Production Quality Improvement of Duplex Carton Packaging for AA Products Using the Six Sigma and Seven New Quality Tools Methods

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Abstract

To survive in today's increasingly stringent manufacturing market, every business must strengthen its production quality control. PT. PHI is a manufacturer specialized in offset printing and packaging, and one of its products is the duplex cardboard AA duplex carton packaging. The objective of this study was to reduce the occurrence of the most frequently recurring types of defect and improve production quality using the six-sigma method through the DMAIC stages (Define, Measure, Analyze, Improve, and Control) and in the improve stage using multiple tools from the seven new quality tools method to recommend improvement proposals. Based on the outcomes of data analysis and processing, the three most common forms of defect are 58.9% unclean ink, 17.3% pond tilt, and 12.6% spot faults. The calculation yielded Cp values of 0.84, CpK values of 0.60, DPMO values of 5861.14, and sigma level values of 4.02. After doing FMEA analysis and implementing seven new quality tools, it was determined that the biggest causal variables for each type of defect were associated with subpar production machine parts. The recommended changes are routine maintenance of industrial machinery, increased monitoring of production, and enhancements to standard operating procedures.

Keywords
Quality Control, Six Sigma, Seven New Quality Tools, Defect, DMAIC.

1. Introduction
In order to maintain customer satisfaction and remain competitive, manufacturing companies must maintain the quality of their final products during production (Limanjaya et al., 2015). Good quality finished goods are contingent on the company's quality control procedures. Good product quality is determined by the compatibility of design specification standards with the functions and purposes of the product itself, allowing companies to produce quality products that satisfy market demands (Besterfield, 1994). However, the occurrence of product defects, which can be caused by a number of human, machine, method, material, and environmental factors, is a common issue in the implementation of quality control (Kotler & Keller, 2016). PT. PHI is an offset printing and packaging company that produces food packaging made primarily from duplex cardboard. One of the company's products is duplex cardboard packaging for AA products, which is made from duplex cardboard, which can be seen in Figure 1 below.

Figure 1. Duplex Cardboard Packaging for AA Products

Historical data on production and the number of types of product defect that occurred during the production stages of duplex cardboard packaging for AA products from January to September 2022 can be seen in Table 1.

Table 1. Production Data and Data on the Number of Types of Defect

Month	Production Total (Pcs)	Unclean Ink	Spot Defect	Light Dark Color	Tilted Pond	Kopek Shredded	Glue Shredded	Total Defect (Pcs)
January	1449750	26325	7800	1771	11500	654	2900	50950
February	824000	16500	3855	300	5839	315	1691	28500
March	467000	8590	1675	-	4855	250	780	16150
April	1628750	37945	5181	3966	7269	754	1535	56650
May	901860	23077	2430	1049	4020	434	1050	32060
June	907657	17430	3200	7320	2257	100	1250	31557
July	1412630	32271	7539	1540	6580	645	2555	51130
August	805200	13150	5468	950	6655	270	1542	28035
September	520235	9552	2510	865	5142	100	385	18554
Total	8396847	184840	39658	17761	54117	3522	13688	313586

Based on Table 1, it can be seen that the production of duplex cardboard packaging for AA products results in several types of defect, including unclean ink, spot defect, tilted pond, light dark color, kopek shredded, and glue shredded. PT. PHI's historical data reveals a defect rate of 3.51%, comprised of various categories of defect; this is quite high, as it is close to the company's maximum defect target of 5%. Defective goods can no longer be used in production, so rejected goods will be discarded. The production of products that cannot be sold to consumers will have a negative effect on the productivity of a company. Therefore, it requires a product quality enhancement strategy that encompasses the entire production process in order to minimize the company's defective product loss. Defect problems will be analyzed using the DMAIC (Define, Measure, Analyze, Improve, and Control) phases and the six-sigma method. Six sigma is a strategy for quality enhancement aimed at achieving a failure rate of 3.4 DPMO (Defects Per Million Opportunities) for each product transaction (Gaspersz, 2002). In addition, during the improve phase, the seven new quality tools will be utilized to characterize problems with verbal data, collect ideas, and plan quality enhancements (Suci et al., 2017). This study's objective was to examine the most prevalent categories of major defect and their underlying causes in order to enhance the production quality of duplex cardboard packaging for AA products.

2. Literature Review

To win the competition, quality is crucial and must be present. Satisfaction of consumer desires, conformity to predetermined standards/benchmarks, and reasonable pricing are the three fundamental elements of quality (Walujo and Utomo, 2020). According to Kotler and Keller (2016), product quality is the capability of a product to perform its functions, which includes durability, dependability, and accuracy. The purpose of quality control on the production line of manufacturing companies is to minimize defective products or defects so that production outcomes are of high quality, do not disappoint consumers, and do not cause damage to manufacturing companies (Gaspersz, 2002). Six Sigma is an approach method that concentrates on the process of enhancing or bolstering the quality of a manufactured product. Six Sigma's objective is to determine the quality and dependability of products in terms of fulfilling the needs and expectations of consumers. Six Sigma is a vision for quality improvement towards the target of 3.4 DPMO (Defects Per Million Opportunities) failures per million opportunities in every transaction of goods and services. Therefore, six sigma is a technique for controlling and enhancing quality that implements activities that are not only geared toward detecting product defects but also defect prevention (Gaspersz, 2002). In the six sigma method implementation stages, it can be arranged based on the DMAIC stages, namely a simple problem solving methodology. The DMAIC stage consists of five steps in the process of process improvement approach carried out, namely Define, Measure, Analyze, Improve, and Control (Setiawan et al., 2002). The seven new quality tools method was developed in 1972 by JUSE (Union of Japanese Scientists and Engineers) which was researching new quality control tools. This method is utilized to control and enhance the quality of a company's products in order to reduce the number of defective products (Suci et al., 2017)

3. Methods

The research method is the process of collecting and processing data and analyzing data to achieve research objectives (Soemohadiwidjoyo, 2017). The stage begins with field research and literature reviews, as well as the identification of defects in the production of AA product duplex cardboard packaging, necessitating an improvement in production quality. The information was gathered from historical data, discussion outcomes, and interviews with PT. PHI employees. If the data has been collected, data processing is performed using the six-sigma method and seven new quality instruments during the improve phase. The data processing steps begin with the define stage, where a Pareto diagram is created to determine the highest percentage of defects, followed by SIPOC diagrams, critical to quality, and project charters. Calculating the P-control chart to ascertain CL, UCL, and LCL, Cp and CpK process capabilities, DPMO, and sigma level at the measurement stage. Create a Pareto diagram and failure mode and effect analysis (FMEA) at the analyze stage to analyze the factors that cause each defect. Improve the production quality of duplex cardboard packaging for AA products and the implementation plans by analyzing the proposed enhancements with the seven new quality tools. Analyze the results of the implementation of the proposed increase in production quality and compare them to the pre-implementation conditions during the phase of control. In an effort to improve the quality of duplex cardboard packaging production for AA products, it is possible to draw conclusions and make recommendations based on an analysis of the research results that have been conducted and adapted to the research objectives.

4. Data Collection

This investigation was conducted at PT. PHI, which is located in Jakarta. Using historical data collected from January 2022 to September 2022, the number of production defects in duplex carton can be determined. This information was obtained from the superintendent of PT. PHI's PPIC section. Offline and online interviews were conducted with PPIC managers, PPIC personnel, and field staff to obtain additional information for the research. Observations were conducted directly on the production floor to determine how the duplex carton is created, how long it takes to create the duplex carton packaging, the working conditions, how the field staff operates, and the duplex carton packaging defects.

5. Results and Discussion

After collecting the necessary data, the research is conducted through the phases of Define, Measure, Analyze, Improve and Control (DMAIC).

5.1 Define Stage

For the process of identifying product defect problems and analyzing which priorities will be addressed in order to reach the desired outcomes, the define phase is executed. The first stage is to create a SIPOC diagram and a critical to quality matrix to describe PT. PHI's problem situation. Figure 2 displays the business's SIPOC diagram.

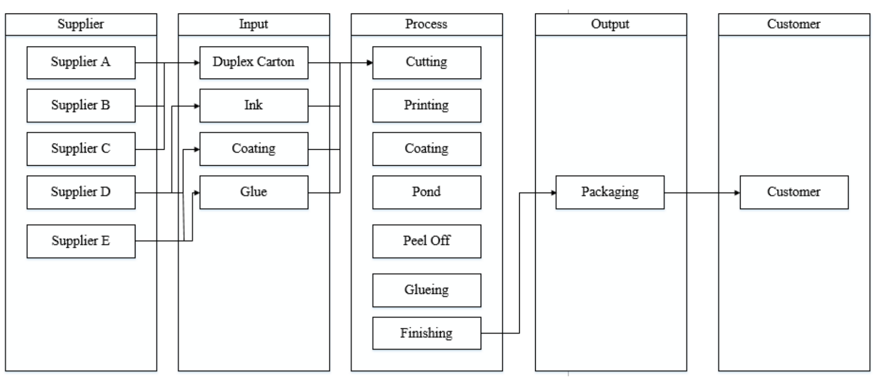

Figure 2. SIPOC Diagram of PT. PHI

Critical to Quality (CTQ) is a regularly employed method for quantifying and simplifying complex customer requirements (Suwandi, 2020). Table 2 depicts the CTQ of duplex carton packaging product AA.

Table 2. CTQ Duplex Carton Packaging Product AA

Product	Factor	CTQ	Specifications
AA Product Duplex Carton Packaging	Visual	There are no defects	Production does not produce various types of defect
		Looks visually appropriate	The colour visual appearance of each product is in accordance with a predetermined design
	Material	Appropriate material type	Products use high quality materials
	Dimension	Dimensions match	Products must comply with the standard dimensions set by the company

Product	Factor	CTQ	Specifications
		Product patterns and designs match	Product designs and patterns are in accordance with the order specifications and those set by the company
	Method	Implementation of the stages of the work method in accordance with the standard operating procedure	The position of placing the product on each production machine must be appropriate and thorough so that errors do not occur

Based on the company's historical data in Table 1, it is known that there are six categories of defect that occur; therefore, a Pareto chart is used to determine the defect type that occurs most frequently and becomes the focus of further research. The Pareto chart calculation outcomes are shown in Table 3.

Table 3. Pareto Diagram

No.	Defect Criteria (Pcs)	Defect Number (Pcs)	Defect Percentage (%)	Cumulative (%)
1	Unclean Ink	184840	58.9%	58.9%
2	Tilted Pond	54117	17.3%	76.2%
3	Spot Defect	39658	12.6%	88.8%
4	Light Dark Color	17761	5.7%	94.5%
5	Glue Shredded	13688	4.4%	98.9%
6	Kopek Shredded	3522	1.1%	100%
	Total	313586	-	-

Based on Table 3, there are three categories of defect that occur most frequently: unclean ink (58.9%), pond tilt (17.3%), and spot defects (12.2%). In this study, these three defects will be the subject of further investigation. The next step is to create a project charter that outlines a formal report containing a plan for quality control improvement activities conducted by this research.

5.2 Measure Stage

The measure stage is performed to validate and quantify problems based on the collected data. Research data are utilized to measure the level of firm performance, including the calculation of control charts, process capability, DPMO, and sigma level. Figure 3 depicts the initial phase of calculating the control chart from data on the production of duplex cardboard packaging for AA products from January through September 2022 using the Minitab software.

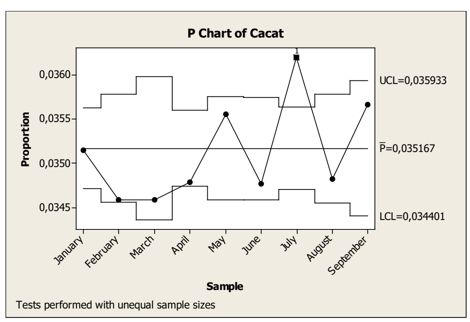

Figure 3. P control map

Figure 3 demonstrates that the data is not sufficiently stable, with one point, July, exceeding the upper control limit. Based on the results of the interviews, it is known that the data for the month of July were out of control due to multiple problems, including poor material quality and production machine damage, which led to a high number of defects. It is necessary to enhance production quality control in order to reduce defects.

The next stage is to calculate the Cp and CpK process capabilities in order to evaluate the company's performance processes for producing products that meet the company's specifications (Sukania et al., 2017). In addition to the results of DPMO calculations and the company's production sigma level, process performance levels were measured (Teja et al., 2022). The calculations are displayed in Table 4.

Table 4. Final Calculation Results of Cp, Cpk, DPMO, and Sigma Values

	Formula	Calculation	Result
Process Capability (Cp)	$\alpha = 1 - \frac{Percentage\ of\ the\ proportion\ of\ defect}{100\ x\ Defects\ Opportunities}$ $Cp = \frac{Titik\ Z}{3}$	$\alpha = 1 - \frac{3,5167}{100\ x\ 6}$ $Cp = \frac{2.52}{3}$	0.84
Kane Process Capability (CpK)	$\alpha = 1 - \frac{Percentage\ of\ the\ proportion\ of\ defect}{100}$ $Cpk = \frac{Z\ point}{3}$	$\alpha = 1 - \frac{3.5167}{100}$ $Cpk = \frac{1.81}{3}$	0.60
DPMO	$\frac{Number\ of\ defect}{Unit\ total\ x\ Defect\ opportunies}\ x\ 1.000.000$	$= \frac{313586}{8396847x\ 6}\ x\ 1,000,000$	5861.14755
Sigma Level	$= NORMSINV\left(\frac{1.000.000 - DPMO}{1.000.000}\right) + 1.5$	$= NORMSINV\left(\frac{1.000.000 - 5861,14755}{1.000.000}\right) + 1.5$	4,0204

Based on the results of the calculations in Table 4, the process capability values Cp 1.00 and CpK 1.00 indicate that the process capability is insufficient to meet the required specifications. Moreover, according to the results of the DPMO calculation, the error rate per one million production opportunities is 5861 pieces, and the sigma level is 4.02, necessitating the repair and enhancement of production quality so that the sigma level reaches a value of 6.

5.3 Analyze Stage

The objective of the third stage, which is to analyze, is to determine the source of the problem by identifying potential sources of defect or the primary problem with defects (Paulin et al., 1985). It is known that the three most common categories of defect will be examined in depth. The three most common varieties of defect are unclean ink, tilted pond and spot defects. According to interviews and discussions with the quality control department, the appearance of defects is the result of suboptimal production activities caused by multiple factors. The fishbone diagram for the three most prevalent varieties of defects is shown below (Figure 4, 5, 6, 7 and 8).

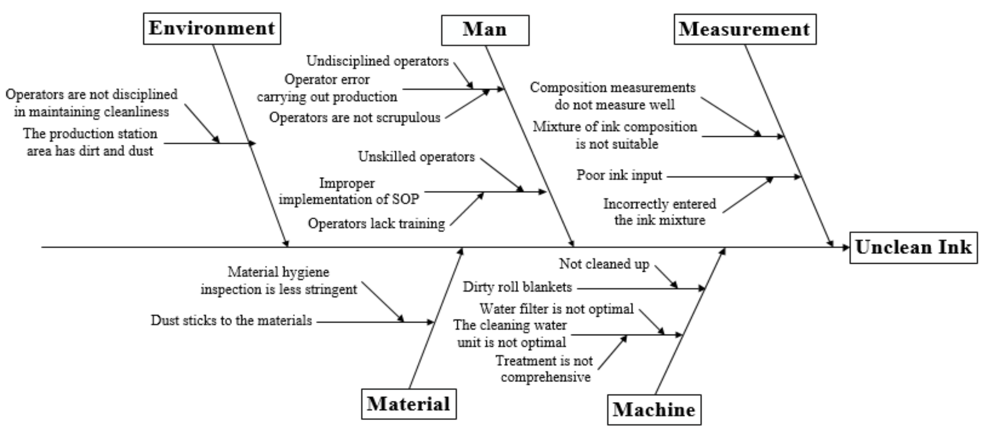

Figure 4. Unclean Ink Fishbone Diagram

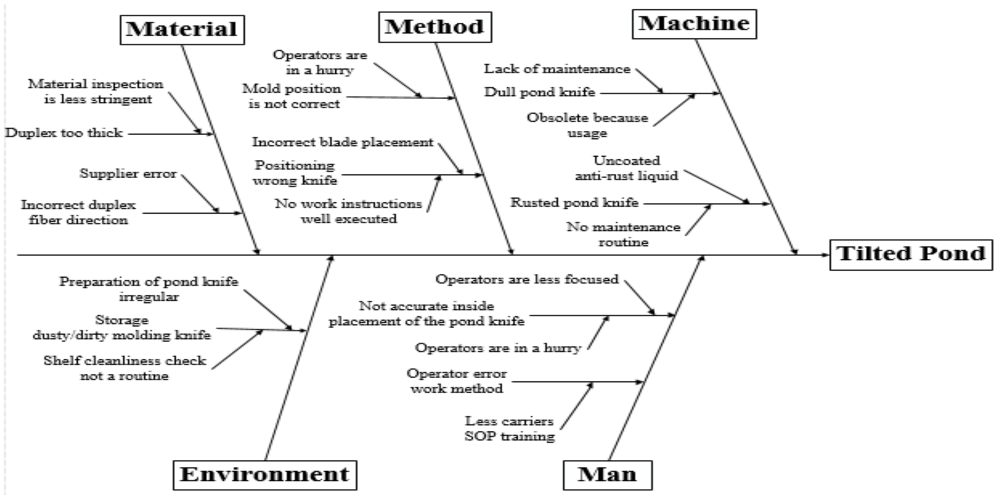

Figure 5. Tilted Pond Fishbone Diagram

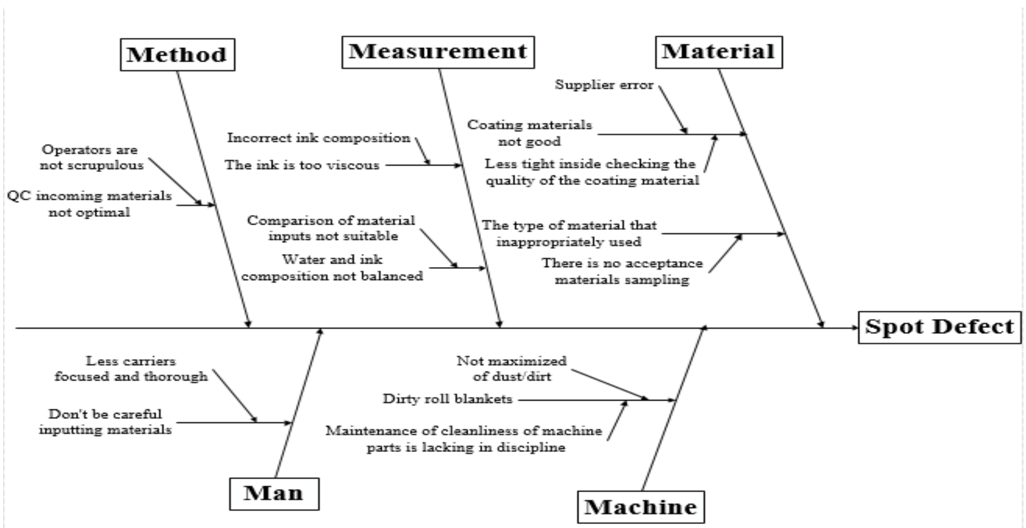

Figure 6. Spot Defect Fishbone Diagram

The final step in the analyze phase is to conduct an analysis utilizing the failure mode and effect analysis (FMEA) technique in order to determine the priority level of problems for each category of the most common defect and causal factors (McDermott, 2009). The calculation of the score is based on the results of expert company employees' interviews and discussions. The outcomes of the FMEA analysis are displayed in Table 5, 6, 7 to 8.

Table 5. Failure Mode and Effect Analysis of Unclean Ink

Key Process Input	Potential Failure Effect	S	Potential Causes	O	Current Process Control	D	RPN	Rank
Unclean Ink	Incorrect ink input and mix	6	The operator was wrong, not careful, less skilled in adjusting the ink composition mixture and it was uneven. There is no ink metering tool	4	Visual check with print sampling	4	96	3

	Production machine parts are not optimal, such as cleaning water units	9	The quality of the water cleaning unit part, namely the filter, is not optimal due to lack of care and maintenance	5	Visual monitoring of the printing process, inspection of printed samples and direct checking of the machine is off	6	270	1
	Materials, dusty and dirty machine parts such as dirty roll blankets	5	Lack of operator care and discipline for the cleanliness of the production area, materials, machine parts before/after printing	5	Cleaning and checking the production area, materials, roll blankets	4	100	2

Table 6. Failure Mode and Effect Analysis of Tilted Pond

Key Process Input	Potential Failure Effect	S	Potential Failure Causes	O	Current Process Control	D	RPN	Rank
Tilt Pond	Dull pond knife is not sharp and rusty	8	The quality of the pond knife is no longer good due to lack of care and maintenance and the SOP for pond knife maintenance is not clear	5	Visual inspection of pond cutting results and replacement of spare pond blade	6	240	1
	The position of the blade placement and the results of the print are wrong and don't fit	6	Operators are not thorough, in a hurry, and lack discipline in setting the knife and placing the mold	5	Monitoring the results of cuts and direct directions from the person in charge of the area and rearranging the position of the knife when the engine is off	4	120	2
	The pond knife storage area is dirty and disorganized	4	Checking the cleanliness of the storage area is not strict enough and pond knives are not arranged neatly	3	Inspection of cleanliness of storage area	2	24	4
	The duplex used is too thick and the fiber direction is wrong	5	Material errors from suppliers, material checking for production is only done visually without quality checking	4	Visual inspection of production materials	4	80	3

Table 7. Failure Mode and Effect Analysis of Spot Defect

Key Process Input	Potential Failure Effect	S	Potential Causes	O	Current Process Control	D	RPN	Rank
Spot Defect	The quality of the coating material is not good	6	The QC of incoming materials is not strict enough and the cleanliness of the place for storing materials is not strict	4	Visual inspection by the operator at the time before starting production	4	96	2
	The ink composition is unbalanced and too thick	5	The viscosity level of the composition of the ink and water was not correct, so it was too thick because it was not measured carefully. There is no ink metering tool	4	Checking the print sampling and visually viewing the sampling results	4	80	3
	Dust/dirt sticks to the roll blanket	7	Lack of concern and discipline for periodic cleaning of roll blankets by operators	6	Cleaning the roll blanket on the printing machine	3	126	1

Based on the results of the RPN score assessment in the three tables above for each category of defect and its contributing factors, all of the highest RPN score assessment results are directly attributable to the production machine tools that are employed. The proposed improvement process will be carried out in relation to suboptimal production machine tools, such as cleansing water units, pond knives, and roll blankets, in the next stage, which is to improve using the seven new quality tools method.

5.4 Improve Stage

On the basis of the Failure Mode and Effect Analysis assessment scores, it was determined that factors related to the production machine tools used were not optimal for achieving the highest RPN score results; therefore, the research will use several of the seven new quality tools methods to plan actions to improve production quality at this stage. The first step of the seven new quality tools method is to create an affinity diagram that groups several problem-causing factors to make it simpler to take steps to improve production quality.

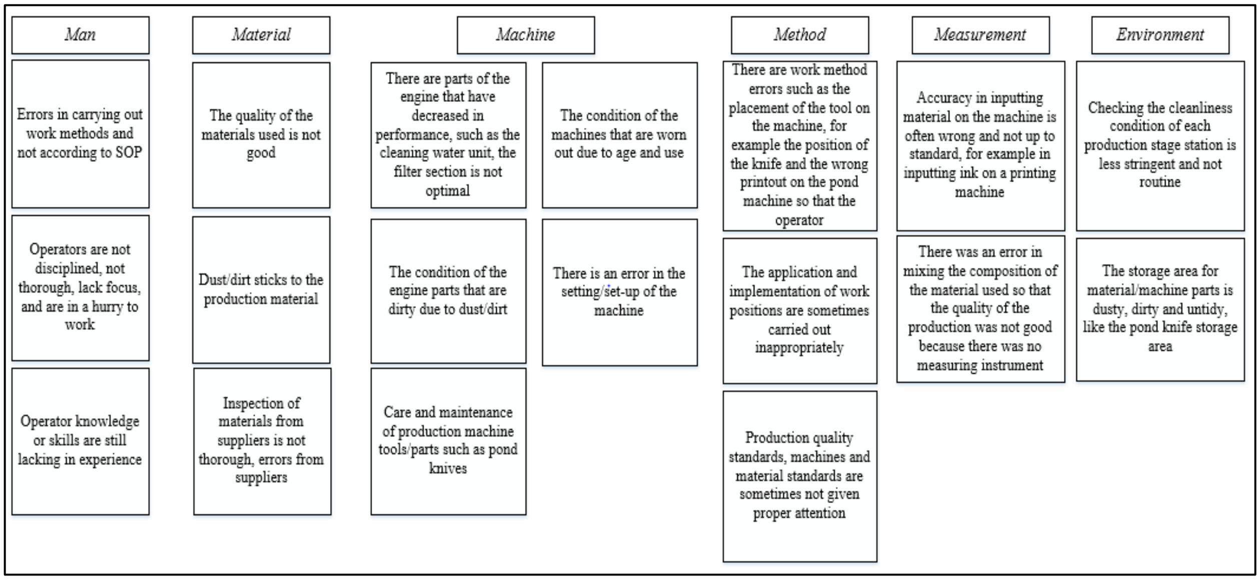

Figure 7. Affinity Diagram

Figure 7 Affinity Diagram identifies the root causes of suboptimal production machine part problems. Using the interrelationship diagram, the problem variables are then searched for their respective relationships, which are the core of the problem.

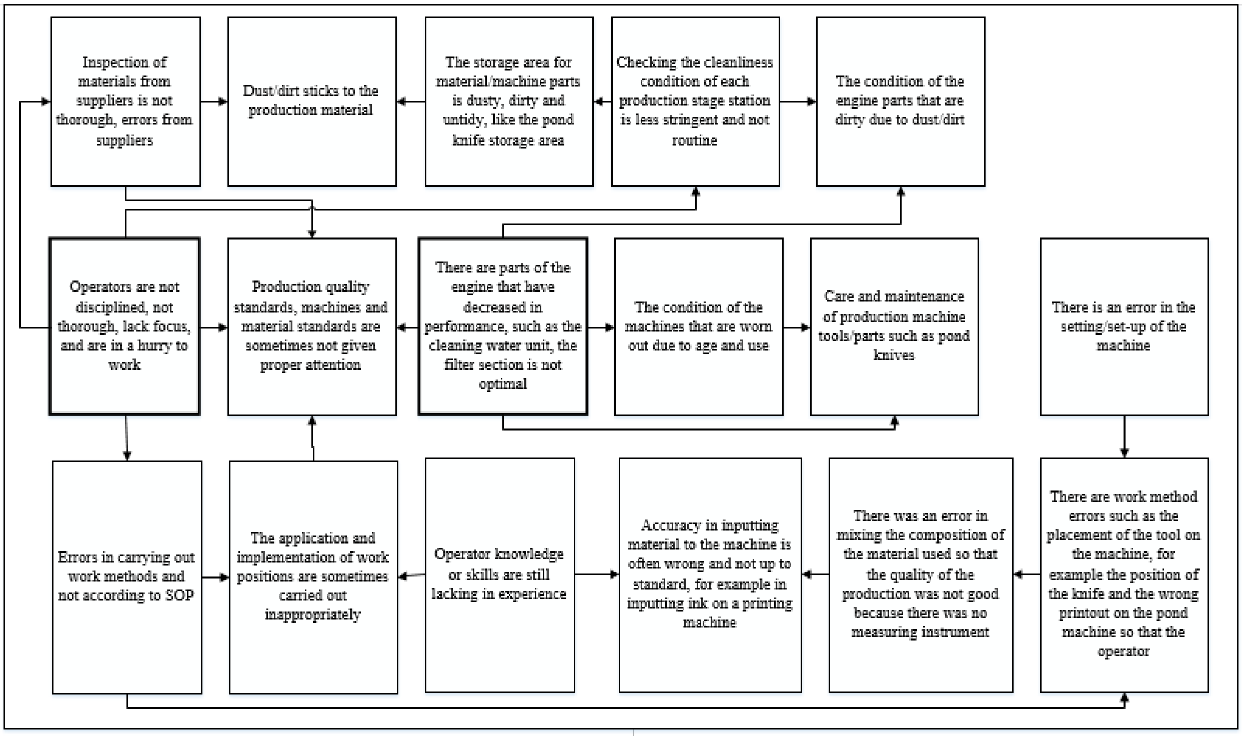

Figure 8. Interrelationship Diagram

The affinity diagram has identified several fundamental causes of the problems that had occurred, which will then be developed into the subsequent stages of the tree diagram based on the problem's focus, the frequency with which problems occur, and the duration of the research. The following is an explanation of the results of the analysis using the tree diagram tool for proposed enhancements based on the identified problem factors (Figure 8).

1. Human factor, including strict operator supervision and training on a regular basis for production machine systems.
2. Material factors, specifically the implementation of a stringent monitoring procedure for incoming materials from suppliers and production materials.
3. Machine factor, checking and maintaining production machines on a regular basis. Can use preventive maintenance check sheet for inspection.
4. Method factor, improving SOPs so that operators can clearly comprehend them, creating SOPs for pond knife inspection, and conducting quality report meetings.
5. Environmental factors, ensure strict supervision of the cleanliness of the work station prior to and after production by forming a cleaning team and providing a one-point instruction on the proper storage of pond knife racks.

The next stage is to determine the priority score for each improvement alternative using matrix data analysis based on the results of the tree diagram. From the outcomes of the interview discussion, the table of improvement alternative criteria and criteria are determined (Table 8).

Table 8. Alternative Improvements and Assessment Criteria

Alternatives of Improvements	Criteria
Improving the quality of operator performance in carrying out production activities (A)	Optimization and improvement of operator supervision is more stringent and maximal (a)
The use of production materials that have better quality (B)	The inspection stage for materials used before the production process is increased to be more thorough and maximal (b)

Alternatives of Improvements	Criteria
Conditioning and improving maintenance and maintenance of production machines is carried out routinely and comprehensively (C)	Maintenance, replacement and maintenance of the main engine or machine parts is carried out routinely and periodically so that it is in good condition and feasible to carry out production (c)
Strictly improve the cleanliness of the production environment throughout the production area (D)	Increased supervision of the concern of all operators/staff regarding the cleanliness of all production areas including the cleanliness of production machines/machine parts (d)
The implementation of the work methods carried out by the operator is in accordance with the SOP that has been set by the company (E)	Improve operator skills and sensitivity to the implementation of work methods used for each type of production machine so that it is carried out correctly and correctly, especially the operation of production machines (e)

The next step is to determine the importance scores for each improvement criterion. Table 9 displays the results of determining the importance ratings on a scale of 1 to 5 based on the responses of experts.

Table 9. Importance Ratings Criteria for Improvement

Criteria	Res. 1	Res. 2	Sum of Score	Final Criteria Ranking
a	2	4	6	3
b	4	4	8	5
c	2	2	4	2
d	4	3	7	4
e	2	1	3	1

After obtaining the importance ratings score, the next stage is to examine each improvement alternative to determine the final ranking score for each improvement criterion. Table 10 displays the outcomes of the calculation of the overall final score ranking.

Table 10. Final Score Ranking of Improvement Criteria for Improvement Alternatives

Improvement Criteria	Final Ranking of Improvement Criteria	A	B	C	D	E
a	3	2	4	4	4	2
b	5	4	1	5	5	4
c	2	3	3	1	2	3
d	4	5	5	2	1	5
e	1	1	2	3	3	1

Table 11 displays the outcomes of the calculation of the overall final score ranking.

Table 11. Final Ranking of Improvement Alternatives

Alternatives of Improvements	Calculation Score	Final Ranking
Improving the quality of operator performance in carrying out production activities	3(2) + 5(4) + 2(2) + 4(4) + 1(2) = 48	3
The use of production materials that have better quality	3(4) + 5(1) + 2(5) + 4(5) + 1(4) = 51	4
Conditioning and improving maintenance and maintenance of production machines	3(3) + 5(3) + 2(1) + 4(2) + 1(3) = 37	2
Strictly improve the cleanliness of the production environment throughout the production area	3(5) + 5(5) + 2(2) + 4(1) + 1(5) = 53	5
The implementation of the work methods carried out by the operator is in accordance with the SOP that has been set by the company	3(1) + 5(2) + 2(3) + 4(3) + 1(1) = 32	1

5.4 Control Stage

PT. PHI can use the proposed and analyzed enhancements to improve the production quality of duplex cardboard packaging for AA products. The management of company divisions, such as the Head of Production and Quality Control, can oversee the process of implementing proposed enhancements in accordance with the approved project charter. PT. PHI can measure the P control chart criteria, Cp and CpK process capabilities, DPMO (Defects per Million Opportunities), and production sigma levels to determine the effect of proposed improvements on the increase in production quality of duplex cardboard packaging for AA product.

6. Conclusion

After conducting research and processing data, several conclusions can be drawn, including the fact that, based on observations, there are six categories of defects, with unclean ink accounting for 58.9%, pond tilting accounting for 17.3%, and freckle defects accounting for 12.6%. Process capability calculations determined that production control was inadequate, with a DPMO value of 5861 units and a sigma level of 4.02. The results of the analyze phase indicate that there are primary factors, with the most common defect problems being associated with suboptimal production machine tools. On the basis of the results of the improve stage analysis using the seven new quality tools method, it can be concluded that the proposal to increase the production quality of duplex cardboard packaging for AA products is based on priority levels, namely the ability to create SOPs for quality inspection of pond knives, preventive maintenance check sheets, SOPs and checklists for incoming material quality, and product quality reports, and also implement quality report meeting.

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