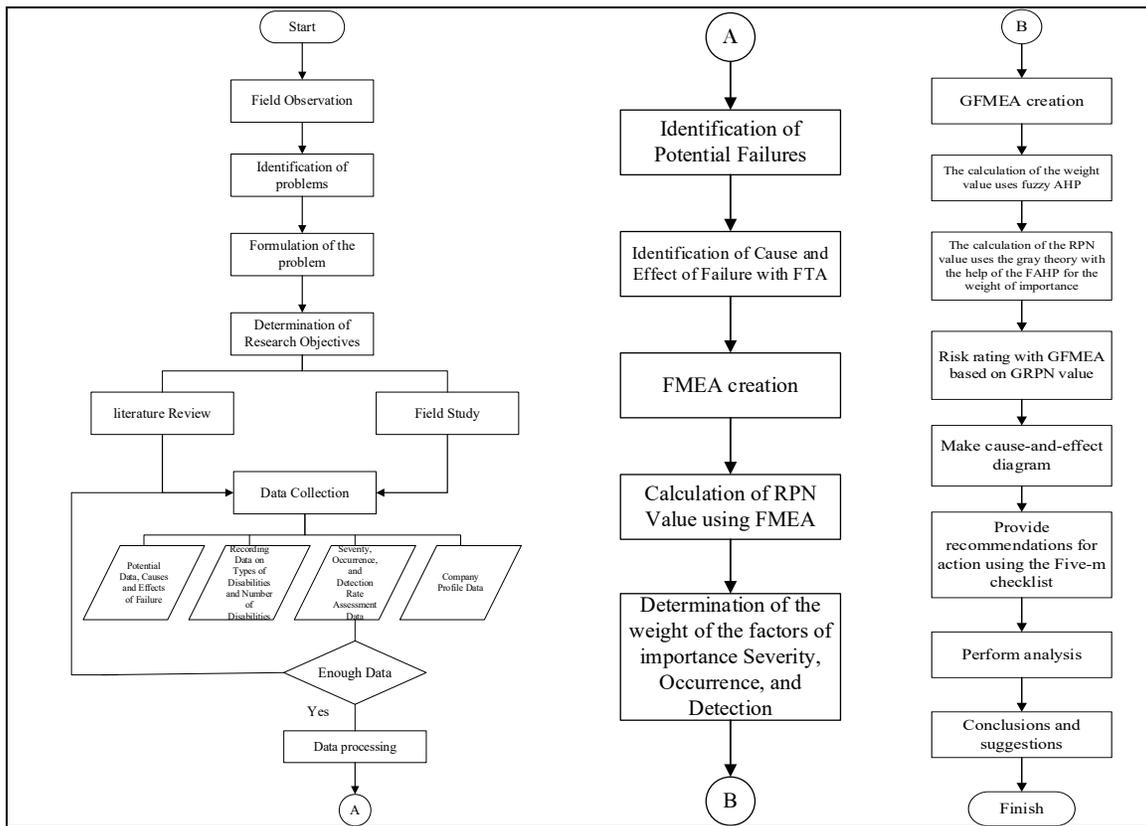


Figure 1. Flow chart of research method

4. Data Collection

The data is taken from interviews with the experts in certain sections.

4.1 Production Process

The production process flow of regular yarn products is as follows

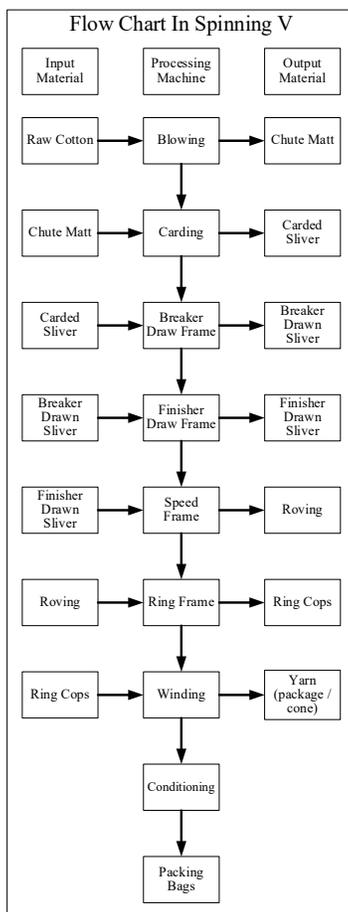


Figure 2. Production Process

4.2 Total Production

The data of total production is taken from the whole production data in the Spinning V section. The data shows in Table 5. is provided by the central production planning and inventory control (PPIC) at PT. ABC.

Table 3. Total Production

Type of Yarn	Total (cone)
25's	1.237.806
30's	
60's	

4.3 Number of Failures

This data is taken from the defect number of regular yarn in the Spinning V that shows in Table 6. This data is provided by the supervisor of Quality Control Spinning V at PT. ABC.

Table 4. Number of Failures

Type of Yarn	Total (cone)
25's	8925
30's	
60's	

4.4 Respondent's Assessment

Data taken from interviews with The supervisor of Quality Control Spinning V at PT. ABC, are shown in Table 5.

Table 5. Respondent's Assessment

Criteria (A)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Criteria (B)
Severity								v										Occurrence
Severity											v							Detection
Occurrence											v							Detection

5. Results and Discussion

In determining the priority of failure using the FMEA method, failures are prioritized based on the highest to lowest RPN values. However, in calculating the RPN value in traditional FMEA, there are still many criticisms because the RPN could have the same value, not consider the priority of the failure factor, and may have different representations. Therefore, to increase the accuracy and reliability of the RPN value, the GFMEA method is used. GFMEA compiles a mathematical model that analyzes the relationship between discrete quantitative and series qualitative. The calculation of the RPN value uses the GFMEA by considering the weight of the importance of each failure factor and the results of the various RPN values, thereby reducing the possibility of obtaining the same RPN value.

5.1 GFMEA

GFMEA methods include FAHP, traditional FMEA, and grey theory. This method is used to make the conventional FMEA results more accurate. Determination of weight is determined based on the assessment of the head of the production department, then calculated using the FAHP method. Table 6 shows the GFMEA priority result, which explains the difference value in each potential of failure.

Table 6. GFMEA priority

Priority	GFMEA	
	GRPN	Potential of Failure
1	0,404084	Thick Thin Sliver Drawing
2	0,406152	Deviated Uster Drawing
3	0,408895	Deviated NE Drawing
4	0,417443	Deflated Speed Carding
5	0,426736	NEPS Carding
6	0,431085	Deflated Ring
7	0,439939	Dirty Winding
8	0,441411	Thick Thin Ring
9	0,450704	Web Hole Carding
10	0,469499	Broken Sliver Carding

In the next step, after determining the weight of each failure factor, we calculate the RPN value using the grey theory method. The grey theory improves the accuracy of determining the RPN and increases the reliability in determining priorities. In this study, the priority of failure was determined through the results of the RPN calculation using GFMEA. After discussing with the head of the production department regarding the GRPN value limit that must be prioritized for analysis and recommendations for improvement. It turned out that the failure had a GRPN value below 0.47 because, according to the head of the production section, this value was very critical. The value so that the priority of potential failure is given ten recommendations for improvement of potential failures, there were thick thin sliver drawing, deviated uster drawing, deviated ne drawing, deflated speed, neps carding, deflated ring, dirty winding, thick thin ring, web hole carding, and broken sliver carding. These ten potential failures are frequently happening in the Spinning V division.

5.2 FTA and Cause effect Diagram

FTA is used to describe each failure in detail. An example of an analysis using FTA shows in Figure 3.

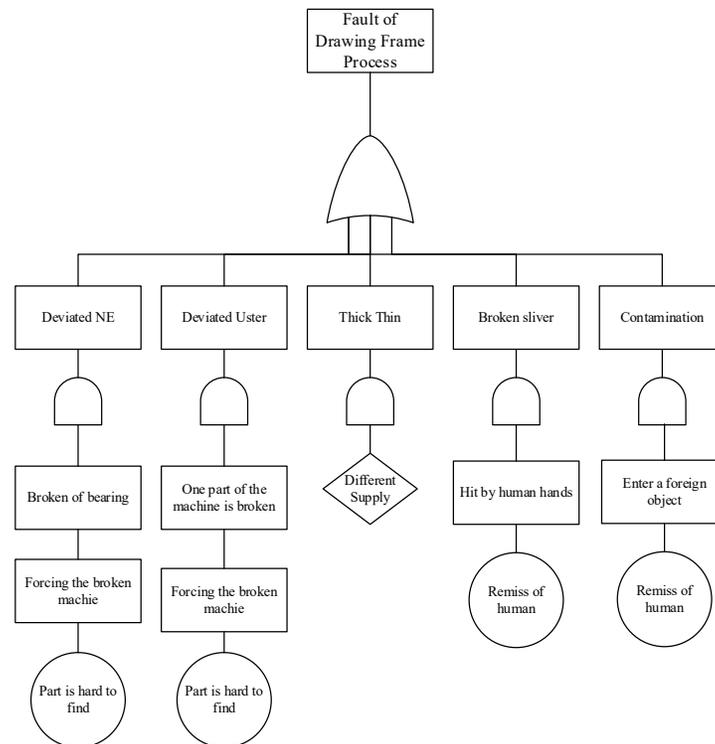


Figure 3. FTA of Drawing Process

Figure 4. shows the analysis examples using a cause and effect diagram of the first failure, thick thin sliver drawing. The most dominant factors are machine and human factors, but other factors must be considered either.

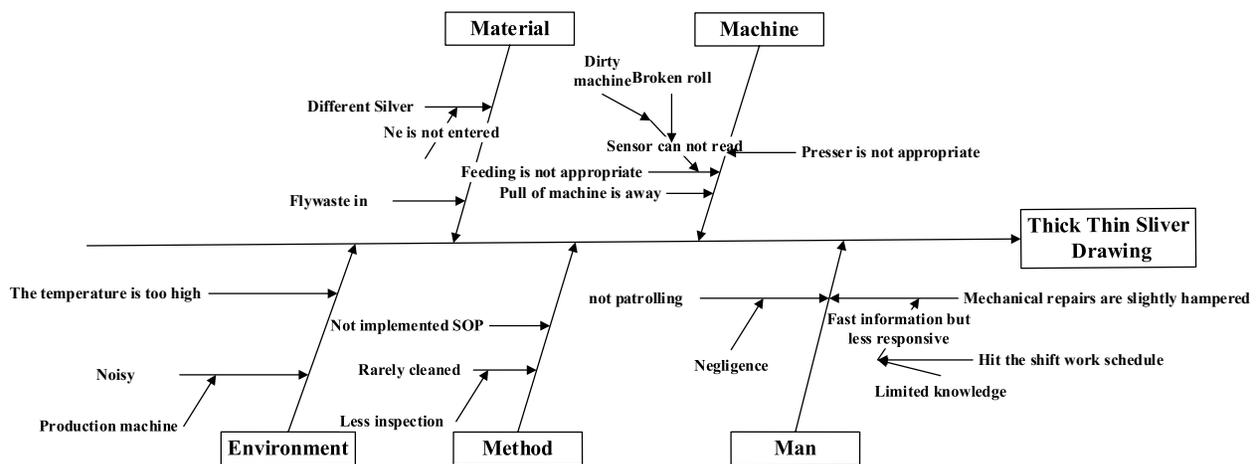


Figure 4. Cause Effect Diagram of Thick Thin Sliver Drawing Failure

5.3 Suggestion of improvement

This research is expected to provide various improvements for the company, for example:

1. Identification of various failures in the company's regular yarn production process can be used as a reference for the repair and improve regular yarn product quality.
2. This suggestion of improvement is expected as a consideration and increase company references. The goals are to reduce complaints from consumers, reduce risks, and increase company productivity.
3. Each level of severity, occurrence, and detection between failures can be considered by the company regarding the risks involved in failure in the regular yarn production process.

4. PT. ABC is expected to provide direction at the company in the morning regarding the implementation of SOPs, provide training to workers every week, and provide warning letters to workers.

6. Conclusion

Determining priorities for correcting a production process failure using the traditional FMEA method gives the same RPN value. It is challenging to decide on which one should be repaired first to maintain product quality according to company standards. Implementation of the GFMEA can remove this problem. There is no equal RPN value, and we can determine the priority of failures and improve them. There are 10 failures that must be prioritized, there were thick thin sliver drawing, deviated uster drawing, deviated ne drawing, deflated speed, neps carding, deflated ring, dirty winding, thick thin ring, web hole carding, and broken sliver carding with GRPN values below 0.47. To be able to overcome the failure of the regular yarn production process which is quite high. PT. ABC is expected to be able to provide direction at the company in the morning regarding the implementation of SOPs, provide training to workers every week, and provide warning letters to workers. If they do not run SOPs so that failures in the regular yarn production process can be resolved.

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Biography

Muhammad Zulfikar is a student born in the small town of Tanjungpinang on May 12, 1999, is the last of two children. He is an Industrial Engineering student at UIN Sunan Kalijaga Yogyakarta, Indonesia. His family consists of nomads ranging from mother, father to brother, and Zulfikar himself migrated to Yogyakarta. He was a wanderer who always wanted to learn. Zulfikar is active in organizations at the University but does not forget about education, from departmental level organizations to university level organizations. Zulfikar has a hobby of reading and writing. Her research interests include quality management, risk management, supply chain management, and related manufacturing. He had an internship at a textile and garment company in Sukoharjo. He was eager to study and had an interest in manufacturing. His big dream is to work for a large company

Irine Indriana Wati is a student who was born in the small Regency of Banyumas on March 16, 1997, is the first of two children. She is an Industrial Engineering student at UIN Sunan Kalijaga Yogyakarta, Indonesia. She was a wanderer who always wanted to learn. Irine is active in organizations at the University but does not forget about education and has a part-time job. Irine likes reading, writing, and cooking. Her research interests include quality management, risk management, supply chain management, and related manufacturing. She was eager to study and had an interest in manufacturing. Her big dream is to work for a large company and become an entrepreneur.

Ira Setyaningsih is a lecturer at Industrial Engineering Department, UIN Sunan Kalijaga, Yogyakarta, Indonesia. She holds a Bachelor in Industrial Engineering, Universitas Gadjah Mada, and a Master in Quality and Productivity Improvement, Universiti Kebangsaan Malaysia. Her research interests include innovation, bibliometric study, small-medium enterprise (SME), green manufacturing, and quality management.