Implementation of Six Sigma Methods with Failure Mode and Effect Analysis (FMEA) as a Tool for Quality Improvement of Newspaper Products (Case Study: PT. ABC Manufacturing – Sidoarjo, East Java – Indonesia)

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Abstract

PT. ABC is a subsidiary of the JawaPos Group, founded in 1996, and is one of the companies in East Java engaged in printing and packaging. The products produced include magazines, books and newspapers. Of all the company's products, one of the most significant defects is found in newspaper products, which is 4% of the average newspaper production of 806.598 copies and produces a moderate defect of 22,743 copies in 2019. The research was conducted to analyze the sigma value and determine the factors of product defects and the impact of the defects to provide suggestions for product quality improvement. In this research, the method applied is the Six Sigma method and Failure Mode and Effect Analysis (FMEA), by implementing and carrying out the stages in the Six Sigma method, namely DMAIC (Define, Measure, Analyze, and Control). From this research, the results obtained are that the company has several newspaper product defects of 181,943 copies consisting of several types of product defects, including damp paper, blurred colours, shaded printing, asymmetrical printing, and running printing. The company is currently at the 4.04 sigma level, so corrective actions need to be taken to achieve six sigma levels. By applying the Failure Mode and Effects Analysis (FMEA) method, it can be seen that the most significant and most frequent product defect is the blurred colour defect. Therefore the recommended alternative solution for repairs is to check the ink and replace the ink with standard ink or have a lower density, perform regular and systematic machine checks, and provide further guidance on newspaper printing production standards to all operators involved.

Keywords: FMEA, Quality, Six Sigma

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1. Introduction

PT. ABC is a subsidiary of the JawaPos Group, founded in 1996 and is one of the companies in East Java that has a business in the printing and packaging sector. The products produced include magazines, books, newspapers, and the Koran. Of all the products that the company has grown, one of the most significant defects is found in newspaper products, which is 4% of the average production of newspaper products of 806.59 copies and makes a moderate defect of 22,743 copies in 2019, which consists of several types of product defects including paper. Damp, blurry colours, shadowed printing, asymmetrical printing, and running printing. The company has applied various methods to improve the quality of its production, but it has not met the target desired by the company.

Six sigma is a methodology often and dominantly applied to companies in product quality control. Product quality control is a systemic control carried out from the initial stage of the production process to the finished product, closely related to quality standardization, even when distributing products directly to customers. The Six Sigma method is assessed as a structured control in the production step. There are stages, Define, Measure, Action, Improve, and Control (DMAIC) is a means to improve product quality (Prabowo, 2016). The Six Sigma method can also be applied to identify the factors in product defects and present suggestions for sustainable improvements.

In addition to improvements made to the company's internal, general strategy design also needs to be considered so that it can be used as a reference, whether the products that have been produced are following the agreed company standards. Based on the problems that exist in PT. ABC, this study aims to analyze the quality of newspaper products and provide recommendations for improving the quality of newspaper products using the Six Sigma method and then developing the results using the Failure Mode and Effect Analysis (FMEA) method.

2. Literature Review

2.1 Product Quality Definition

Product quality is vital and decisive for the company in measuring the company's performance. Product quality represents the product to the extent to which the product meets consumer needs visually or is perceived by the customer (Armstrong & Chen, 2009). This is the same as the opinion of (Chinomona & Pooe, 2013) that product quality is a reflection of a product in fulfilling its function. Thus, a product with a high-quality value is considered because the product can meet expectations and needs according to its role.

2.2 Six Sigma

Six sigma is a set of stringent processes to help focus attention on controlling and developing product quality to an almost perfect level (Gamal Aboelmaged, 2010). Sigma can also be described as a statistical tool that can measure the magnitude of the discrepancy or deviation from one of the production results to an almost optimal quality standard (Tjahjono *et al.*, 2010). Six sigma's discussion or important point is measuring and identifying the types of defects in a production process. It can describe how to minimize product defects and get targeted production outputs (Marques, Saraiva and Fraza, 2013).

Six sigma is a method that can measure quality by setting a target value that does not exceed or exceed 3.4 defects per 1,000,000 products and can be seen and measured from customer improvement. Applying the six sigma method hopes to satisfy customers, grow company profits, minimize production costs, and add value-added (Sigma *et al.*, 2016). Six sigma has terms in it that must be known, including (Mast & Lokkerbol, 2012):

1. Critical to Quality (CTQ) is a necessary condition that occurs in one of the stages of production, which is closely related to the effect on product results correlated with customer satisfaction.
2. Opportunity is a benchmark in each event or event that provides an opportunity so that the specification limits of the CTQ can be met.
3. A defect is something related to the incompatibility of results with customer satisfaction.
4. Defects Per Million Opportunities (DPMO) is the number that represents a non-conformity in 1,000,000 occurrences.

The Six Sigma method has several steps, namely DMAIC (Define, Measure, Analyze, Improve, and Control). DMAIC is an effort carried out continuously to improve the quality of the value of six sigma. DMAIC can also be carried out planned based on the existing reality. The stages of sig sigma itself, namely DMAIC, include (Prabowo, 2012):

1. In the six sigma method, the define stage identifies the target to be studied and as a determinant in the proposed improvement. In this stage, the measuring stage aims to determine the characteristics of Critical Quality so that developments in planning can be known from the data collected during observation through predetermined measurements.
2. The Analyze stage is the stage after the measurement, which is used to analyze the results of identifying factors from a failure in the production process.

3. Improve stage, a step to improve the system running by providing appropriate alternative improvements in overcoming activities that cause deviations that often occur and need changes.
4. The control stage is the final step in the concept of six sigma. Observing the progress of recommendations for improving the production process is carried out after being given at the improvement stage.

2.3 Failure Mode and Effect Analysis (FMEA)

A reliable method of considering the potential reasons for the effects of interference or damage resulting in FMEA-based risk can be used to prevent unwanted events or avoid customer dissatisfaction in the industry (Wang *et al.*, 2009). In its application, this method can be applied to various problems. In making the Failure Mode and Effect Analysis (FMEA) has the following stages, among others (Bonfant & Belfanti, 2010):

1. Identify every event that occurs in the production process.
2. Make a list of deviations and problems that can be the cause.
3. Assess the impact on the probability and detectability of the problem.
4. Calculating and rating the value obtained from the Risk Priority Number (RPN)
5. Provide improvement solutions aimed at reducing risk

Failure Mode and Effect Analysis (FMEA) is a method for mapping failures, evaluating the impact, and prioritizing failures based on the effects (Sharma & Srivastava, 2019). The failure factors in Failure Mode and Effect Analysis (FMEA) include:

a. Severity is an assessment of the severity of the effects. The severity level starts from the lowest to the highest, with a 1 – 10.
b. Occurrence is the probability of an instrument causing failure. The level of value given is 1 - 10, with 10 being the highest value indicating frequent losses caused by specific tools and 1 being an event with a low probability or not even occurring.
c. Detection measures the capacity to control or control failures that can occur. The test level is 1 - 10, where ten means that preventive measures are invalid (accurate), and one indicates that preventative measures are effective (Kim *et al.*, 2018).

3. Results and Discussion

3.1 Data Collection

We are collecting data taken from this research by conducting identification and direct observation of the company regarding the amount of production and the number of product defects from January to August 2019. The following is a breakdown of the number of production and product defects obtained from PT.ABC:

Table 1. Production data and product defects for the period January – August 2019

Month	Production Quantity (Copies)	Number of Defective Products (Copies)
January	807.405	22.654
February	805.645	21.805
March	809.248	23.763
April	806.984	22.823
May	803.876	21.765
June	809.108	23.826
July	804.673	22.432
August	805.848	22.875
Total	6.452.787	181.943
Average	806.598	22.743

3.2 Data Processing

At the data processing stage of newspaper product analysis at PT. ABC, several settings must be carried out in this research. The scenes are described below:

1. Define Step
   Define is the first step in using the six sigma method. Identification of the research object, as for problems or mismatches that often occur in the newspaper production process, namely the high level of product defects. This research focuses on the stages of the newspaper production process in the period January to August 2019.

2. Measure Step
   Measure this is the second step in six sigma. At this stage, the measurement of the research object, namely newspaper products at PT.ABC.
   a. Determination of CTQ (Critical To Quality)
      The Critical To Quality in the newspaper product consists of 5 (five) Critical To Quality, including:
      (1) Wet paper is a condition of product incompatibility caused by the roll of newspaper sheets that absorb too much liquid so that it is moist, resulting in newspaper prints being less precise and unreadable.
      (2) Blurred colour is a condition of product mismatch due to the ink on the printing not coming out correctly. This causes the newspaper's visuals to be seen not clearly and be challenging to read.
      (3) Shaded printing is a condition of product discrepancy due to the double-printed writing on the newspaper, which makes the report can not read correctly and clearly.
      (4) Not Symmetrical is a product mismatch condition where the printout of the newspaper is not the same as the expected specification.
      (5) Running printing is a condition of product mismatch where the distance between the image and the text does not match its size.

      Below is a table of production data and types of newspaper product defects based on the predetermined Critical to Quality (CTQ).

Table 2. Production data and type of defect during January – August 2019

Month	Production Quantity (Copies)	Number of Defective Products (Copies)	Type of Defect				
			Moist Paper	Blurred Colour	Shaded Printing	Not Symmetrical	Running Printing
January	807.405	22.654	2.756	18.456	588	439	415
February	805.645	21.805	2.453	18.085	489	378	400
March	809.248	23.763	2.932	18.965	879	467	520
April	806.984	22.823	2.832	18.623	583	355	430
May	803.876	21.765	2.442	18.032	465	421	405
June	809.108	23.826	2.985	18.986	884	425	546
July	804.673	22.432	2.734	18.435	587	455	486
August	805.848	22.875	2.787	18.754	591	420	323
Total	6.452.787	181.943	21.921	148.336	5.066	3.360	3.525

   b. Calculation of Defect Per Opportunity (DPO) Value
      The value of DPO (Defect Per Opportunity) can be obtained by the calculation below:

$$\text{DPO} = \frac{\text{number of product defect}}{\text{s,number of units} \times \text{CTQ}} \tag{1}$$

In the table of DPO (Defect Per Opportunity), calculation results can be obtained based on the data in Table 2. Production data and type of defect during January – August 2019 period are:

Table 3. DPO Value (Defect Per Opportunity) for newspaper products January – August 2019

Month	Production Quantity (Copies)	Number of Defective Products (Copies)	Critical to Quality	Defect Per Opportunity
January	807.405	22.654	5	0,005612
February	805.645	21.805	5	0,005413
March	809.248	23.763	5	0,005873
April	806.984	22.823	5	0,005656
May	803.876	21.765	5	0,005415
June	809.108	23.826	5	0,005889
July	804.673	22.432	5	0,005575
August	805.848	22.875	5	0,005677

c. Calculation of DPMO Value (Defect Per Million Opportunities)
Determine the value of DPMO (Defect Per Million Opportunity) can be done with the following measures:

$$\text{DPMO} = \frac{\text{total product defect}}{\text{number of units} \times \text{CTQ}} \times 1.000.000 \quad (2)$$

The table below shows that the DPMO (Defect Per Million Opportunities) calculation obtained is based on Table 3. The DPO (Defect Per Opportunity) value for newspaper products during the January – August 2019 period is:

Table 4. Results of DPMO (Defect Per Opportunity) for newspaper products during January – August 2019

Month	Production Quantity (Copies)	Number of Defective Products (Copies)	Critical to Quality	Defect Per Opportunity	Defect PerMillion Opportunity
January	807.405	22.654	5	0,005612	5.612
February	805.645	21.805	5	0,005413	5.413
March	809.248	23.763	5	0,005873	5.873
April	806.984	22.823	5	0,005656	5.656
May	803.876	21.765	5	0,005415	5.415
June	809.108	23.826	5	0,005889	5.889
July	804.673	22.432	5	0,005575	5.575
August	805.848	22.875	5	0,005677	5.677

d. Determination of Sigma Level Value
The data obtained in the table above is then converted to the DPOMO (Defect Per Million Opportunities) value to determine the sigma level by looking at the sigma level table to be interpolated. The calculations are as follows:

$$\frac{(x-x_1)}{(x_2-x_1)} + \grave{} \frac{(y-y_1)}{(y_2-y_1)} \quad (3)$$

Below is a table of the calculation results of the sigma level values obtained from data table 4. The results of the DPMO Value of Newspaper Products during January – August 2019 period are:

Table 5. Sigma Level Value of newspaper products during January – August 2019

Month	Production Quantity (Copies)	Number of Defective Products (Copies)	Critical to Quality	Defect Per Opportunity	Defect PerMillion Opportunity	Level Sigma
January	807.405	22.654	5	0,005612	5.612	4,04
February	805.645	21.805	5	0,005413	5.413	4,05
March	809.248	23.763	5	0,005873	5.873	4,02
April	806.984	22.823	5	0,005656	5.656	4,04
May	803.876	21.765	5	0,005415	5.415	4,04
June	809.108	23.826	5	0,005889	5.889	4,02
July	804.673	22.432	5	0,005575	5.575	4,04
August	805.848	22.875	5	0,005677	5.677	4,04
Average						4,04

From the table above, it can be seen that the average product sigma level during January to August 2019 was at the level of 4.04.

3. Analyze Step
   At this stage, analyzing the data obtained at the measuring stage is carried out by determining the root cause of Critical To Quality using a fishbone diagram.
   a. Fishbone diagram on moist paper defect type

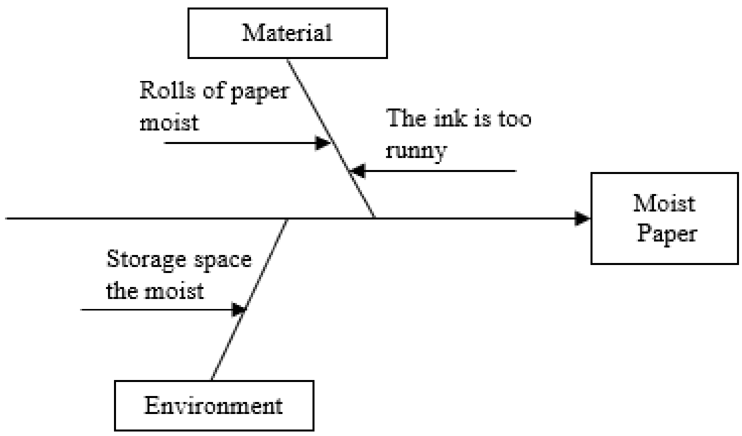

Figure 1. Fishbone Diagram on moist paper defect type

   b. Fishbone diagram on blurred colour defect type

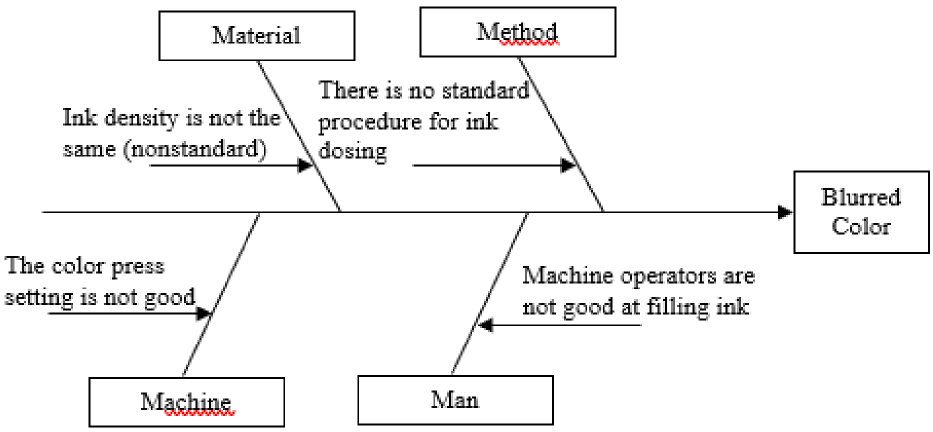

Figure 2. Fishbone diagram on blurred color defect type

c. Fishbone diagram on shaded printing defect type

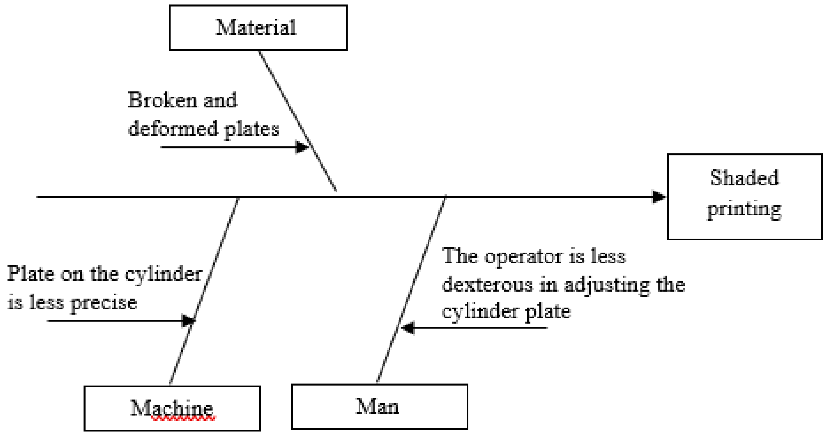

Figure 3. Fishbone Diagram on shaded printing defect type

d. Fishbone diagram on not symmetrical defect type

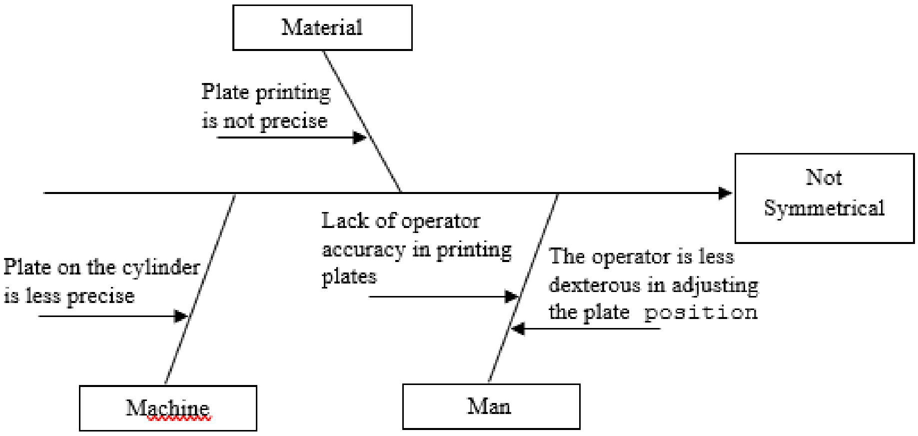

Figure 4. Fishbone diagram on not symmetrical defect type

e. Fishbone diagram on not running printing defect type

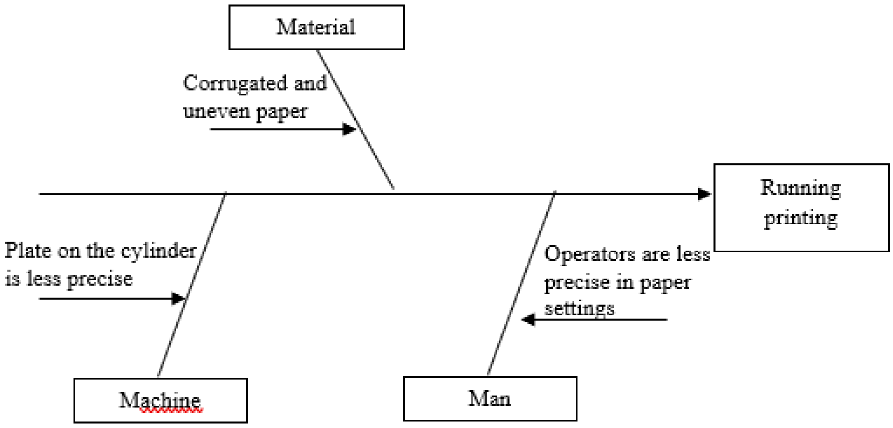

Figure 5. Fishbone diagram on running printing defect type

4. Improve Step
   In the improvement stage, proposals will be made to improve various types of product defects that occur by using FMEA (Failure Mode and Effect Analysis)
   a. The FMEA (Failure Mode and Effect Analysis) for Moist Paper Defect
      The FMEA (Failure Mode and Effect Analysis) value for the type of moist paper product defect can be seen in the table below:

Table 6. FMEA (Failure Mode and Effect Analysis) for moist paper defect

Mode of Failure	Effect of Failure	S	Causes of Failure	O	Current Controls	D	RPN
Moist Paper	Newspaper printouts cannot be read	6	**Material** • Roll of moist paper (high moisture content)	2	• Selecting and separating wet or sticky paper	2	24
			• The ink is too runny	4	• Slow down the speed and reset the machine	2	48
			Environment • Humid storage space	5	• Open the storage room door and adjust the room temperature	5	150

As for the recommendations for improvement that can be proposed, for the condition of the humid paper roll storage room, the RPN value is 150, with the recommendation of improving the addition of a blower to suck and expel the air so that the room temperature is stable. For conditions that are too dilute, the RPN value is 48, with recommendations for improvements to set up the colour density on the machine according to the standards set by the company. For moist paper roll conditions, the RPN value is 24, with recommendations for improving sorting and moving the paper rolls so that a quarantine process is carried out to reduce the water content in the paper rolls.

   b. The FMEA (Failure Mode and Effect Analysis) Blurred Color
      The FMEA (Failure Mode and Effect Analysis) value for the type of blurred colour product defect can be seen in the table below:

Table 7. FMEA (Failure Mode and Effect Analysis) for blurred color defect

Mode of Failure	Effect of Failure	S	Causes of Failure	O	Current Controls	D	RPN
Blurred Color	Images and text cannot be seen properly	7	**Method** • There is no standard procedure for ink dosing	2	• Fill ink sufficiently to fit the ink tank on the machine	2	28
			Man • The machine operator is not good at filling ink	2	• Conduct a briefing before starting the printing process	2	28
			Material • The ink density is not the same (non-standard)	7	• Slow down the speed and reset the machine	7	343
			Machine • Setting press colour is not good	5	• Conduct regular or scheduled machine inspections	4	140

As for improvements that can be proposed, for conditions of unequal (non-standard) ink density, the RPN value is 343, with recommendations for repairing, slowing down the speed and resetting the machine. For conditions of unfavourable colour press settings, the RPN value is 140, with recommendations for repairs to carry out regular or scheduled machine inspections. The operator is less agile in filling ink for the machine's condition. The RPN value is 24, with recommendations for improvement to conduct a briefing or briefing before starting the production process. For the condition that there is no standard procedure for the size of the ink dose, the RPN value is 28, with recommendations for repairing filling ink sufficiently to adjust the ink tank on the machine.

c. The FMEA (Failure Mode and Effect Analysis) for Shaded Printing Defect
The FMEA (Failure Mode and Effect Analysis) value for the type of shaded printing product defect can be seen in the table below:

Table 8. FMEA (Failure Mode and Effect Analysis) for shaded printing defect

Mode of Failure	Effect of Failure	S	Causes of Failure	O	Current Controls	D	RPN
Shaded Printing	The writing is not read well	6	**Material** • Broken and deformed plates	4	• Replace the plate with a new plate	2	48
			Man • Lack of skill of the operator in adjusting the cylinder plate	6	• Conduct a briefing before starting the printing process	3	108
			Machine • The plate on the cylinder is less precise	5	• Slow down the speed and reset the machine	5	150

As for the recommendations for improvement that can be proposed, for the condition of the cylinder plate being less precise, the RPN value is 150, with recommendations for slowing down the speed and resetting the engine. For less agile conditions, the operator adjusting the plate cylinder gets an RPN value of 108 with recommendations for improvement to conduct a briefing or briefing before starting the printing process. For damaged and defective plate conditions, the RPN value is 48, with recommendations for repairs to replace the damaged plate with a new plate.

d. The FMEA (Failure Mode and Effect Analysis) for Not Symmetrical Defect
The FMEA (Failure Mode and Effect Analysis) value for the type of not symmetrical product defect can be seen in the Table 9 below.
As for the recommendations for improvement that can be proposed, for the condition of the plate on the cylinder that is less precise, it gets an RPN value of 75 with recommendations for repairing, slowing the engine speed and resetting the engine. For less agile conditions, the operator adjusting the plate position gets an RPN value of 54 with recommendations for improvement through briefing or briefing before starting the printing process. For less accurate conditions, the plate operator gets an RPN value of 36 with recommendations for improvement, providing direction to re-check when printing the plate. For less precise plate mould conditions, the RPN value is 24, with recommendations for repairs to replace the plate with a new plate.

Table 9. FMEA (Failure Mode and Effect Analysis) for not symmetrical defect

Mode of Failure	Effect of Failure	S	Causes of Failure	O	Current Controls	D	RPN
Not Symmetrical	The printout of the newspaper is not the same as the layout.	3	**Man** • Lack of skill of the operator in adjusting the position of the plate	6	• Conduct a briefing before starting the printing process	3	54
			• Lack of operator accuracy in printing plates	4	• Provide directions or re-checking when printing plates	3	36
			Material • Plate printing is less precise	4	• Replace the plate with a new plate	2	24
			Machine • The plate on the cylinder is less precise	5	• Slow down the speed and reset the machine	5	75

e. FMEA (Failure Mode and Effect Analysis) for Running Printing Defects
The FMEA (Failure Mode and Effect Analysis) value for the type of running printing product defect can be seen in the table below:

Table 10. FMEA (Failure Mode and Effect Analysis) for running printing defects

Mode of Failure	Effect of Failure	S	Causes of Failure	O	Current Controls	D	RPN
Running Printing	the image and the text do not match their size.	4	**Man** • Operators are less careful in paper setting	6	• Provide directions for re-checking when loading paper into the machine	5	120
			Material • Corrugated and uneven paper	4	• Replace the damaged piece with new paper	4	64
			Machine • The plate on the cylinder is less precise	5	• Slow down the speed and reset the machine	4	80

As for the recommendations for improvement that can be proposed, for the operator's condition being less precise in paper settings, the RPN value is 120, with recommendations for improvement providing directions for re-checking when inserting paper into the machine. For the condition of the plate on the cylinder that is less precise, it gets an RPN value of 80 with recommendations for improvements to slow down the speed and reset the engine. For the condition of the wavy and uneven paper, it gets an RPN value of 64 with recommendations for repairs to replace damaged paper with new paper.

4. Conclusion

From the research, it can be concluded that the results of data processing that has been carried out from January to August 2019 obtained a sigma level on the product of 4.04. 5 Critical Quality appears in the flow of the newspaper production process, namely damp paper, blurred colours, shaded printing, asymmetrical printing, and running printing. Suggestions for improvement were found, namely adding a blower to suck and expel the air so that the room temperature is stable, checking ink and replacing ink with ink that has a lower density, carrying out regular or scheduled machine inspections, and providing continuous guidance and training on production standard printing—newspapers to all operators who work to reduce existing product defects.

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