The Fuzzy Failure Mode and Effect Analysis (FMEA) Method to Improve Roofing Product’s Quality (case study: XYZ Company)

Aulia Ishak¹, Khawarita Siregar², Rosnani Ginting³ and Afrianti Manik⁴

¹,²,³,⁴Industrial Engineering Department, Faculty of Engineering, Universitas Sumatera Utara, Medan, Indonesia

E-mail: afriendymaniker12@gmail.com aulia.ishak@usu.ac.id

Abstract. Evaluation and improvement of production performance are things that must be considered in an effort to maintain and improve the quality of production results. One level in measuring production performance is smooth production. Good risk management can support and maintain the smooth production process in the company. This research was conducted at PT XYZ with the aim to reduce the risk of failure of zinc products and propose improvements to the risk of product failure to improve the quality of zinc products. The method used in this case is Fuzzy FMEA (Failure Mode and Effect Analysis). Fuzzy logic approach is preferred to eliminate this shortcoming in setting risk priorities number. The use of the Fuzzy FMEA method can generate priority figures for failure modes so that problems can be solved efficiently in an effort to improve production performance. The results of this study are failure modes. One of the rollers got the highest FRPN value of 880,289 so that failure due to incorrect grinding machine settings and the lack of operator accuracy in positioning zinc was recommended as a major improvement to minimize milling error failures in the production process.

1. Introduction

Currently the manufacturing industry is competing to improve the quality of the products produced. High demand causes competition in similar manufacturing industries. Quality is the main factor for consumers in choosing products [1]. The quality of products produced by a company is determined based on certain sizes and characteristics. Companies must always check and repair in various stages [2].

The importance of quality control in efforts to improve product quality can be responded to by the discovery and development of the production process carried out to ensure the level of product errors and defects can be minimized. However, seeing the relevant conditions in the industrial sector there are still products that are not in accordance with the company’s quality standards that cause losses and have an impact on increasing repair costs that must be incurred, therefore we need a tool that can control and improve the production process so as to minimize the number of product defects in the company [3]. On the off chance that the consequences of QC tests can't satisfy the acknowledgment models, the aftereffects of examination of the entire arrangement of the estimations on that day must be eliminated or should be re-dissected, and an incomplete or full re-approval of the strategy considered [13].
XYZ Company is a company engaged in coated steel sheet which produces flat zinc and corrugated zinc which is adjusted to SNI 07-2053-2006 standards applied by the company. The main products of XYZ company are roofing with three types of sizes namely (1829 x 762 x 0.02) mm, (2134 x 762 x 0.02) mm and (2438 x 762 x 0.02) mm where each size consists of three brands namely BT Hard, SF Hard and DM Hard. Roofing is one of the main needs in the field of building construction. At present the public demand for zinc products is increasing due to prices that are classified as standard and suitable for people with middle economic levels. Seeing the condition of population growth which is increasing every year, the need for zinc products will also increase. The increasing demand for zinc products will lead to a level of business competition between companies that produce zinc so that product quality control is needed to face business competition [4].

The problem that company faced is the presence of defective products enough high with an average percentage of 5.95% per month exceeding the company's quality standard of 2% which will cause a decrease in profits, decreased productivity and decreased customer confidence. This is due to ineffective product quality control. Therefore it is necessary to do an analysis of the quality problems that occur, find the causative factors and propose further actions to be taken in an effort to improve the quality of the roof.

Previous research using Statistical Quality Control technique is Nuchpho, P. et al discuss the use of the fuzzy FMEA method to determine the factors that influence / cause factors for disability products of plated bath process which produce sanitary ware product type page settle (K-160) of and the results of the discussion show that it can being problem solving and discover of efficiently the potential failure modes and effects and can reduce the number of defective products [5].

Other research applying the Fuzzy Failure Mode and Effect Analysis (FMEA) method is carried out to analysis the error factors in the food processing production process of poultry industrial companies in Thailand which are the cause of defects in processed food products. By providing an assessment of Severity, Occurrence and Detection of the risk of product damage developed with fuzzy logic rules, research results show that the material shifting process is not according to the standard when on a machine with a FRPN value of 409 causing the marking rod to burn [6].

Therefore the suitable method as a problem solving of quality problem in this company is Fuzzy FMEA (Failure Mode and Effect analysis) rather than conventional FMEA [7]. So that by analysis the quality of the product, a significant type of product is obtained for the overall defect product so causes factors that can be identified so and then the company can take corrective action to reduce the defective product.

2. Literature Review
The application of FMEA began in 1949 in the aviation sector to solve the problem reliabilities and safety of the phases designing and production. FMEA being a standard practice in manufacturing companies in Japanese, European and American, both in the sector of automotive, food industry, electronics and energy to pharmaceuticals sector. A lot of research has been done for improving FMEA's performance in past decade. Even though research provides the opinion that studies with conventional FMEA have results with low accuracy, so fuzzy rule-based analysis is expert to construct the rule more logical and realistic. By using fuzzy membership functions, incorrect information is corrected to reflect the actual situation. The using the fuzzy IF-THEN, rules gathered from experts, expert knowledge, and experience are fed into the risk assessment tool. It is easier to distinguish risk representations between failure modes that have the same RPN [8].

Bowles and Pelaez discuss fuzzy logic as a new technique for prioritization which failure must have corrective action in the failure mode and Effect Analysis with the same assessment based on severity, occurrence, and item detection failure. In this case the fuzzy sets, combined by matching them to the rules on the basis, then evaluate it using min-max formulation, and then defuzzification phase to assess the failure risk [9]. Pinnarat Nuchpho discuss FMEA being a management method used for improvement in process of management. This paper purposed to identify factor that cause of product defects in poultry production at industry. The problem causes had analyzed using process of
brainstorming. Failure Mode and Effect Analysis method using number of RPN that will indicate risk problem being priority to do corrective action and can evaluating number of severity, occurrence and detection. Therefore, recommends to using FMEA method based fuzzy approach for rank result of RPN priority and reducing poultry products efficiently defects, which are defined based on the fuzzy logic give the significant comparison with conventional FMEA. The results showed that the FMEA fuzzy method can be efficient an reduce defects in poultry products. Md. Fazle Rabbi using the analysis and proposed improvements of risk of the Reach Stacker Crane engine maintenance team in the service industry by comparing the use of conventional FMEA and Fuzzy FMEA methods and the results showed that showing that a more accurate and reasonable ranking could be achieved by applying fuzzy FMEA. Nuchpho, P. et.al discuss the use of the fuzzy FMEA method to determine the factors that influence / cause factors for product disabilities in the plated bath process which produce sanitary ware products type page settle (K-160) and the results of the discussion show that it can solve the problems and efficiently discover the potential failure modes and effects. Arash Geramiana modify and improve quantitative / math features both the computational and analytical aspects of the Failure Mode and Effect Analysis (FMEA). Used a hybrid approach including FMEA based on Fuzzy Logic (FFMEA) and the Collective Process Capability Analysis (CPCA) has been developed in three phases. The results showed that the diameter deviation in insulator A was the most critical failure effect caused by an average shift to the right of 0.32 cm. In addition, Capability process index has increased from 0.41 to 1.12, and defective products were reduced from 115,083.09 to 336.98 parts per million [10].

The paper presented applies Fuzzy FMEA to provide proposals for improving the production system for quality improvement of roofing product and minimizing of disabilities product results.

3. Methodology

3.1. FMEA (Failure Mode and Effect Analysis)

Failure Mode and Effect Analysis is a method for analyzing the failure causes and predict the cause’s factors. Using FMEA is to assess the causes and consequences of failure modes in each component, determine possible failure modes, reduce possible failure modes and determine what can be eliminated. The result of FMEA called RPN is applied to assess the causes of failures, it have 3 parameters are severity (S), occurrence (O) and detection (D). The results analysis can help correct errors and determine the causes of harm in the process and complete performance in each phase of the operation. In FMEA, the score of severity, occurrence and detection (risk factors), determined by experts used to calculate the Risk Priority Number (RPN) which used to determine rating of failure. FMEA assessment and calculation steps made due to computational aspect of FMEA. In addition, the analytical aspects of FMEA require investigation of the causes and effects of failures, current controls, and recommended corrective actions. The aim of this research is to modify and improve both aspects, quantitatively / mathematically. The following are some of the limitations of the computational aspect of FMEA: (i) The calculation of the questionable RPN, namely the multiplication of risk factors; (ii) uncertainty in determining risk factors; and (iii) the possibility to allocate the same relative importance weighting to risk factor[9]. Use number 1-10, to measure severity, occurrence, and detection by asking analysts or experts to assign scores ranging from 1 to 10 for different factors. After the errors were analyzed by the FMEA technique, they were collected and considered RPN. Then, RPN is categorized from the most to at least. The RPN is calculated in Eq.

\[ RPN = S \times O \times D \]  \hspace{1cm} (1)

After the failure mode or effect has been analysis by the FMEA method, then necessary to perform the priority action according to the failure mode which have the higher RPN value given more importance to improvement than a lower RPN value.
3.2. Fuzzy Logic

Fuzzy logic is a way to map the problem from input to expected output. According to Cox there are several reasons why people use fuzzy logic, such as first, concept of fuzzy logic is easy to understand. Because fuzzy logic uses base on fuzzy set theory, the mathematical concepts that underlie fuzzy reason be easy to understand, second, logical fuzzy very flexible. It’s mean can adapt to changes and uncertainties in problems. Third, fuzzy logic has a tolerance for incorrect data. If given enough homogeneous data and there are some exclusive data, then fuzzy logic able to handle the exclusive data. Fourth fuzzy logic is able to model complex non-linear functions. Fifth fuzzy logic can build and apply the experiences of experts directly without have a training process. Sixth, fuzzy logic can working using the conventional of control techniques. last, fuzzy logic had made in natural language so easy to understood [11].

3.3. Fuzzy Approach to Failure Mode and Effect Analysis (FMEA)

In Literature review of Liu et al show that Artificial Intelligence (AI), with a 40.00% reviewed, most popular methodology have discuss about deficiency of FMEA method in using for problem solving . In the FMEA conventional, the value of the risk of failure can be obtained by multiplying the score of severity, occurrence and value of detection. However conventional FMEA does not pay attention to the importance of each input, resulting in the calculation of the input has the same level importance. In addition, subjective and qualitative assessments and also RPN scores are only obtained from the results of the multiplication of the three inputs and maybe has the same RPN value while it have different importance for the effect. Therefore, the number of severity, occurrence and detection value are assessed using Fuzzy Logic of Mamdani method by the formula of Min-Max to get the value of FRPN (Fuzzy Risk Priority Number) with critical analysis. More precise is that Fuzzy Logic-based FMEA (FFMEA) was addressed as the most popular methodology in AI. This fact make the authors of the present research to modify FMEA using Fuzzy Logic, and the result in an enhanced FMEA computational aspect. The structure in using FMEA based on fuzzy theory can be seen in the Figure 1.

![Figure 1. FMEA structure based on fuzzy theory](image)

For input and output variable parameters using triangular and trapezoidal membership functions which can be seen in Figure 2-3, that the membership function for each input value entered has a scale of 10 levels which is divided into 5 different areas.

![Figure 2. Membership function of input variables](image)

![Figure 3. Membership function of output variables](image)
4. Result and Discussion

4.1. Failure Mode and Effect Analysis (FMEA)

After observing and analyzing the results of production, there are 2 modes of failure that give 80% influence on production results, namely scratch defects and milling errors. FMEA assessment results are shown in the following Table 1.

**Table 1. Analysis of failure mode and effect analysis**

| Risk Mode | Failure Effect | Factor | S | Causes of Failure | O | Improvement’s Proposed | D | Risk Priority Number |
|-----------|----------------|--------|---|-------------------|---|------------------------|---|---------------------|
| Scratches | Material       |        |   | Poor quality of   | 2 | Make a PMC (Production Material Control) team that focuses on material inspection | 4 | 56                  |
|           |                |        |   | raw materials     |   |                        |   |                     |
|           | Machine        |        | 7 | Poor engine       | 4 | Doing routine checks on the machine before the machine is used / set up the machine | 6 | 168                 |
|           |                |        |   | performance       |   |                        |   |                     |
|           |                |        |   | because it is not |   |                        |   |                     |
|           |                |        |   | routinely        |   |                        |   |                     |
|           |                |        |   | maintained        |   |                        |   |                     |
|           | Man            |        |   | The operator is   | 6 | Doing more stringent and routine supervision every day and conduct briefings before the production process is carried out. | 5 | 210                 |
|           |                |        |   | not careful in    |   |                        |   |                     |
|           |                |        |   | setting the wind  |   |                        |   |                     |
|           |                |        |   | blade nozzle      |   |                        |   |                     |
|           | Method         |        |   | Cleaning of       | 5 | Prepare a machine maintenance procedure checklist and arrange a special schedule for machine maintenance on a regular basis outside the production schedule | 5 | 175                 |
|           |                |        |   | engine components |   |                        |   |                     |
|           |                |        |   | is less scheduled |   |                        |   |                     |
| Milling Error | Material     |        |   | Poor quality of   | 2 | Check the material before entering the initial process by the operator | 4 | 64                  |
|           |                |        |   | raw materials     |   |                        |   |                     |
|           | Machine        |        |   | Poor engine       | 3 | Doing routine checks on the machine before the machine is used / set up the machine | 6 | 144                 |
|           |                |        |   | performance       |   |                        |   |                     |
|           |                |        |   | because it is not |   |                        |   |                     |
|           |                |        |   | routinely        |   |                        |   |                     |
|           |                |        |   | maintained        |   |                        |   |                     |
|           | Man            |        | 8 | Operators are not | 5 | make aids in the form of a buffer to help position zinc so that it is more even and symmetrical. | 5 | 200                 |
|           |                |        |   | careful in        |   |                        |   |                     |
|           |                |        |   | positioning       |   |                        |   |                     |
|           |                |        |   | roofing when it    |   |                        |   |                     |
|           |                |        |   | want to           |   |                        |   |                     |
|           |                |        |   | grinding         |   |                        |   |                     |
|           |                |        |   | process          |   |                        |   |                     |
|           | Method         |        |   | The engine       | 6 | making of the machine adjustments procedure and specifications based on each type of roofing product | 5 | 240                 |
|           |                |        |   | settings are not  |   |                        |   |                     |
|           |                |        |   | appropriate to    |   |                        |   |                     |
|           |                |        |   | the specifications|   |                        |   |                     |
|           |                |        |   | of the material   |   |                        |   |                     |
|           |                |        |   | produced         |   |                        |   |                     |
Based on Table 1. above is obtained that the highest RPN value on scratch defects is 210 with the cause of failure that is the operator is not careful in setting the wind blade nozzle and the highest RPN value on the milling error is 240 with the cause of failure which is the machine setting is not right so both of them are a type of failure which is the first priority for immediate improvement.

4.2. Fuzzy Logic

The reality is based on the results of the research showing that conventional FMEA doesn’t give attention to the importance of each input parameter, that are severity, occurrence and detection so that in its calculation each input multiplication has the same importance. Besides this, the assessment of each parameter is subjective and qualitative, plus the method of obtaining the RPN value is only from multiplying the three input parameters. Therefore, determining the values of S, O, D is assessed using the Fuzzy Logic approach with the Mamdani method (Min-Max) to obtain a more accurate FRPN (Fuzzy Risk Priority Number) value [12]. Category index number of parameters of severity, events, detection, and membership functions for input and output variables can be seen in Table 2.

**Table 2. Input variable category**

| Rank | Severity (S) | Occurance (O) | Detection (D) |
|------|--------------|---------------|---------------|
| 1    | 1            | 1             | 1             |
| 2,3  | 2,3          | 2,3           | L             |
| 4,5,6| 4,5,6        | 4,5,6         | M             |
| 7,8  | 7,8          | 7,8           | H             |
| 9,1  | 9,1          | 9,1           | VH            |

**Table 3. Parameters of input variable membership function**

| Categories | Types of curve | Parameters          |
|------------|----------------|---------------------|
| VL         | Trapezoid      | (0; 0; 1; 2,5)      |
| L          | Triangle       | (1; 2,5; 4,5)       |
| M          | Trapezoid      | (2,5; 4,5; 5,5; 7,5)|
| H          | Triangle       | (5,5; 7,5; 9)       |
| VH         | Trapezoid      | (7,5; 9; 10; 10)    |

The parameters for the output variable membership function can be seen in the table 4.

**Table 4. Output variable membership function parameters**

| Categories | Types of curve | Parameters          |
|------------|----------------|---------------------|
| VL         | Trapezoid      | (0, 0, 25, 75)      |
| VL-L       | Triangle       | (25, 75, 125)       |
| L          | Triangle       | (75, 125, 200)      |
| L-M        | Triangle       | (125, 200, 300)     |
| M          | Triangle       | (200, 300, 400)     |
| M-H        | Triangle       | (300, 400, 500)     |
| H          | Triangle       | (400, 500, 700)     |
| H-VH       | Triangle       | (500, 700, 900)     |
| VH         | Trapezoid      | (700, 900, 1000, 1000)|
4.3. Fuzzy Failure Mode and Effect Analysis (FMEA)

**Table 5. Result Of calculating priority number values using fuzzy logic.**

| Failure Mode | Failure Effect                                                                 | Cause of Failure                                                                 | FRPN    | Category | Rank |
|--------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------|---------|----------|------|
| Scratches    | Scratches make product's appearances being look not good and unattractive which make it can't received by customer and the product that has been scratched cannot be reworked | Poor quality of raw materials and unattractive                                   | 166.62  | L - M    | 6    |
|              |                                                                                  | Poor engine performance because it is not routinely maintained                      | 733.91  | H – VH   | 3    |
|              |                                                                                  | The operator is not careful in setting the wind blade nozzle                       | 788.333 | H – VH   | 2    |
|              |                                                                                  | Cleaning of engine components is less scheduled                                   | 788.333 | H - VH   | 2    |
| Milling Error| Milling Error defects cause product appearance unattractive and asymmetrical, reduce the overall functional level of the product, the product will not be accepted by consumers, the wrong milled product cannot be reworked | Poor quality of raw materials and unattractive                                   | 707.214 | H – VH   | 5    |
|              |                                                                                  | Poor engine performance because it is not routinely maintained                      | 747.765 | H – VH   | 4    |
|              |                                                                                  | Operators are not careful in positioning roofing when it want to grinding process  | 880.289 | VH       | 1    |
|              |                                                                                  | The engine settings are not appropriate to the specifications of the material produced | 880.289 | VH       | 1    |

**Table 6. Comparison of conventional FMEA and fuzzy FMEA results**

| Failure Mode | Failure’s Effect                                                                 | Failure’s causes                                                                 | Risk Priority Number | Rank | Fuzzy Risk Priority Number | Rank |
|--------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------|------|---------------------------|------|
| Scratches    | Scratches make product's appearances being look not good and unattractive which make it can't received by customer and the product that has been scratched cannot be reworked | Poor quality of raw materials                                                   | 56                   | 8    | 594.65                    | 6    |
|              |                                                                                  | Poor engine performance because it is not routinely maintained                    | 168                  | 5    | 679.435                   | 3    |
|              |                                                                                  | The operator is not careful in setting the wind blade nozzle                      | 210                  | 2    | **788,333**               | 2    |
|              |                                                                                  | Cleaning of engine components is less scheduled                                   | 175                  | 4    | **788,333**               | 2    |
| Milling Error| Milling Error defects cause product appearance unattractive and asymmetrical, reduce the overall functional level of the product, the product will not be accepted by consumers, the wrong milled product cannot be reworked | Poor quality of raw materials                                                   | 64                   | 7    | 707,214                   | 5    |
|              |                                                                                  | Poor engine performance because it is not routinely maintained                    | 144                  | 6    | 747,765.                  | 4    |
|              |                                                                                  | Operators are not careful in positioning roofing when it want to grinding process  | 200                  | 3    | 880,289                   | 1    |
|              |                                                                                  | The engine settings are not appropriate to the specifications of the material produced | 240                  | 1    | 880,289                   | 1    |
Based on the results of the calculation of the value of Fuzzy Risk Priority Number as in Table 5 it was found that the highest FRPN value was 880,289 for the failure mode of the wrong rollers with the cause of failure namely the setting of the grinding machine was incorrect and the operator was not careful in positioning the zinc when grinding. Meanwhile, the second rank is in the stroke failure mode with a value of FRPN 788,333 with the cause of failure. The operator is not careful in setting the wind blade nozzle and cleaning the engine components is less scheduled so that the type of failure is a top priority for immediate repairs to improve product quality.

In the Conventional FMEA calculation, the machine settings are not in accordance with the specifications of the material produced which has the highest RPN value of 240, whereas operators are not careful in regulating the wind blade nozzle to have the second highest RPN value of 210. While in calculations using Fuzzy FMEA, the FRPN value of the machine settings does not match the specifications of the material produced and the operator is not careful in positioning the roof when he wants the milling process to have the same FRPN value and is the highest value with the FRPN 880,289 value. While the causes of risk are ranked second that is cleaning of engine components is less scheduled and the operator is not careful in setting the wind blade nozzle with FRPN value 788,333. There are differences which the result of calculation using Conventional FMEA that have by multiplying the number of severity, occurrence and detection regardless of the importance of input parameters. This is because its use is only using linguistic terms when determining score of severity, occurrence and detection in the FMEA conventional. So that by Fuzzy based FMEA the RPN value will produced by observe the importance of every input parameters that obtain by the results of Fuzzy fases. To test the accuracy of the results of fuzzy calculations we can use Matlab software with the following results.

5. Conclusion
Fuzzy FMEA theory that used is proposed and developed by an expert risk assessment system, by using FMEA based fuzzy, number of severity, occurrence and detection ratings in natural language show an unrealistic result. Risk Priority Number generated by assigning three ratings ignores the relative importance among these parameters and causes misunderstanding. With the application of linguistic terms, experts may be able to provide more plausible and meaningful information for these three parameters. Based on fuzzy rules can help experts to build more realistic and logical rules. Based
on the calculation of Fuzzy Risk Priority Number, the cause of disability that has the highest FRPN value is that the machine settings are not appropriate in accordance with product specifications and the operator is not careful in positioning the zinc when entering the grinding machine with a value of FRPN 880.289 in the very high category so it needs to be repaired immediately with Proposal Making procedures for guiding machine settings and specifications based on each type of zinc product and installing aids in the form of a buffer to help position zinc so that it is more even and symmetrical. So can the recommendation can be given that implement the proposed improvements given to minimize the number of scratch defects and milling errors in the company while minimizing the loss of production costs and need more systematic division of tasks needs to be developed so that members from each field focus on their responsibilities, especially the formation of inspection and maintenance teams for machinery and equipment.

Acknowledgements
The Authors would like to thank XYZ company for providing the data in this research

References
[1] Ishak A, Siregar K, Asfriyati and Naibaho H 2019 IOP Conference Series: Materials Science and Engineering 505 012057
[2] Kulkarni S, Kulkarni C, Vimal K E K and Jayakrishna K 2019 Statistical Quality Control of Torque Wrenches Used in Assembly Department Advances in Manufacturing Technology pp 199–208
[3] Bankel K 2014 Implementation Of Statistical Quality Control (SQC) In Welded Stainless Steel Pipe Manufacturing Industry International Journal of Research in Engineering and Technology Volume 03 Issue 09 pp 270-273
[4] Nuchpho P, Nansaarng S and A Pongpullponsak 2018 Modified Fuzzy FMEA Application in the Reduction of Defective Poultry Product Eng J vol. 23 No 1 pp 171-190
[5] Nuchpho P et al 2014 The fuzzy FMEA Method To Improve The Defects In Sanitary Ware Manufacturing Process International Conference Applied Statistics Khon Kaen Thailand
[6] Nuchpho P, Nansaarng S and A Pongpullponsak 2018 Modified Fuzzy FMEA Application in the Reduction of Defective Poultry Product Eng J vol. 23 No 1 pp 171-190
[7] Suryoputro M R, Khairizzahra L, Amarria D S and Nawang Wahyu W W 2019 Failure Mode and Effect Analysis (Fuzzy FMEA) Implementation for Forklift Risk Management in Manufacturing Company PT.XYZ IOP Conference Series: Materials Science and Engineering 528 (1) 012027
[8] Rabbi M D Assessment of Fuzzy Failure Mode and Effect Analysis (FMEA) for Reach Stacker Crane (RST): A Case Study International Journal of Research In Industrial Engineering 7 (3) Pages 336-348
[9] Bowles J B and Peláez C E 1995 Fuzzy Logic Prioritization of Failures In A System Failure Mode, Effects And Criticality Analysis Reliability Engineering & System 50 pp 203-213
[10] Geramian A, Arash S, Behzad M and Jiju Antony 2019 Enhanced FMEA: An Integrative Approach of Fuzzy Logic-Based FMEA and Collective Process Capability Analysis Journal of the Operational Research Society 71 (5) pp 800-812
[11] Kusumadewi Sri 2018 Aplikasi Logika Fuzzy untuk Pendukung Keputusan Edisi 2 (Yogyakarta: Graha Ilmu).
[12] Aisyah S 2017 Implementasi Failure Mode Effect Analysis (FMEA) dan Fuzzy Logic sebagai Program Pengendalian Kualitas JIEMS (Journal of Industrial Engineering and Management Systems)
[13] Indrayanto G 2018 Recent development of quality control methods for herbal derived drug preparations Natural Product Communications, 13 (12)