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Minimize the potential failures in the wire rod production process using six sigma and multi attribute failure mode analysis method

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Abstract. Wire rod mill (WRM) plant is one of the factories in Company X that produces wire rod. In 2018 and 2019, WRM was recorded producing high quantity of rejected product exceeding the set standard. This study deploys systematic problem identification and improvement to the process. The methods used was Sigma method to evaluate current condition and process capability, followed by Multi Attribute Failure Mode Analysis (MAFMA) with Grey AHP approach to identify root cause and weighted failure process that will be put into priority of improvement. Based on the research results, the sigma value obtained is 4.297503 σ with DPMO value is 2,928.626. Improvements to the five highest of the causes of process failure is to improve the state of bearing roll, roll entry, hydraulic valve, an improvement on roll adjustment and improvement of inter-roll partings. It was concluded that the potential causes that the hot button bearing roll has the highest weight is 0.94569, so making it a top priority improvement.

1. Introduction

Wire Rod Mill (WRM) plant of Company X is known to have production process problems that resulting in nonconformance products. Repair time to overcome problematic process was causing delay in production and affecting the capability of achivening production target of the plant.

The WRM has determined that permissible product defect to be 0.2% and 0.25% in year 2018 and 2019 respectively. However, production data of steel wire WRM shows that in June 2018 defect product produced was 12,693 ton from target of 9,049 ton, while in January 2019 defect product produced was 158.12 ton from maximum target of 50.66 ton.

In this research, method to identify problem and proposal development to solve the production problems was deployed. The method was Six Sigma method, followed by Multi Attribute Failure Mode Analysis (MAFMA). Six Sigma method is known to be a method that focuses on the process and prevention of defects [1]. Follow up of Six Sigma method is Multi Attribute Failure Mode Analysis (MAFMA) which is an analytical technique that used to determine the cause of potential failure. MAFMA integrates the conventional aspects of FMEA with cost aspects, so that the causes of failure can be seen as influencing the costs. The AHP method is used for weighting against criteria or sub criteria and Greys are used as a comparison. Grey is developed as a quantitative approach to assisting decision making by examining the degree of similarity or difference between two sequences based on the relationship class [2].

Previous research by Elias [3] regarding quality control efforts for treable bridge type B1 parts in the upper end thicness in order to obtain the specifications desired by consumers with the DMAIC method approach at PT.Yamaha Indonesia. Another study was conducted by Kristyanto [4], regarding operational risk analysis in the sugar production process using MAFMA in the PG case study Kebon Agung Malang, produess nine critical risks which have the highest risk level out

of 23 potential operational risks that disrupt the stability of the sugar production process. Anisa [5], that study identified the cause of stop line using the MAFMA method by determining the cause of stop line based on roll. The cause of potentia failure is bearing failure. Another study by Amalia [6] concerning the cause of potential failures in the wire rod production process using the six sigma method and identifying the cause of failure using MAFMA, and the latest research from M.Ulfah [7]. In this research, a proposed improvement is made to the problems that occur in the production process, which is to minimize the failure of the cold sheet steel production process at PT.X's Cold Rolling Mill by using lean six sigma and MAFMA with the fuzzy AHP approach.

2. Literature review

2.1. The six sigma concept

Six Sigma is a statistical concept that measures and reflects the capability of the actual process. Six Sigma is a method or technique of a process that is very orderly in terms of controlling and improving products where the system is very comprehensive and flexible [8]. At the state of Six Sigma value there are only 3.4 defects from a million occasions, meaning 99.99966% process perfection or zero defects.

Table 1. Benefit from achieving some level of sigma

Level of Sigma	DPMO	COPQ (Cost Of Poor Quality)
1-sigma	691,462 (very uncompetitive)	Can not be calculated
2-sigma	308,538 (industry average Indonesia)	Can not be calculated
3-sigma	66,807	25-40% of sales
4-sigma	6,210 (USA industry average)	15-25% of sales
5-sigma	233	5-15% of sales
6-sigma	3.4 (Industry world class)	< 1% of sales
Each increase or 1-sigma shift will provide a profit increase about 10% of sales		

Source: [9]

2.2. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) method was developed by Thomas Saaty in the 70's when at Warston School [9]. States that the AHP is a theory of the measurements used to the scale ratio either from the paired comparison of discrete or continuous [10]. AHP method is one of the methods used in the decision-making system by observing the factors of perception, preference, experience and intuation. AHP combines personal judgments and values in a logical way. Analytic Hierarchy Process (AHP) can solve complex multi criteria problems through hierarchy of decision. A complex problem can be interpreted as the criteria of a problems, the uncertainty of the problem structure, the uncertainty of opinion from the decision maker, more than one person of the decision maker, and the inaccuracy of available data.

2.3. Grey theory

Grey systems theory is a new methodology that focuses on research about problems involving small samples and incomplete information. Grey systems theory handles an uncertain system with partial information through generating, digging and retrieving useful information from what is available. In grey theory, according to the level of information, if the system information is fully known, the system is called a white system. If the information is unknown, the system is called a black system. A system with known information partly is called the grey system [11].

3. Methodology

Data collection was conducted in the production division and quality control division of Wire Rode Mill (WRM) plant of Company X which produce wire rod on December 19, 2019 until January 25, 2020.

1. Secondary data

    The data used are from the last two years starting from January 2018 until December 2019. Data collected to support the research includes production data which consisting of number of

reject products, production plans, production results, and percentage of production reject. In addition, production delay time due to defective product and delay cost data were also collected.

2. Primary data

Primary data consists of interviews, brainstorming and questionnaire distribution. The questionnaire consists of two: Failure Mode Effects and Analysis (FMEA) and Multi Attribute Failure Mode Analysis (MAFMA). Troubleshooting path that is described in the form of a flow chart of MAFMA Calculation is shown in Figure 1.

The following were steps to implement the Six Sigma method:

1. Define:

Identification and selection of a Six Sigma project, identification of physical flow of production process, and to identify the Critical-To-Quality (CTQ).

2. Measure:

Calculation of DPMO number and sigma value.

3. Analyze:

Identification of dominant defects using Pareto Diagram, analysis the cause of the failure process toward the dominant defects using Root Cause Analysis (5 Whys method), and analysis the causes of potential failure process using Multi Attribute Failure Mode Analysis (MAFMA).

4. Improve

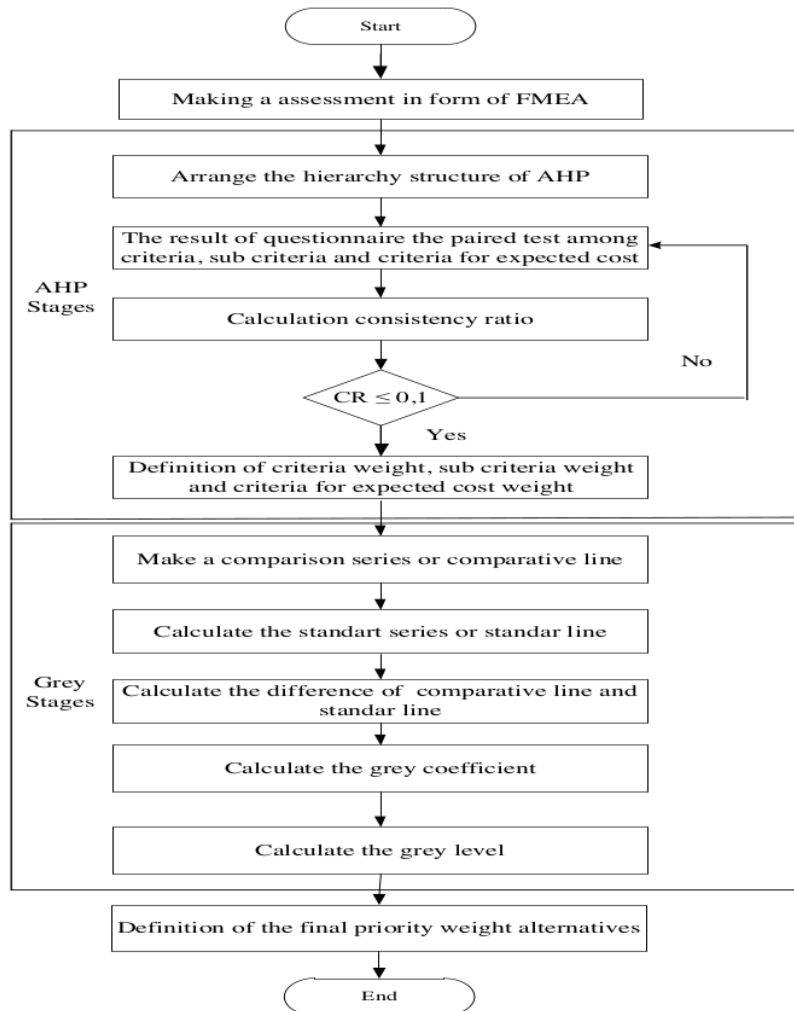The proposed improvements using 5W + 1 H method.

Figure 1. Flow chart of calculation MAFMA method

4. Result and discussion

In the implementation of Six Sigma concept consists of 5 stages namely DMAIC (Define, Measure, Analyze, Improve and Control). As the nature of the study is to find the cause of problems, the researchers limited the discussion up to the improve stage.

4.1. Define stage

Define is the stage for defining goals and backgrounds as well as identifying issues that need to be improved in order to achieve better quality performance.

1. Identify the selection of a six sigma project

   The Six sigma project is deployed based on the failure of the production process that causes rejected. The quantity of rejected products produced in the Wire Rod Mill during the year 2018 and 2019 was above the Company X set standard.

2. Identification of physical flow of production process

Physical flow described as the flow of production in the manufacture of products from raw materials until becoming finished products. The physical flow identification was evaluated using SIPOC diagrams (Suppliers, Inputs, Process, Outputs, and Customers).

3. Identify Critical to Quality (CTQ)

Critical to Quality (CTQ) is a characteristic of a product or service that fulfill the needs of the consumer namely: lacps, overfill, underfill, creep speed, crumpled, not center, cross roll/un round, other deft, scratch, scrappy, roll mark, and coil.

Wire rod product consists of 12 types of quality characteristics that are divided into 3 types of criteria (surface defect, dimention defect, and mechanical defect). Characteristics of this quality was used as a benchmark to produce products with good quality.

4.2. Measure stage

Measure is the second step in the DMAIC method which is a follow up of the define step. This stage focuses on understanding the work of the selected process for improvement at this time. In Measure phase, calculation of the value of DPMO and sigma level were conducted. Based on the calculation, the average DPMO value is 2,928.626 and the average sigma value is 4.297503. It states that from a million opportunities there will be 2,928.626 the possibility that the process will cause defect and the level of achievement of Company X in producing wire rod is quite good, that is equal to 4.297503 which has reached the industry average of USA (approximately 4 sigma or nonconforming and level of achievement of Company X in producing wire rod).

4.3. Analyze stage

Analyze is the third step in the DMAIC method. Identification is done to determine the factors that influence the failures and type of factors are considered the most dominant in order to make improvements to the existing process.

1. Pareto diagram

The Pareto diagram is a bar graph showing the problem based on the sequence of the occurrences number. Pareto diagram formed based on the principle that 80% of problems caused by 20% of the root of the problem. Therefore, the researcher takes 80% of the overall reject percentage on the wire rod product to be followed up by the cause of the reject or identify the failure of the process. The percentage of 80% are laps defects, creep speed defects, underfill defects, overfill defects and scrappy defects.

2. Root Cause Analysis (RCA)

Root Cause Analysis is a problem-solving method that aims to identify the root cause of the problem from the occurrence of the problem. One of method in Root Cause Analysis (RCA) is 5 Whys. The 5 Whys were obtained from interviews with production division and synchronized with the quality control division because both of divisions are interconnected in handling the failure of production processes that cause product defects and production delay. Based on the results of 5 Whys, there are 18 causes of the failure process. Then, these indentified causes was used as input in subsequent data processing, namely Multi Attribute Failure Mode Analysis (MAFMA).

3. Multi Attribute Failure Mode Analysis (MAFMA)

Multi Attribute Failure Mode Analysis (MAFMA) is a method that integrates the conventional Failure Mode and Effect Analysis (FMEA) by considering the economic aspects [12]. In this research, Multi Attribute Failure Mode Analysis (MAFMA) method uses Grey AHP approach.

4.3.1. Failure Mode and Effect Analysis (FMEA)

First FMEA team was established to fill out the FMEA questionnaire where the selected respondent is company parties that experienced in the scope of process failure ad its impact. Respondents consist of quality control technicians, employees of process control divisions and production supervisors.

4.3.2. Hierarchy structure preparation

The structure of MAFMA hierarchy consists of objectives, criteria, sub criteria and alternatives. The purpose of this hierarchical structure is the selection the causes of production process failure. On the

criteria, there are four criterias, namely severity, occurrence, detection and expected cost. This criterion is based on FMEA that has been developed into MAFMA, so there are additional expected cost criteria. In severity criteria, there are three sub criteria, namely potential damage, operation delay and time to repair. Classification of the sub criteria is based on an interview with the company parties. The structure of the MAFMA hierarchy is shown in Figure 2.

4.3.3. Determination of criteria weight on MAFMA hierarchy structure
The first step which taken in determining the criterion weight is conduct paired tests among criteria. Then, we will calculate the priority weight and value of Consistency Ratio or CR to know the consistency of the three respondents to the assessmen. Based on the calculation, it is known that the value of RI = 0.9 with n = 4 [10] will obtained the value of CR = 0.02244, there are indicating that the level of importance between the criteria of potential failure can be said respondents provide consistent assessment. This is because CR ≤ 0.1 [13].
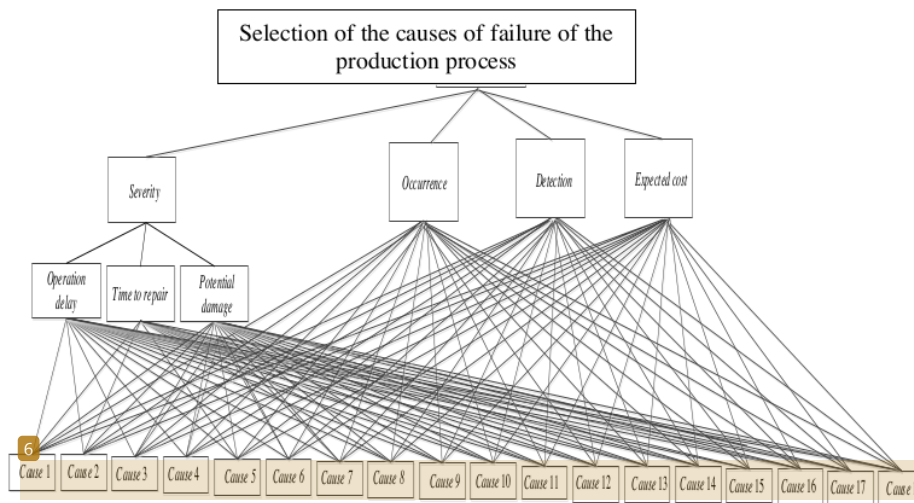

Figure 2. MAFMA hierarchy structure

Determination of alternative weight
a. Pairwise comparison test for criteria at expected cost
b. Build comparative series or comparative line
To perform the processing by grey method, the data that were obtained on the FMEA results of the three respondents were calculated in comparative series or comparative series.
c. Define standard series or standard rows
The standard that be appointed is the smallest value which found in severity, occurrence, and detection is 1.333. The following is the standard series or standard line of comparative or comparison line data Xo = [1.33333   1.3333   1.33333]
d. Determining the difference between comparative lines and standard rows
The difference between a comparative line and a standard line was done by subtracting the value from the comparison series with the standard series.
e. Calculating the grey coefficient
Grey coefficients were used to compare comparative sequences and reference sequences. In the grey coefficeint calculations, it is known that $\zeta \in [0, 1]$ is the coefficient used to control the resolution scale and ζ is normally a value of 0.5 [14].
f. Calculating grey level

The Grey level is used to show the degree of similarity between the comparative sequence and the reference sequence. Based on calculations using the AHP method, the weight of each criterion and sub criteria were obtained. The weight was used to calculate the grey level by multiplying it with the cause of failure data on the grey coefficient. From these results the total weight of potential causes of process failure based on criteria and sub criteria were obtained. For expected cost criteria, priority weight was processed by using AHP method while severity, occurrence, and detection criteria using grey method where priority weight is obtained from grey calculation.

g. Final determination of alternative priority weight

Table 2. Sequence of Failure Process Potency

Code	Cause	Total	Sequence
Cause 13	Hot roll button bearings	0.94569	1
Cause 3	Bearing broken	0.82369	2
Cause 9	The hydraulic valve is not working	0.81108	3
Cause 14	Roll entry cracked	0.78896	4
Cause 17	Parting is not perfect	0.78494	5

h. From the calculation of grey level, the final weight of improvement priorities was determined. From the eight sequence of causes of process failure, the most potential cause is cause number 13, which is hot button bearing roll. However, from the eighteen causes of the failure of wire rod production process, researcher took five of the highest potential failures that would be proposed for improvement.

4.4. Improve stage

After the root cause of the production process failure is identified based on the AHP grey approach, the next step is to find solution to the problem and reducing the cause of process failure. The step is improved using 5W + 1H method.

Improvements that can be made to minimize the failure of the process include:

1) Overcome the cause of hot roll bearing button by lubricating the roll on a regular basis, perform continuous inspection of roll usage and, make record of how often the hot button bearing roll,
2) Repair the damaged bearing by conducting continuous inspection and change the bearing regularly if it is not feasible to use and providing sufficient grease lubricant.
3) Repair non-working hydraulic valve by the careful installation of oil connection, replacing the damaged parts and the replacement must be in accordance with the specifications. Filtering of oil valve could be replaced.
4) Overcome the cracked roll entries by creating rolling tape monitoring record form, regular lubricating, and adjustment of roll appropriately,
5) Overcome imperfect parting between rolls by checking the bar size on a regular basis, revise the check sheet of the production division by adding description line 2. Measuring the size bar on line 2 should be careful and give a sanction for those who do not do their job well.

5. Conclusion

Based on this research, it can be concluded that quality characteristics or CTQ (Critical to Quality) on the wire rod production process are laps, overfill, underfill, scratch, scrappy, roll mark, coil multiple pieces, no center, cross roll / un round, crumpled and creep speed. The sigma value of the wire rod production process is 4.297503 which has reached the industry average of USA (± 4 sigma). Cause of failure of process including hot roll bearing button (0.94569), broken bearing (0.82369), hydraulic valve is not working (0.81108), roll entry cracked (0.78896), parting imperfect (0.78494), setting stopper control (0.75041), non-homogeneous spare part (0.69258), loose lock (0.66183), twist wear out (0.64855), poor adjustment (0.62455), guide less lubricant (0.60438), leakage cooler (0.59048), setting rotate bias (0.58745), base metal unclean (0.58355), lub lubricant roll (0.57084) and spare parts (0.57016). Several suggestion of improvement has been proposed.

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