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# Application of Lean Six Sigma and Failure Mode and Effects Analysis (FMEA) to Reduce Waste Defects in The Paper Slitting Production Process on Release Liner at Paper Manufacturing Company

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***Abstract:***

*This study was carried out at a paper manufacturing company that uses a two-stage production process that includes paper coating and paper slitting to create labelstock, release liner, and digital printing media. Controlling waste, particularly defects, is the issue that arose during the release liner product's paper slitting process. By calculating Defect Per Million Opportunities and Sigma Level and offering suggestions for improvement, the study seeks to determine the sigma level in the production process based on the production and defect data. According to the study's findings, the DPMO value was 1.550 at the sigma level of 4.58.Based on the Failure Mode and Effects Analysis's Risk Priority Number, the company's suggested improvement recommendations include: improving the quality of the release liner paper prior to slitting; enhancing regular material inspections and issuing supplier complaints when needed; and enhancing worker coordination and attention to detail during in-process material inspection.*

***Keywords:*** *Defect, Failure Mode and Effects Analysis, Lean Six Sigma, Production Process*

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## 1. Introduction

Currently, industries are experiencing development, causing tight competition between companies, especially paper manufacturing companies. One of these companies is located in East Java, producing labelstock, release liner, and digital printing media, coated with silicone and/or glue in the paper coating process and slit (which means cut) according to demand received in the paper slitting process.

Paper slitting is the process of cutting large paper sheets in the form of jumbo rolls into smaller sizes, either as rolls or flat sheets, after being coated with silicon and/or glue. This process uses a slitting machine, which guides the paper's position and performs the cutting operation. One of the products that is processed in the paper

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slitting process is release liner. It is a protective paper layer that shields adhesive surfaces from external exposure until the product is ready for use. It is widely used in various industrial applications, particularly in labeling, packaging, and adhesive-based products.

The problem happens in the paper slitting process of the release liner product on this company is inconsistent waste and quality control of release liner, especially defects. A defect is a condition where a product or service does not fulfill the quality standard, becoming one of the company's biggest concerns. Defects in the slitting process of release liner paper commonly occur during material selection, cutting, rewinding, or packaging. These issues can arise from various factors, including human error, machine performance, methods, measurement inaccuracies, materials, or environmental conditions

To solve this problem, Lean Six Sigma and Failure Mode and Effects Analysis (FMEA) are used. According to Adeodu et al. (2021), Lean Six Sigma has effectively addressed real-time productivity issues and waste in paper manufacturing, directly impacting customer satisfaction. It also offers theoretical and practical insights by providing a lean framework for continuous improvement in process industries. Besides, Syarifudin et al. (2022) applied the Six Sigma method to roll products processed by a slitter machine in a company, successfully identifying major defect types and proposing improvements to enhance product quality. According to Lutfianto and Prabowo (2022), Failure Mode and Effect Analysis (FMEA) is used to propose improvements based on the causes of defects, aiming to enhance product quality and approach the Six Sigma target.

The research aims to analyse defects in the paper slitting production process for release liner products by calculating defects per million opportunities (DPMO) and Sigma level based on predetermined critical to quality (CTQ) criteria using the Lean Six Sigma method. Furthermore, Failure Mode and Effects Analysis (FMEA) gives improvements based on the causes of defects. Hopefully, the combination of these methods could reduce defects in the paper slitting production process on the release liner product efficiently.

## 2. Theoretical Background

**Waste:** Waste, referred to as *muda* in Japanese, includes all non-value-added activities in the production process (Gasperz, 2007, as cited by Shintyastuti & Handayani, 2023). According to Agustina (2024), in manufacturing, waste is anything that increases production cost and time without enhancing product value, commonly known as non-value-added activities. Such waste negatively impacts the company and must be minimized or eliminated as much as possible (Fattahillah et al., 2020). According to Gasperz (2007) cited by Baharudin et al. (2021), there are nine types of waste: environmental, health, and safety (EHS), defect, overproduction, waiting, non-utilizing employee, transportation, inventory, motion, and excess processing.

**Lean Six Sigma:** According to Gaspersz (2007), as cited by Rahmadianto (2024), lean is a systematic approach to identifying and eliminating waste or non-value-adding activities through continuous improvement efforts. Besides, Widodo and Soediantono (2022) stated that Six Sigma can be defined as a business process improvement method aimed at identifying and reducing defect causes, minimizing cycle time and production costs, increasing productivity, meeting customer needs, optimizing machine utilization, and achieving better outcomes in both production and services. It can be concluded that Lean Six Sigma is a combination of Lean and Six Sigma, serving as a systemic and systematic approach to identifying and eliminating waste or non-value-added activities through radical and continuous improvement to achieve Six Sigma performance levels.

**DMAIC:** Implementation of the Lean Six Sigma method uses the DMAIC (define-measure-analyse-improve-control) to solve the problem systematically. Define is the first stage of this framework, which defines activities with mapping (Nugraha et al., 2023) or making SIPOC (suppliers-inputs-process-outputs-customers) to identify the factors in a production process (Saragih et al., 2021). Second, measure aims to measure the process capability by evaluating the company's Sigma level based on the defect data collected (Shintyastuti & Handayani, 2023). Third, analyse aims to know the causes of the problem happened with the tools available: Pareto Chart, cause-and-effect diagram (fishbone), making the main factors of the problem clearer. The next stage is improve, which is proposing the improvement based on the factors to identify effective solutions and ensuring that proposed improvements positively impact product quality. The last stage is control, which the company implements the improvement based on the stage before and ensures that implemented improvements are not only sustained over the long term but also remain consistent (Khalisan and Hasibuan, 2025).

**Failure Mode and Effects Analysis (FMEA):** According to Islamey et al. (2023), Failure Mode and Effect Analysis (FMEA) is a structured procedure used to identify and prevent as many failure modes as possible (Casadai, 2007, as cited in Islamey et al., 2023). A failure mode refers to any defect in design or out-of-limit condition that disrupts a product’s function. By eliminating these failure modes, FMEA enhances product and service reliability, ultimately improving customer satisfaction. It is a systematic analysis of potential failure modes aimed at preventing issues before they occur, with a focus on defect prevention, safety improvement, and increased customer satisfaction.

## 3. Methodology

This research was conducted at a paper manufacturing company in East Java from April 2025 until sufficient data was collected. The study focused on analysing defects in the slitting paper production process of the release liner product using Lean Six Sigma and Failure Mode and Effects Analysis (FMEA) methodology. The data used in this research has two types:

1. Primary Data
   Primary data is data collected during field research by researchers on the object. In this research, researchers used three methods: observation, interview, and questionnaire shared with qualified workers in the field.
2. Secondary Data
   Secondary data is data collected based on historical data in the company. The data collected in this research is from January to December 2024, which consists of production process flow, total production quantity, total production process time, and total defects.

This research will use a systematic approach. The researcher used the DMAIC (define, measure, analyse, improve, and control) framework (Gasperz, 2005).

1. Define
   Define is the first stage of DMAIC, where mapping the process flow (Nugraha et al., 2023) or SIPOC diagram to identify the supplier, inputs, process, outputs, and customer (Saragih et al., 2021) could be used to define the process. This research used Big Picture Mapping to define the slitting paper production process on the release liner. The following stage was detecting the defect that occurred in the product.
2. Measure
   This stage assesses process performance by calculating the company's Sigma level based on defect data (Shintyastuti & Handayani, 2023). Researchers counted defect per opportunities (DPO), defect per million opportunities (DPMO), and the sigma level based on the critical to quality. Critical to quality (CTQ) are the attributes that are present during the process, directly related to the consumer's demand and satisfaction (Agustina, 2024).
   To know the sigma level, the formula used were:
   a. Defect Per Opportunities (DPO)
   $$DPO = \frac{Total\ defect\ produced}{Total\ produced\ unit\ x\ CTQ} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$
   b. Defect Per Million Opportunities (DPMO)
   $$DPMO = \frac{Total\ defect\ produced}{Total\ produced\ unit\ x\ CTQ}\ x\ 1.000 \ldots\ldots\ldots\ldots\ldots(2)$$
   c. Sigma Level
   $$Sigma\ Level = NORMSINV\left(\frac{(1.000.000 - DPMO)}{1.000.000}\right) + 1,5 \ldots\ldots\ldots(3)$$
3. Analyse
   This phase involves analysing the collected data and identifying types of defects in the production process. It also explores root causes and influencing factors using Pareto and fishbone diagrams. Additionally, process capability is assessed to evaluate performance before improvement efforts.
4. Improve
   This phase focuses on proposing improvement alternatives for the causes of waste defects by analyzing the Risk Priority Number (RPN) through Failure Mode and Effect Analysis (FMEA), followed by recommending corrective actions based on the results. According to Islamey et al. (2023), FMEA is a

structured procedure used to identify and prevent potential failure modes as early and as thoroughly as possible.

$$RPN = Severity \times Occurrence \times Detection \qquad (4)$$

5. Control
   The Control phase is the final stage in the DMAIC Lean Six Sigma methodology, aimed at monitoring improvements in the process. In this research, however, the Control phase was not implemented, as the results are presented in the form of recommendations submitted to the company.

## 4. Empirical Findings/Result

### Data Collection

Based on the research, the collected data contains total production data and defects in the slitting paper production process on the release liner product from January to December 2024. The release liner was the Forest Stewardship Council type of paper, collected from production and quality control departments.

**Table 1. Total Production and Defects of Slitting Paper Production Process on Release Liner (FSC) on 2024**

| Month | Total Production Amount ($m^2$) | Bad Roll ($m^2$) | Curling Paper ($m^2$) | Wrinkling/Fold Visual ($m^2$) | Silicon Defect ($m^2$) | Yellow Spot ($m^2$) | Incorrect Printing Design ($m^2$) | Total *Defect* ($m^2$) |
|---|---|---|---|---|---|---|---|---|
| January | 2,644,442 | 1,608 | 3,264 | 528 | 466 | 105,388 | 0 | 111,254 |
| February | 2,762,727 | 13,208 | 0 | 1,560 | 3,717 | 0 | 4,908 | 23,393 |
| March | 1,851,403 | 9,169 | 0 | 810 | 5,670 | 981 | 0 | 16,630 |
| April | 1,268,232 | 505 | 5,522 | 0 | 630 | 0 | 5,400 | 12,057 |
| May | 2,689,825 | 7,587 | 0 | 270 | 0 | 0 | 540 | 8,397 |
| June | 2,776,638 | 3,211 | 0 | 1,150 | 627 | 4,500 | 270 | 9,758 |
| July | 3,620,406 | 260 | 0 | 3,519 | 40,204 | 809 | 5,670 | 50,462 |
| August | 4,639,587 | 1,080 | 4,860 | 1,318 | 0 | 0 | 11,340 | 18,598 |
| September | 2,966,618 | 1,080 | 0 | 1,080 | 0 | 0 | 8,910 | 11,070 |
| October | 2,569,957 | 0 | 0 | 8,246 | 0 | 1,620 | 1,142 | 11,008 |
| November | 3,081,538 | 0 | 676 | 0 | 22,164 | 0 | 5,443 | 28,283 |
| December | 2,777,012 | 630 | 0 | 0 | 738 | 0 | 4,60 | 1,828 |
| **Total** | **33,648,384** | **38,338** | **14,322** | **18,481** | **74,216** | **113,298** | **44,082** | **302,737** |

### Define

This stage marks the beginning of the DMAIC framework, focusing on identifying issues in the slitting paper production process for release liner products. The identification is carried out using big picture mapping, which outlines the process's information flow and physical flow. This mapping helps visualize the material and activity flow within the production process. Based on the mapping, a table is created to classify activities into value added, necessary non-value added, and non-value added categories.

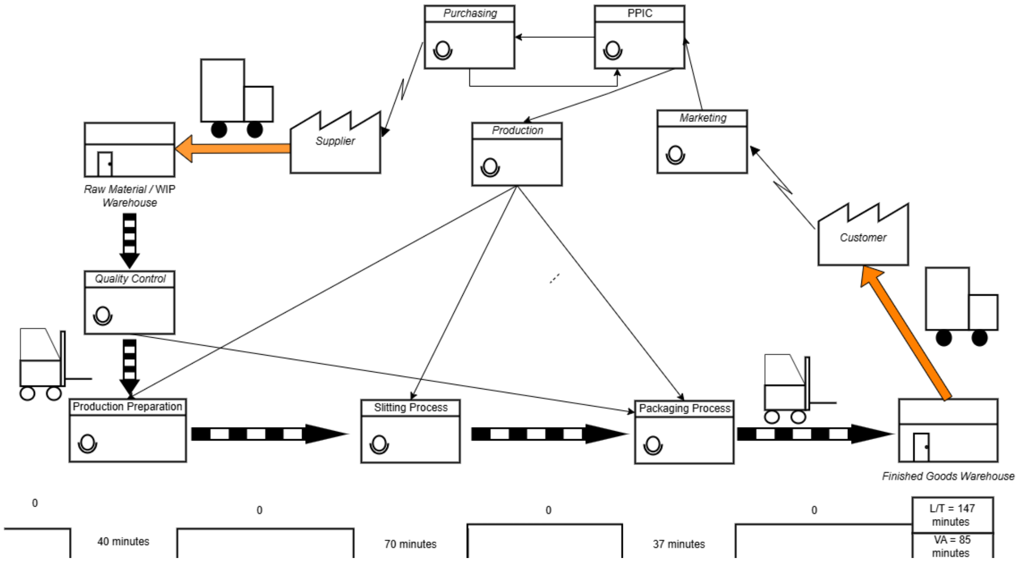


**Figure 1. Big Picture Mapping**

## Physical Flow

The physical flow of the production process is shown in the picture below.

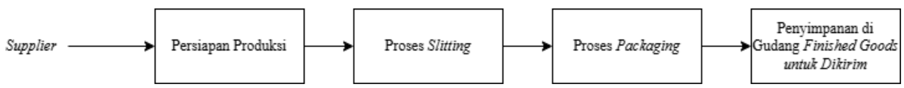


**Figure 2. Physical Flow**

Based on the physical flow, the production process begins from the raw material, received from the supplier. After receiving the raw material, workers (supervisor, operator, and helper) prepare the production process (*persiapan produksi*). The next step is the production process, the slitting process (*proses slitting*), which cuts a jumbo paper roll into small rolls. The packaging process is the next step, packing the small rolls with plastic and cardboard (*proses packaging*). The last step is putting the packaged rolls in the finished goods warehouse (*penyimpanan di gudang finished goods untuk dikirim*).

## Information Flow

The information flow is obtained based on physical information and is a more detailed description of a production process. The information flow is shown in the table below:

**Table 2. Information Flow and Activity**

| No | Activity | Time (Minutes) | Activity Category | Activity Type |
|---|---|---|---|---|
| | | **Production Preparation** | | |
| 1 | Receiving Work Order Card | 5 | NNVA | I |
| 2 | Picking up raw material (jumbo roll) from inventory | 10 | NNVA | T |

| | | | | |
|---|---|---|---|---|
| 3 | Quality inspection on raw material | 5 | NNVA | I |
| 4 | Setting up the slitting machine | 20 | VA | O |
| | **Total Time** | **40** | | |
| | | **Slitting Process** | | |
| 5 | Setting up jumbo roll in the machine (early unwinder, slitting, and rewinder) | 15 | VA | O |
| 6 | Quality inspection on the set-up jumbo roll | 5 | NNVA | I |
| 7 | Slitting process | 30 | VA | O |
| 8 | Quality inspection | 5 | NNVA | I |
| 9 | Labeling and adhesives | 5 | VA | O |
| 10 | Transfer slit results to the packaging area | 5 | NNVA | T |
| 11 | Reporting the production result | 5 | NNVA | I |
| | **Total Time** | **70** | | |
| | | **Packaging Process** | | |
| 12 | Packaging Process | 10 | VA | O |
| 13 | Transfer and arrangement on the pallet | 5 | NNVA | T |
| 14 | Label scanning on packaged rolls | 7 | NVA | D |
| 15 | Inventory process | 15 | NNVA | T |
| | **Total Time** | **37** | | |
| **Total All-Activity Time (Lead Time)** | | **147** | | |

The activity table contains activities, divided into three categories: value added (VA), non-value added (NVA), and necessary non-value added (NNVA). The value added activities mostly are in the slitting process, whereas the non-value added and necessary non-value added activities are evenly distributed in the activities. As for every activity, there is a division based on the type, such as operation (O), transportation (T), inspection (I), storage (S), and delay (D). According to the time in activities, the researcher counted the process cycle efficiency (PCE) of the process:

$$CE = \frac{Value\ Added}{Lead\ Time} x\ 100\% = \frac{85}{147} x\ 100\% = 58\%$$

According to the PCE result, the efficiency result is 58%. Based on George (2002), it is concluded that the process is very efficient and can be said to be “lean.”

**Measure**
This stage marks the process after defining the slitting paper production process on the release liner (FSC) product in the company, measuring the sigma level based on the available data.

**Critical to Quality**
The quality control in the production and quality control departments is being done in the raw material checking, the production process, and the finished goods checking. According to the quality control in the slitting paper process of the release liner, the types of critical defects in every quarantine are:

**Table 3. Critical to Quality**

| Month | Bad Roll ($m^2$) | Curling Paper ($m^2$) | Wrinkling/Fold Visual ($m^2$) | Silicon Defect ($m^2$) | Yellow Spot ($m^2$) | Total *Defect* ($m^2$) |
|---|---|---|---|---|---|---|
| January | 1,608 | 3,264 | 528 | 466 | 105,388 | 111,254 |
| February | 13,208 | 0 | 1,560 | 3,717 | 0 | 23,393 |
| March | 9,169 | 0 | 810 | 5,670 | 981 | 16,630 |
| April | 505 | 5,522 | 0 | 630 | 0 | 12,057 |
| May | 7,587 | 0 | 270 | 0 | 0 | 8,397 |
| June | 3,211 | 0 | 1,150 | 627 | 4,500 | 9,758 |
| July | 260 | 0 | 3,519 | 40,204 | 809 | 50,462 |
| August | 1,080 | 4,860 | 1,318 | 0 | 0 | 18,598 |
| September | 1,080 | 0 | 1,080 | 0 | 0 | 11,070 |
| October | 0 | 0 | 8,246 | 0 | 1,620 | 11,008 |
| November | 0 | 676 | 0 | 22,164 | 0 | 28,283 |
| December | 630 | 0 | 0 | 738 | 0 | 1,828 |
| **Total** | **38,338** | **14,322** | **18,481** | **74,216** | **113,298** | **302,737** |

Based on critical to quality (CTQ), a histogram chart is used to identify the most defects that occurred. Therefore, the handling of the defective products could be done according to the priority, which is indicated by the percentage.

**Table 4. Defect Percentage on Release Liner in Slitting Paper Production Process**

| No | Defect | Total Defect (m2) | Total Production (m2) | Defect Percentage |
|---|---|---|---|---|
| 1 | Bad Roll | 38.338 | 33.648.384 | 0,114% |
| 2 | Curling Paper | 14.332 | 33.648.384 | 0,043% |
| 3 | Wrinkling/Fold Visual | 18.481 | 33.648.384 | 0,055% |
| 4 | Silicon Defect | 74.216 | 33.648.384 | 0,221% |
| 5 | Yellow Spot | 113.298 | 33.648.384 | 0,337% |
| 6 | Incorrect Printing Design | 44.082 | 33.648.384 | 0,131% |

According to the percentage, the highest percentage refers to the yellow spot, with a value of 0,337%, followed by silicon defect (0,221%), incorrect printing design (0,131%), bad roll (0,114%), wrinkling/fold visual (0,055%), and curling paper (0,043%). The histogram is shown in the picture below.

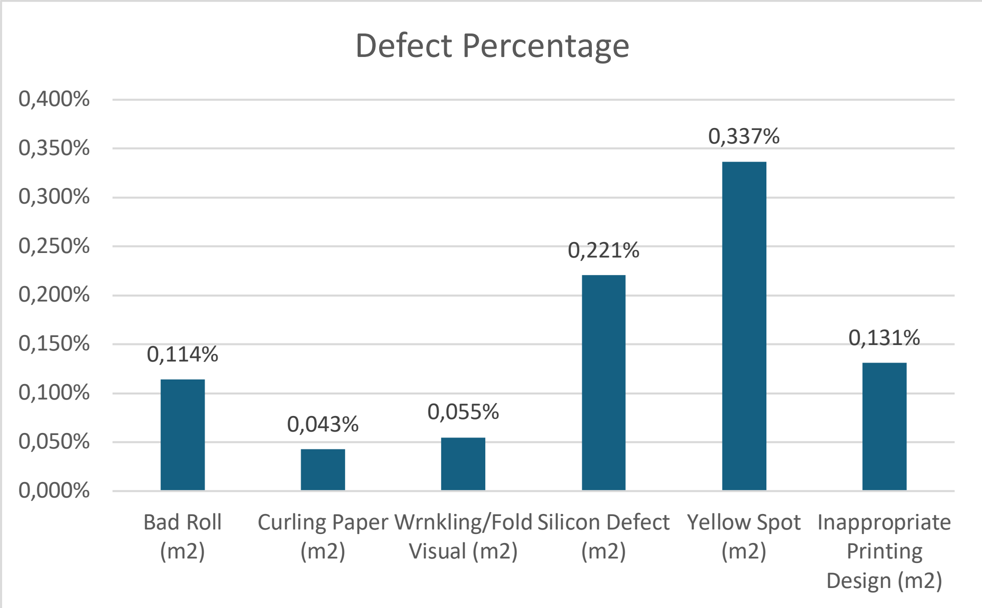


**Figure 3. Histogram**

**Sigma Level Calculation**

Sigma level calculation is the next step of "measure", calculating Defect Per Opportunities (DPO), Defect Per Million Opportunities (DPMO), and the sigma level based on data available. Before collecting all the calculations, here are some examples of the calculations, according to January 2024:

$$DPO = \frac{total\ defect}{total\ production\ x\ CTQ} = \frac{11.254}{2.644.442\ x\ 6} = 0{,}007012$$

$$DPMO = DPO\ x\ 1.000.000 = 0{,}007012\ x\ 1.000.000 = 7.012$$

$$\sigma = NORMSINV\ \left(\frac{(1.000.000-7.012)}{1.000.000}\right) + 1{,}5 = 3{,}96$$

According to the calculations, in January 2024, the sigma level is 3,96. The calculations in February-December 2024 are shown in the table below.

**Table 5. DPO, DPMO, and Sigma Level on Release Liner in Slitting Paper Production Process in 2024**

| Month | Total Production (m2) | Total Defect (m2) | CTQ | DPO | DPMO | Sigma Level |
|---|---|---|---|---|---|---|
| January | 2,644,442 | 111,254 | 6 | 0.007012 | 7012 | 3.96 |
| February | 2,762,727 | 23,393 | 6 | 0.001411 | 1411 | 4.49 |
| March | 1,851,403 | 16,630 | 6 | 0.001497 | 1497 | 4.47 |
| April | 1,268,232 | 12,057 | 6 | 0.001584 | 1584 | 4.45 |
| May | 2,689,825 | 8,397 | 6 | 0.000520 | 520 | 4.78 |
| June | 2,776,638 | 9,758 | 6 | 0.000586 | 586 | 4.75 |
| July | 3,620,406 | 50,462 | 6 | 0.002323 | 2323 | 4.33 |
| August | 4,639,587 | 18,598 | 6 | 0.000668 | 668 | 4.71 |
| September | 2,966,618 | 11,070 | 6 | 0.000622 | 622 | 4.73 |
| October | 2,569,957 | 11,008 | 6 | 0.000714 | 714 | 4.69 |
| November | 3,081,538 | 28,283 | 6 | 0.001530 | 1530 | 4.46 |

| | | | | | | |
|---|---|---|---|---|---|---|
| December | 2,777,012 | 1,828 | 6 | 0.000110 | 110 | 5.20 |
| **Average** | | | | 0,00155 | 1.550 | 4,58 |

$$\text{Average DPMO} = \frac{Total\ DPMO}{12} = \frac{18.557}{12} = 1.550$$

$$\text{Average } \sigma \text{ Level} = \frac{Total\ sigma}{12} = \frac{55}{12} = 4{,}58 \approx 4$$

According to the results, this company is at four-sigma level, with the DPMO average result is 1.55, which means in every one million production chances, it produces 1.550 $m^2$ defects. It is shown that this company has reached a good level of quality control, but still has not reached the six sigma target, namely, world-class company standards. Therefore, improvements are needed by analysing the factors causing defects so that the sigma value can approach the six sigma value.

**Analyse**

This is the step when researchers determine an analysis based on the sigma level calculation. A Pareto Chart is used to discover the cause of the highest defects that occurred.

**Figure 4. Pareto Chart**

According to the Pareto Diagram above, the common defects are yellow spot (37,42%), silicon defect (24,51%), incorrect printing design (14,56%), bad roll (12,66%), wrinkling/fold visual (6,1%), and curling paper (4,73%). The next step is discovering the causes of the defects that occurred with the fishbone diagram.

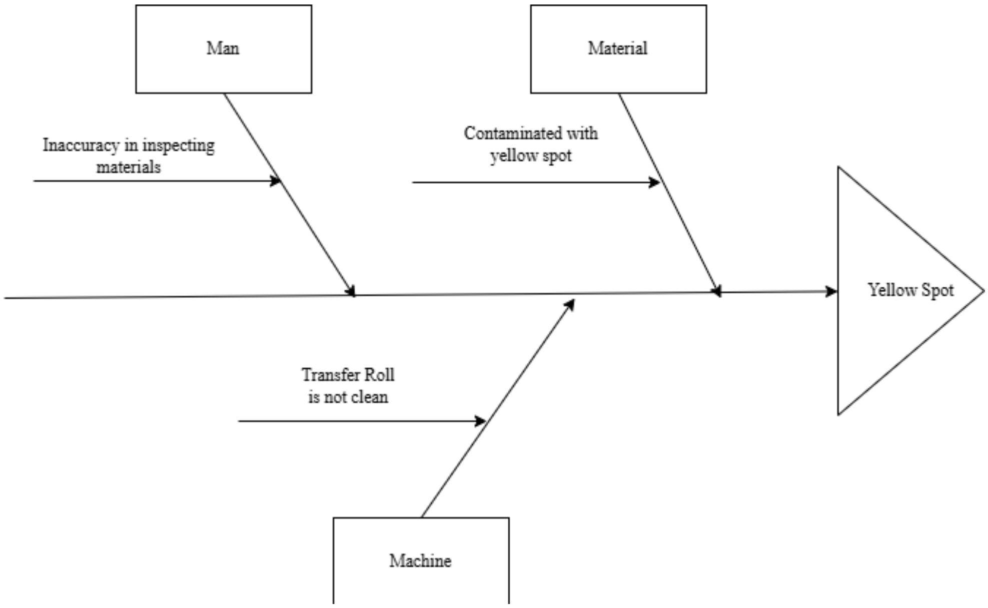


**Figure 5. Yellow Spot Defect**

Yellow spot on materials can result from several factors. Human error, such as workers failing to properly inspect materials during processing, may allow defects to go unnoticed. On the machine side, dirty transfer rolls can transfer "spot" onto the fabric. Additionally, raw materials may already be contaminated with yellow spot before they enter the production line, either from the supplier or during earlier handling.

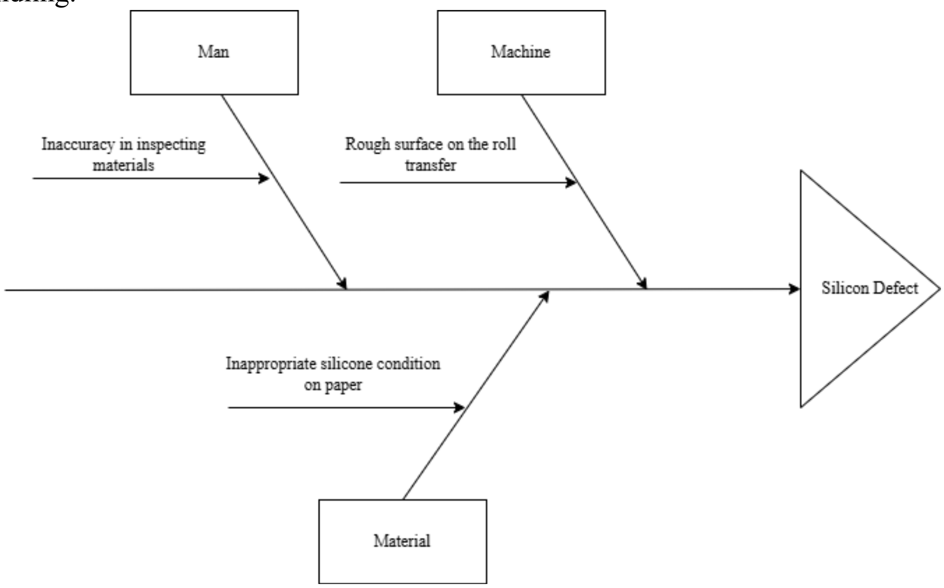


**Figure 6. Silicon Defect**

Defects in the silicone layer on release liner materials can be caused by several factors. Human error, such as the lack of thorough inspection by supervisors or operators, may result in undetected silicone defects. Material issues can also occur when the silicone layer does not meet standards—whether it's too thin, missing in certain areas, or unevenly applied. Additionally, machine-related problems, like a rough transfer roll surface, can physically damage the silicone layer during processing.

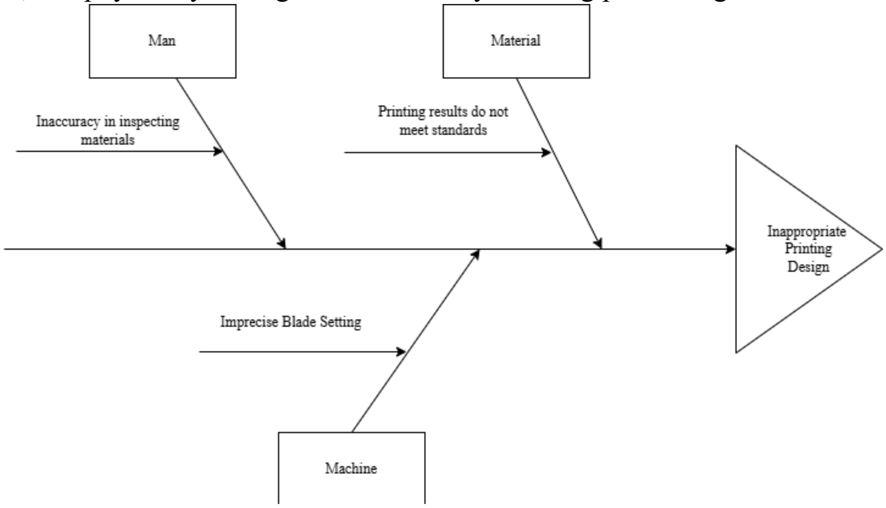


**Figure 7. Incorrect Printing Design Defect**

Defects in the design or printed layer of coated materials can arise from various sources. Human error, such as insufficient inspection of materials that already have defects from the coating process or design issues, can allow flaws to continue through production. Material-related problems may stem from defects in the printed design, either from the silicone coating process or from suppliers who conduct printing outside the company's standard procedures. Machine issues, particularly imprecise blade settings, can also lead to parts of the design being unintentionally cut.

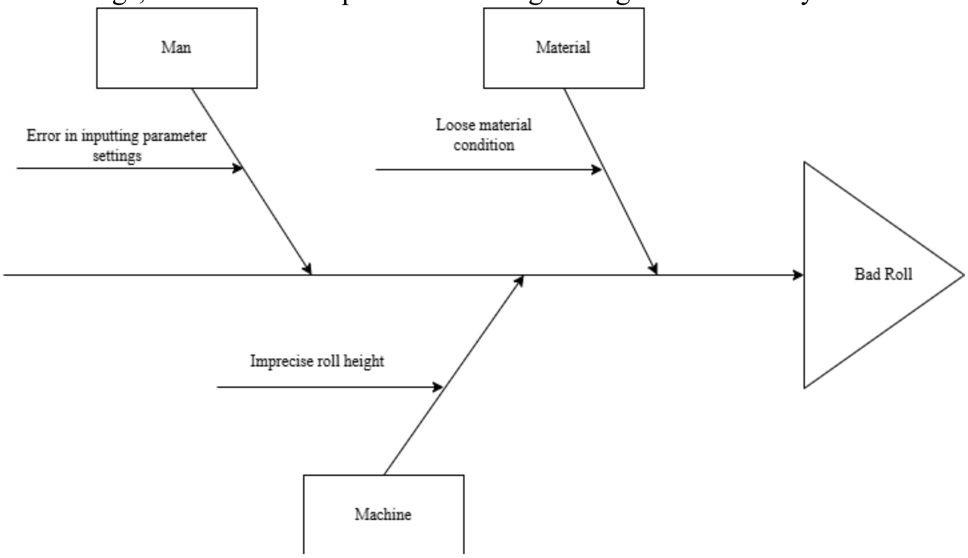


**Figure 8. Bad Roll Defect**

Several factors can lead to inconsistencies in the production results. Human error, such as incorrect parameter settings inputted by the operator, can cause the output to fall below standard. Material issues, like loose material, may lead to improper tension during processing, affecting the quality. From the machine side, an imprecise roll height can result in uneven surfaces, which in turn impacts the roll quality.

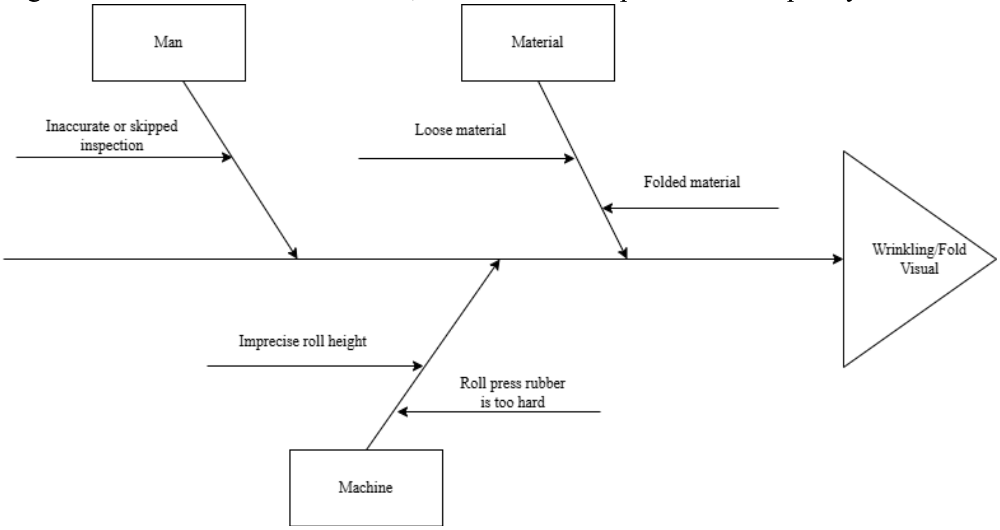


**Figure 9. Wrinkling/Fold Visual Defect**

Wrinkles or fold visual in the paper (release liner) can be caused by multiple factors. On the human side, insufficient or skipped inspections during production may allow defects to go unnoticed. Machine-related issues include imprecise roll height, which leads to uneven surfaces and folding, as well as overly hard press roll rubber, which creates improper pressure and increases the risk of creasing. Material problems may involve loose paper that causes tension issues, leading to fold lines or wrinkles. In some cases, the paper may already be folded or creased before entering production—either from the raw material itself or during the silicone coating process—only becoming visible during processing.

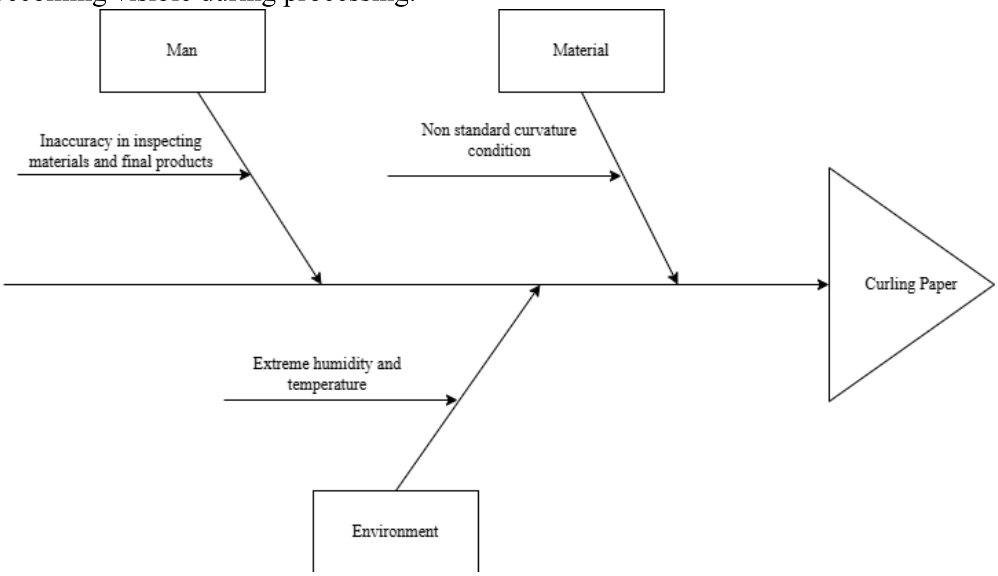


**Figure 10. Curling Paper Defect**

Curling in release liner materials can result from several contributing factors. Human error, such as lack of thorough inspection of either the raw material or finished release liner, may allow upward or downward warping to go unnoticed. Material-related causes include curvature in the material that does not meet standard specifications. Environmental conditions also play a role—extreme humidity below 20% and room temperatures above 35°C in the production area can significantly affect the material's shape and stability.

**Improve**

This stage marks the steps to reduce defects in the release liner product on the slitting paper production process, giving plans to improve the quality of the release liner according to the priorities.

**Table 6. RPN Value**

| Potential Failure Mode | Potential Effect of Failure | S | Potential Cause | O | Current Control | D | RPN |
|---|---|---|---|---|---|---|---|
| Yellow Spot | Paper (release liner) has yellow spot from foreign substances or dirty slitter machine | 8 | Workers not thorough during material inspection | 5 | Improve worker attention and coordination during inspection | 4 | 160 |
| | | | Contaminated materials, from raw materials or supplier | 6 | Regular material checks and supplier complaints | 4 | 192 |
| | | | Dirty transfer roll on the machine | 4 | Regular machine checks and cleaning | 2 | 64 |
| Silicone Defect | Release liner has missing silicone | 8 | Supervisor or operator misses silicon defect during inspection | 5 | Better inspection, more briefings, and training | 4 | 160 |
| | | | Silicone layer is not up to standard (thin, missing, or uneven) | 6 | Tighten silicone standards and coordinate with silicone coating team | 3 | 144 |
| | | | Rough transfer roll damages silicone layer | 3 | Repair or replace transfer roll | 3 | 72 |
| Incorrect Printing Design | Release liner print design has | 7 | Worker missed defect during | 5 | Improve inspection, | 3 | 105 |

| Potential Failure Mode | Potential Effect of Failure | S | Potential Cause | O | Current Control | D | RPN |
|---|---|---|---|---|---|---|---|
| | lines or is cut incorrectly | | coating process or design issue | | coordination, and training | | |
| | | | Design defect from supplier or outside printing process | 6 | Coordinate with coating team and file complaint to supplier | 2 | 84 |
| | | | Blade setting not precise, cuts the design | 5 | Adjust blade settings accurately | 2 | 70 |
| Bad Roll | Rolled paper (release liner) shows uneven edges or telescoping due to tension or thickness | 7 | Operator input wrong parameter settings | 5 | Recheck settings based on SOP | 2 | 70 |
| | | | Loose material causes improper tension during process | 7 | Regular checks before, during, and after process | 3 | 147 |
| | | | Roll height not accurate causing uneven winding | 5 | Adjust roll height properly | 3 | 105 |
| Wrinkling / Fold Visual | Wrinkles or folds appear on release liner due to tension, slope, or pressure issues | 8 | Poor or skipped inspection during production | 6 | Regular inspection, better coordination and training | 3 | 144 |
| | | | Loose paper increases risk of wrinkles | 6 | Regularly check paper condition before cutting | 3 | 144 |
| | | | Paper already folded from raw material or silicone coating process | 7 | Regularly check paper condition before cutting | 3 | 168 |
| | | | Roll height not precise causes uneven | 5 | Adjust roll height properly | 3 | 120 |

| Potential Failure Mode | Potential Effect of Failure | S | Potential Cause | O | Current Control | D | RPN |
|---|---|---|---|---|---|---|---|
| | | | surface and folding | | | | |
| | | | Hard press roll rubber creates poor pressure, increases risk of folding | 5 | Check and replace press roll rubber | 3 | 120 |
| Curling Paper | Paper curves toward or away from silicone layer (e.g. RH+1%, RH–1%) | 6 | Inaccurate checking of release liner curvature | 5 | Improve inspection, briefing, and training | 2 | 60 |
| | | | Curved material not within standard | 6 | Regular checks during WIP, production, and quality check stages | 2 | 72 |
| | | | Extreme temperature and humidity (below 20% RH, over 35°C) in production area | 6 | Control temperature and humidity, increase checks in quality control room | 2 | 72 |

According to the RPN value results, the researchers proposed the prioritized improvement based on the highest ranking.

**Table 7. Prioritized Improvement**

| Priority | Potential Failure Mode | Potential Cause | RPN | Improvement Recommendations |
|---|---|---|---|---|
| 1 | Yellow Spot | Contaminated materials, from raw materials or supplier | 192 | Regular material checks and supplier complaints |
| 2 | Wrinkling / Fold Visual | Paper already folded from raw material or silicone coating process | 168 | Regularly check paper condition before cutting |
| 3 | Yellow Spot | Workers not thorough during material inspection | 160 | Improve worker attention and coordination during inspection |
| 4 | Silicone Defect | Supervisor or operator misses silicone defect during inspection | 160 | Better inspection, more briefings, and training |

During the improvement stage using FMEA, several actions were proposed to move toward Lean Six Sigma quality. To address the yellow spot caused by contamination, regular material inspections will be enhanced, and supplier-related issues will be formally addressed. For defects like wrinkles or folds on visual, periodic checks on the release liner paper before cutting are planned. The yellow spot due to oversight during inspection will be mitigated through better coordination and attention among workers. Lastly, to reduce silicone defects, efforts will focus on more thorough inspections, improved communication with the coating team, and strengthened training.

## 5. Discussion

Defects in the release liner during the slitting paper process can significantly impact overall production efficiency and product quality. The analysis of the 2024 production data using the Lean Six Sigma approach revealed a defect per million opportunities (DPMO) of 1,550 and a Sigma level of 4. While this indicates a relatively high level of quality performance, it still falls short of the Six Sigma benchmark of 3.4 defects per million, highlighting opportunities for further process optimization (Gaspersz, 2007; Adeodu, Kanakana-Katumba, & Rendani, 2021).

The identification of six Critical to Quality (CTQ) defects—yellow spots, silicone defects, incorrect printing design, bad roll, wrinkling/fold visual, and curling paper—was crucial in defining measurable quality dimensions. Root cause analysis using the fishbone (Ishikawa) diagram indicated that these defects are primarily driven by four categories: human error, machine condition, material inconsistency, and environmental factors. These findings are consistent with previous research in similar industrial settings, where human and machine factors are frequently the dominant causes of product defects (Saragih, Anne Marie, & Mubarani, 2021; Nugraha, Nofrisel, & Setyawati, 2023).

The application of the Failure Mode and Effects Analysis (FMEA) further helped prioritize improvement efforts. By evaluating the severity, occurrence, and detection ratings of each defect, the team developed targeted corrective actions. For example, yellow spots due to contamination were linked to lapses in material inspection and poor coordination between workers. This confirms findings by Lutfianto and Prabowo (2022), who emphasized the importance of integrating FMEA with Six Sigma to systematically reduce high-risk failure modes in paper-based manufacturing.

Corrective actions proposed include enhancing material quality checks, improving communication among inspection staff, and scheduling regular equipment maintenance. These align with recommendations from Shintyastuti and Handayani (2023), who noted that disciplined implementation of standard operating procedures (SOPs) and machine reliability maintenance can greatly reduce visual and structural defects. In addition, operator training is crucial to reduce inspection errors and ensure proper response to variations in product quality (Syarifudin, Septiana, & Wijaya, 2022).

Despite achieving a Sigma level of 4, which is considered above average for many Indonesian manufacturing firms (Widodo & Soediantono, 2022), continuous improvement is still needed. This supports the DMAIC framework (Define, Measure, Analyze, Improve, Control) that underpins Lean Six Sigma methodology, emphasizing that process stability is a dynamic and ongoing target rather than a fixed achievement (Agustina & Rochmoeljati, 2024).

The implementation of Lean Six Sigma in this study has proven effective not only in identifying performance gaps but also in formulating strategic improvement plans. Compared to traditional quality control, Lean Six Sigma provides a structured, data-driven approach that reduces process variability and enhances product consistency (Rahmadianto, 2024; Baharudin, Purwanto, & Fauzi, 2021). Therefore, the combination of DPMO analysis, FMEA prioritization, and process-based intervention should be viewed as an integrated strategy rather than isolated tools.

In conclusion, this study reinforces the critical role of structured quality management approaches like Lean Six Sigma and FMEA in enhancing operational efficiency within paper-based production environments. Future improvements should also consider the integration of digital monitoring systems and real-time defect tracking to further elevate quality performance and achieve a Sigma level closer to the ideal benchmark.

## 6. Conclusions

The Lean Six Sigma analysis of the slitting paper production process for release liner indicates that the process currently operates at a 4-sigma level, with Defect Per Opportunity (DPO) of 0.00155 and a Defect Per Million Opportunities (DPMO) of 1,550. This implies that for every one million square meters produced, approximately 1,550 $m^2$ are defective. According to the sigma level result, improvements aimed at reducing these defects were identified through the use of Failure Mode and Effects Analysis (FMEA). Based on the calculation of the Risk Priority Number (RPN), several key corrective actions were prioritized. The highest RPN value of 192 was linked to yellow spot defect caused by contamination, for which enhanced material inspections and supplier complaints were recommended. Wrinkle or fold visual defect, with an RPN of 168, are to be addressed through regular checks of the release liner paper before cutting. Yellow spot resulting from inspection oversight, and silicone-related defects—both with RPN values of 160—require improved worker coordination, more diligent inspection, stronger communication with the coating team, and additional training initiatives. These targeted improvements are expected to enhance process capability and bring the production closer to Lean Six Sigma standards. Based on the findings of this study, several recommendations can be made to support further improvement in the production process. First, it is advised that the company consistently apply and strengthen continuous improvement initiatives. This includes reducing defect-related waste and enhancing the quality of release liner products, with the goal of elevating the current Sigma level from 4 to 6.

In addition, future research is encouraged to broaden its focus beyond the release liner, by also examining other products within the company, such as labelstock and digital printing media. This would provide a more comprehensive understanding of quality and process performance across product lines. Furthermore, upcoming studies should consider analyzing waste in a more holistic manner—not limited only to defects, but also covering other types of waste as classified in the nine categories of waste. This broader approach can help identify hidden inefficiencies and offer more targeted improvements. Lastly, future researchers are encouraged to explore not only the use of Lean Six Sigma and FMEA, but also other methodologies that could effectively analyze and minimize waste and defects within the production process.

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