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Quality Control of Sandwich Panel Products Using Seven Tools and Six Sigma Methods

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ABSTRACT

Objective: *The purpose of this research is to identify product defect factors and provide technical recommendations to improve quality.* ***Method:*** *The methods used are Seven Tools and Six Sigma to identify and evaluate potential failures at PT XYZ. The Seven Tools method by applying improvement steps and analyzing the types of defects with the Six Sigma method.* ***Results:*** *The results showed that the factors causing product defects that can be seen from the fishbone diagram are known, namely, humans, machines, materials, and methods and provide suggestions for improvements that are applied to minimize the occurrence of defects. After the corrective action taken, it was able to minimize the number of defects by 5%.* ***Novelty:*** *PT XYZ is a company engaged in manufacturing that produces sandwich panels. The problem faced by this company is the large number of product defects during the production process in the October-December 2023 period amounting to 10% of total production.*

INTRODUCTION

Product quality is determined by its capacity to meet the explicit and implicit needs of customers [1]. Product quality is a factor that companies must maintain to improve competitiveness and customer loyalty. Thru structured and controlled quality management, waste can be effectively eliminated and the company's ability to compete can be enhanced [2]. As indicated by ISO-8402, quality is the overall trademark of an item or service in a work that satisfies customer needs [3]. Quality control aims to ensure that cycles are completed in a manner consistent with established guidelines and then produce goods or services that meet standards [4]. Therefore, to obtain high-quality products that meet customer expectations, a company must be able to understand what customers expect [5]. There are several approaches to quality control, including using skilled workers, high-tech production machinery and equipment, and high-quality material inventory [6].

In a company, the issue of defective products is a critical problem. Beside being clearly unfit for sale to customers, damaged products also negatively impact the company's ability to generate profits. Some factors that can cause product damage include inadequate equipment used during production, worker carelessness, and inadequate supervision of the work process [7]. Products that are physically unsuitable for use as finished goods but can later be repaired and marketed as second-grade items [8]. One of the main problems faced by PT. XYZ is the very high rate of defective products. In the last three months, this company experienced a 10% decrease in product quality from the standard limit of 5%. 2,639 pieces of good product were produced and

278 pieces were defective. Due to the high rate of defective products, the company is experiencing losses in both material and financial terms. This is because the product is not suitable for sale at the normal price, as it has incurred significant material costs [9]. Thus, with the increasing number of defective products experienced by the company, efforts must be made to improve and promote all methods of improvement.

The use of the seven tools and Six Sigma methods has been widely adopted by other companies to minimize product defects. This is similar to the research conducted by K. Damayant [10], which uses the seven tools method commonly used to analyze defects and attempt to minimize them. Based on research by Astuti [11], which also discusses product quality control using the seven tools method, it shows that the method is quite good and effective for analyzing the extent of the types of defects that occur, and can explain the factors causing defects in the product. The seven tools method is a set of seven tools used to address problems experienced by the production process, particularly those related to product quality [12]. Six Sigma is a methodology that can be understood as a measurement process using instruments and statistical approaches to reduce the number of product defects to lower than 3.4 DPMO (Defects per Million Opportunities) or 99.99 percent, with a focus on achieving customer satisfaction [13]. Six Sigma has five systematic steps, namely the define, measure, analyze, improve, and control phases [14].

Based on research conducted using the seven tools and six sigma methods, the objectives of this study are to identify defects in sandwich panel products and the factors causing these defects. Additionally, the study aims to provide technical recommendations for improving the quality and productivity of sandwich panels.

RESEARCH METHOD

A. Time and Place of Research

This research was conducted at PT. XYZ, located in Pasuruan Regency. PT. XYZ is a manufacturing company that produces sandwich panels, roofing panels, and sliding doors. The objects to be studied as data sources in this research are the production results and the equipment used in the production process.

B. Data Collection

This data collection stage has three methods, as follows:

1. Observation

   This observation stage is carried out by observing the field to obtain the percentage of defects found in the production results.
2. Interview

   The interview stage involves collecting data thru question-and-answer sessions and discussions with the relevant individuals, in this case, information can be obtained from the production manager and supervisors directly involved in the process.
3. Data Collection

   The data collected in this study is primary data, which is data obtained from the field, including product quality (quality rate), production volume, and the number of defective products. Secondary data was obtained from the company, particularly from the production division.

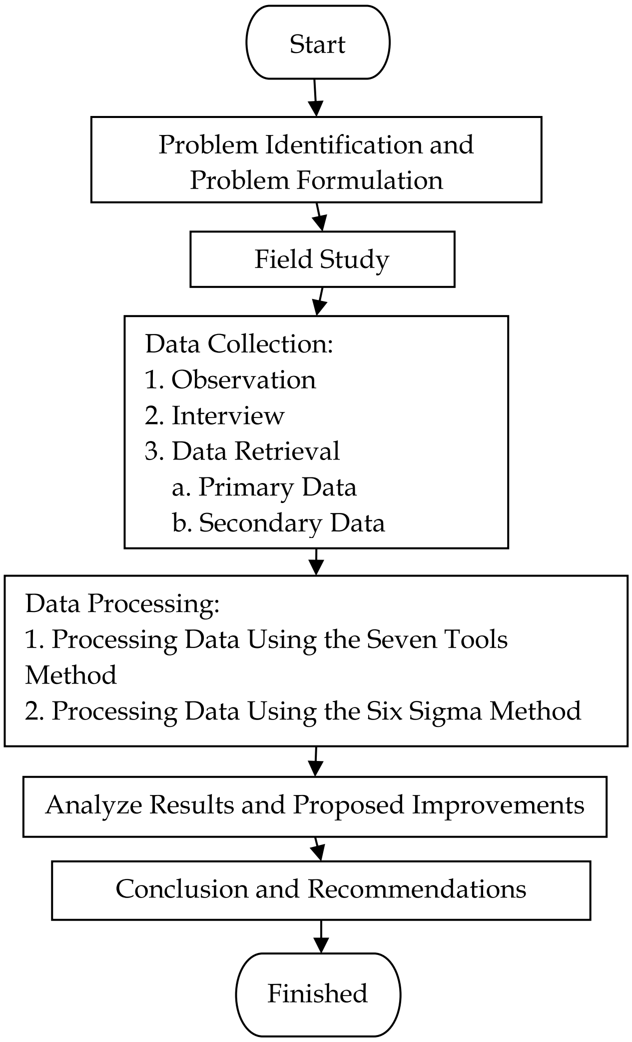

Figure 1. Research Flowchart.

C. Research Stages Integrating Seven Tools and Six Sigma

1. Seven Tools Method

The seven tools method is a set of seven tools used to address problems experienced by the production process, particularly problems related to product quality [12]. The following is a description of the seven (7) statistical tools used in the seven tools approach to identify various types of defects and their causes in products.

1. Flow Chart

   Creating a flow chart can make it easier to visualize the production flow. Additionally, a flow chart can help identify which parts of the production process are prone to causing defective products [15].

2. Check Sheet

   Data collected from the production process, especially the results of defective products, is presented in a neatly and structurally organized table. This method is used to simplify data understanding so that deeper data analysis can be performed [15].

3. Histogram

   To make it easier for readers and to present data accurately, the data will be processed into a histogram, which will serve as a visual data presentation tool in the form of a bar graph showing values numerically [15].

4. Pareto Diagram

   After the data is presented in a histogram, it is then presented in a Pareto diagram, which shows the data graphically to determine the percentage of the highest type of defective product [15].

5. Scatter Diagram

   A scatter diagram is a graph that shows the possible relationship (connection) between two sets of factors and indicates the closeness (degree) of the relationship between those two factors (strong or weak), expressed by the connection coefficient. A scatter diagram can also be used to examine whether one variable can be used to replace another. In its application, the scattering outline requires a collection of information as standard test material, specifically a collection of x-quality values as independent variables paired with a collection of y-value as dependent elements [16].

6. Control Chart (control map)

   A control chart is a graphical method used to evaluate whether a product is under control or not, thus solving problems and achieving quality improvements [17]. The following are the steps for creating a p-control chart.

   1. Calculate the Percentage of Defects

      $$P = \frac{np}{n} \quad (1)$$

      Source: [17]

      Explanation:
      np = Quantity of defective products in the subgroup
      n = Quantity of products inspected

   2. Calculating the Center Line

      The center line is the mean of the defective products (p).

      $$CL = \bar{p} = \frac{\sum np}{\sum n} \quad (2)$$

      Source: [17]

      Explanation:
      $\bar{p}$ = Mean product defect
      $\sum np$ = Quantity of defective products
      $\sum n$ = Total quantity of products observed

3. Calculating the Upper Control Limit

$$UCL = \bar{p} + \frac{\sqrt{\bar{p}\,(1-p)}}{n} \quad (3)$$

Source: [17]

Explanation:
$\bar{p}$ = Mean product defect
n = Production quantity

7. Fishbone Diagram (Cause and Effect Diagram)

After identifying the most prominent main issues using a Pareto diagram, a cause-and-effect diagram will be applied to analyze the factors contributing to product defects, thereby facilitating the analysis of the root causes of excessive product defects [15]. The functions of the seven tools include increasing process improvement capacity to achieve the following:

1. Increase work capacity.
2. Reduce material costs and increase product flexibility.
3. Increase human resource capacity.

The usefulness of the seven tools method is as follows:

1. Understand the causes of product defect problems.
2. Narrow down the causes of the problem.
3. Find the factors that are the cause of the problem.
4. Prove the factors causing the problem.
5. Avoid errors due to lack of care.
6. See the results of improvements [18].

2. Six Sigma Method

Six Sigma is a quality control approach that attempts to reduce costs and increase customer loyalty by minimizing waste thru the creation of interactions and the delivery of products or services [19]. Six Sigma has five systematic steps: define, measure, analyze, improve, and control [14].

1. Define

The first operational stage of a quality improvement program is called the definition stage. In this situation, it's important to break down each procedure and the accompanying consumer interactions. A SIPOC (Supplier-Input-Process-Output-Customer) diagram must be created to determine this. This diagram is very helpful for process improvement initiatives. [14].

2. Measure The steps for performance and disability assessment are known as the measurement stage. Currently, there are three items that need to be completed, specifically:
    a. Identifying quality attributes that are critical to Critical to Quality (CTQ).

b. There are three stages in developing a plan to collect data for quality measurement: process, output, and results stages.
c. Initial performance measurement, namely sigma level and DPMO, which are initial results measurements used in Six Sigma.

$$\textbf{DPMO} = \frac{\text{Banyak produk cacat}}{\text{Banyak produk yang diperiksa} \times \text{CTQ} \ (\mathit{critical\ to\ quality}) \ \text{potensial}} \times 1.000.000 \quad (4)$$

Source: [14]

The DPMO value of a product will describe the average measurement of a process [14].

3. Analyze

   The analysis stage is the stage of identifying and determining the cause of a problem [14].
4. Improve

   The improvement stage is the stage of proposing a corrective action plan to improve product quality [14].
5. Control

   The final step in the Six Sigma process is the control stage. This stage will serve as a working reference, standardize and disseminate best practices that have proven to improve production results, document procedures, and disseminate the results of quality improvements. [14].

RESULTS AND DISCUSSION

As an effort to reduce product defects, the first analysis will be conducted using the seven tools method, followed by the six sigma method.

1. Product Defect Analysis Using the Seven Tools Method

As an effort to reduce product defects, the first analysis will be conducted using the seven tools method. The results obtained in this study are as follows.

A. Process Flow Chart

Since the seven tools method will be used, the first tool is the process flow chart, which is a tool designed to make it easier to understand the process of identifying product defects by breaking down the manufacturing process into manageable steps. The flowchart illustrating the steps in the production of sandwich panel goods, created using observation data obtained from the head of the production department, can be seen in Figure 2.

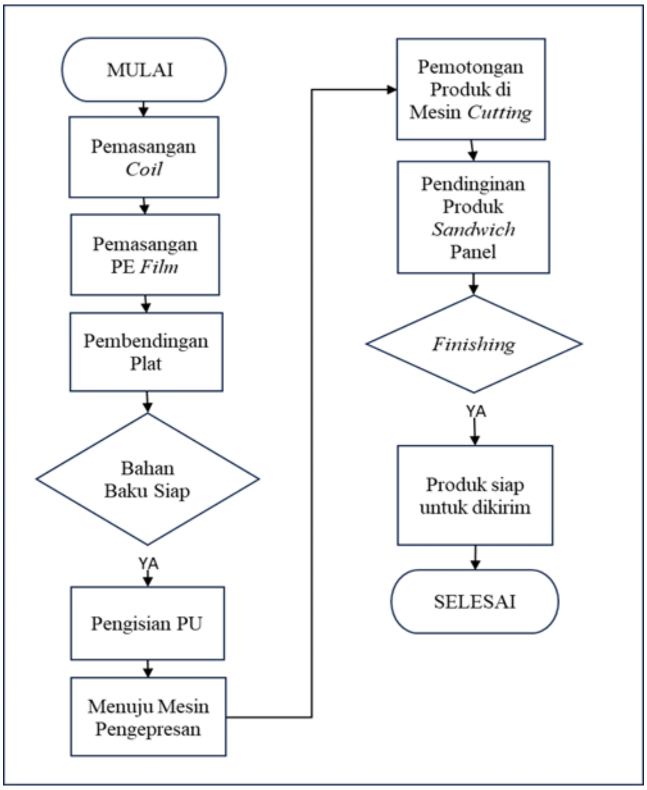

Figure 2. Flowchart of Sandwich Panel Production Process.

B. Check Sheet

The second tool, the check sheet, is data collected from the production process, especially defective product results, presented in a neatly and structured table. The check sheet to be used is a report from PT. XYZ, as shown in Table 1.

Table 1. Check Sheet Data.

Month	**Production Quantity (*Pcs*)**	**Types of Product Defects (*Pcs*)**				**Total**	**%**
		Plate Marking	PU Leakage	Wavy Surface or Bubbles	Hollow		
October 2023	1.008	19	11	36	15	81	8
November 2023	996	18	15	39	31	103	10
December 2023	913	25	14	31	24	94	10
Total	2.917	62	40	106	70	278	10

The problems faced by the company are that, among other types of defects, the wave or bubble category accounts for 106 pieces, followed by voids at 70 pieces, plate marking at 62 pieces, and PU leakage at 40 pieces. This finding is based on production check sheet data and the types of defects mentioned above.

C. Histogram

Histograms are very helpful in visualizing the most common types of products that experience defects based on check sheets. For easier readability, defective product data is displayed in the form of a bar graph segmented by the type of defective product. A histogram or bar graph is created to display the details of the quantity shown in Figure 3.

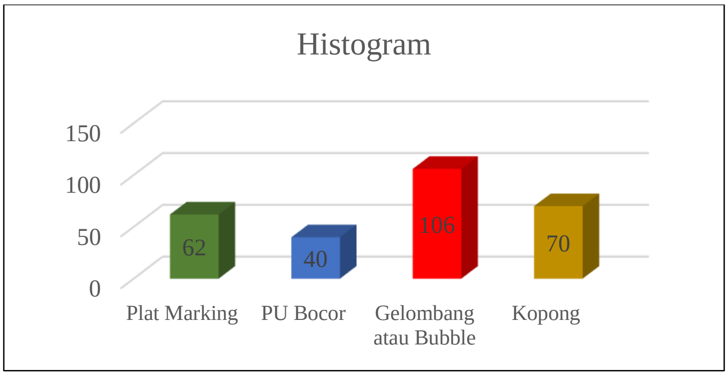

Figure 3. Histogram of Sandwich Panel Production.

Based on the histogram of defects in sandwich panels, it can be seen that the types of product defects that occur are: 106 pieces of wavy or bubble panel defects, 70 pieces of hollow panel defects, 62 pieces of plate marking defects, and 40 pieces of leaking PU defects. It can be seen that wavy or bubble defects are the most common type.

D. Pareto Diagram

The next step is to create a Pareto diagram to make it easier to see the percentage of each type of defect that occurred when production data and defect data from product sampling collected during October - December 2023 were compiled.

Table 2. Product Defect Percentage Data.

No	Types of Defects	Total *Defect*	Cumulative	%	% Cumulative
1	Wavy Surface or Bubbles	106	106	38	38 %
2	Hollow	70	176	25	63 %
3	Plate Marking	62	238	22	86 %
4	PU Leakage	40	278	14	100 %

Table 2 shows that products with wave or bubble defects account for 38% of the total, products with hollow defects account for 25%, products with plate marking defects account for 22%, and products with PU leakage defects account for 14%. Figure 4 illustrates a compilation of images based on the information in Table 2.

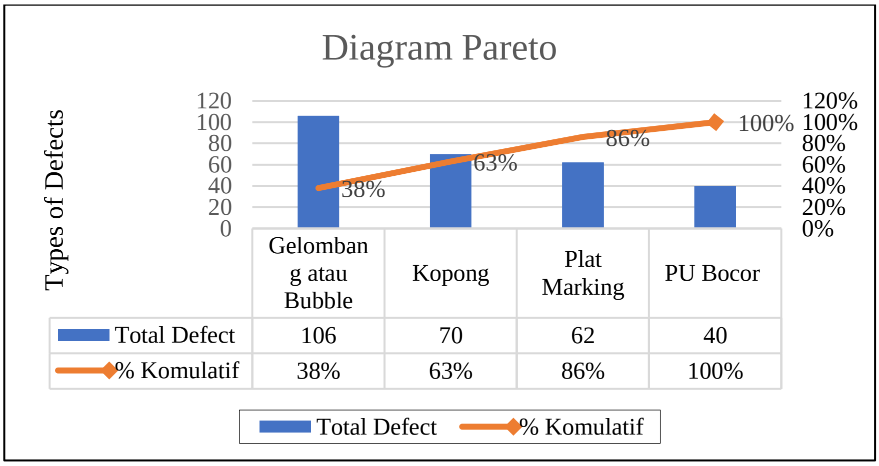

Figure 4. Pareto Diagram of Defective Products in Sandwich Panels.

E. Scatter Diagram

A scatter diagram is used to determine whether there is a positive, negative, or no relationship at all between two variables, or simply to test the strength of the relationship.

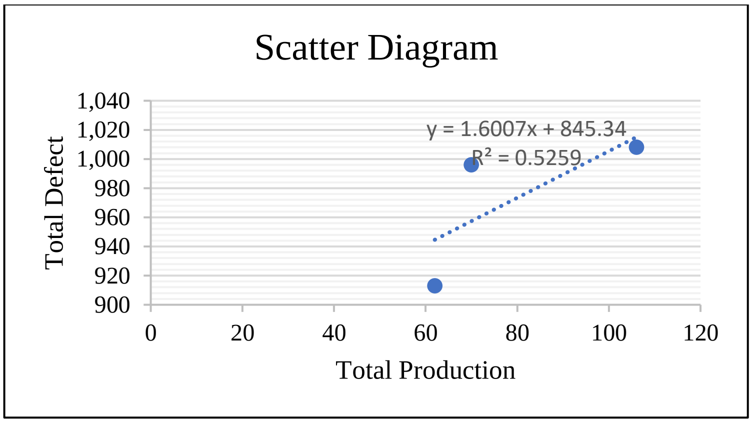

Figure 5. Scatter Diagram of Defective Products on Sandwich Panels.

Figure 5 illustrates how the distribution shape is almost uniform because the number of defective product types produced is independent of production volume, which means that the number of good items produced has a significant impact on the occurrence of defective products.

F. Control Chart

Table 3. Data from Control Chart Calculations.

No	Month	Production Quantity	Number of Samples	Number of Defects	Proportion	CL	UCL	LCL
1	October 2023	1.008	120	81	0,675	0,772	0,772	0,706

2	November 2023	996	120	103	0,858	0,772	0,772	0,706
3	Desember 2023	913	120	94	0,783	0,772	0,772	0,706
	Total	2.917	360	278	2,317			

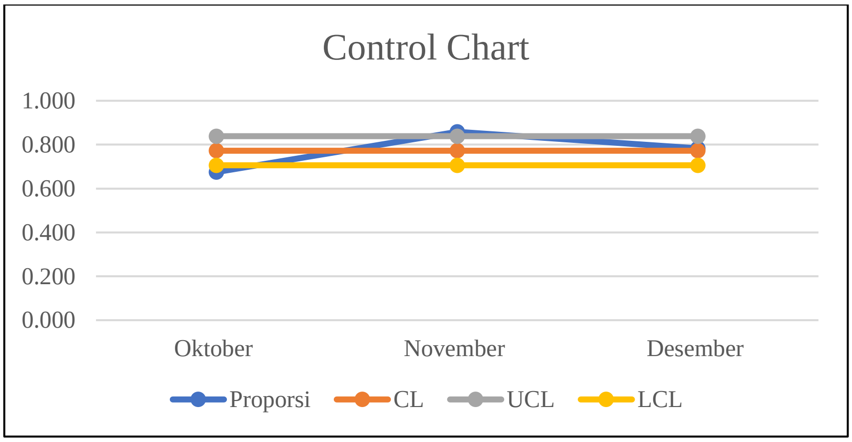

Figure 6. Control Chart Calculation Results Graph.

Figure 5 shows the graph on the control chart p above. We can see that there are still data points outside the control limits at points 1 and 2, or October-November, and the most dominant causes are wave panels or bubbles and hollow panels. Therefore, it can be said that the process is uncontrolled or shows deviations. Because there are points outside the control limits, this indicates that there are still problems in the production process. Therefore, further analysis is still needed to determine why there are deviations in the production process at PT. XYZ. Further analysis using a cause-and-effect diagram (fishbone diagram) is needed to identify the causes of these product deviations.

G. Fishbone Diagram

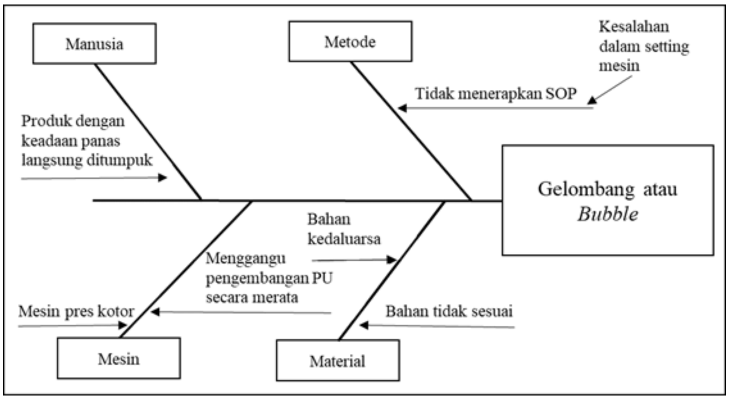

Figure 7. Fishbone Diagram of the Causes of Wave or Bubble Panel Defects.

From the fishbone diagram above, it can be seen that product defects occur due to several factors, namely:

1. Human - One human factor contributing to product defects is when hot products are stacked directly without being cooled first.
2. Method - One method factor causing product defects is operator failure to optimize system process settings.
3. Machine - One of the main causes of many product defects is the machine factor, namely the neglect of machine cleaning, which can disrupt the uniform development of PU.
4. Material - One of the contributing causes of product failure is the use of substandard or non-standard materials according to the material factor.

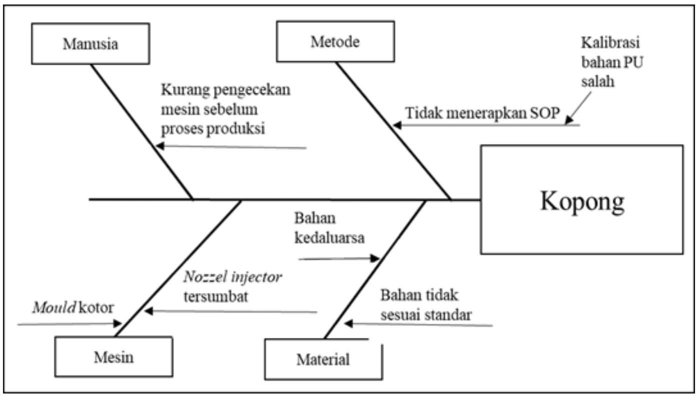

Figure 8. Fishbone Diagram of the Causes of Hollow Panels.

From the fishbone diagram above, it can be seen that product defects occur due to several factors, as follows:

1. Human - From the human factor, product defects are caused by insufficient machine checks before the production process.
2. Method - From the method factor, insufficient calibration checks of incorrect PU materials and not properly implementing SOPs.
3. Machine - From the machine factor, insufficient mold cleaning can interfere with the even development of PU, and clogged injector nozzles cause uneven material distribution, which can lead to many product defects.
4. Material - From the material factor, poor material quality and materials that do not meet standards are one of the factors causing product defects.

2. Product Defect Analysis Using the Six Sigma Method

As an effort to address the ongoing occurrence of product defects, a second analysis will be conducted using the Six Sigma method. The results obtained in this study were carried out in the following stages.

A. Define

A SIPOC diagram is a representation of key process needs and requirements and their interactions. As shown in Figure 9.

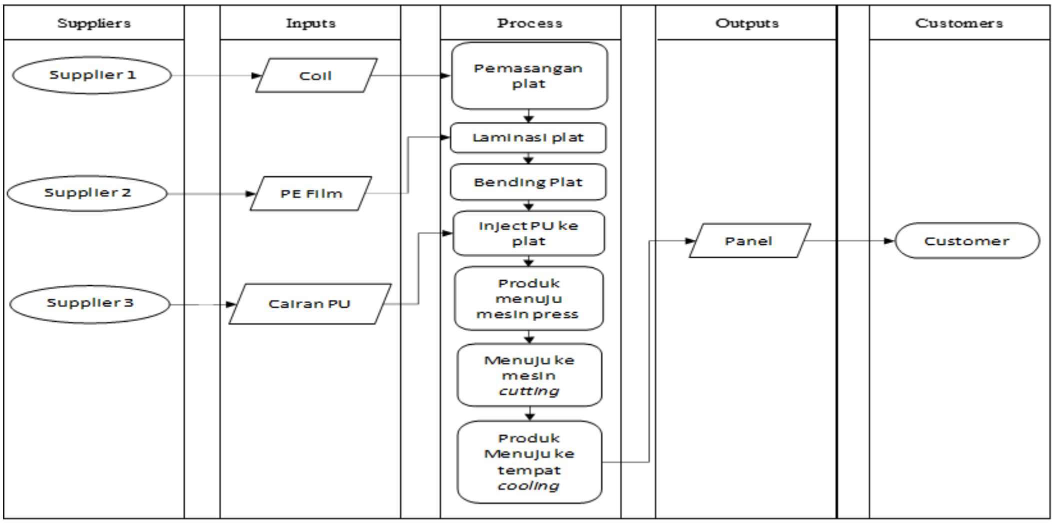

Figure 9. SIPOC Diagram.

PT. XYZ is a company that produces sandwich panels, so raw materials from suppliers enter the company in the form of coil material, PE film, and PU liquid. Each of these raw materials comes from suppliers in the Jakarta area and is imported from abroad. Then the production process begins with installing the sheet onto the roll former machine, followed by coating the sheet with PE film, moving it to the sheet bending area to form a surface, and then to the PU injector. After the material is filled, the product goes to the pressing area, where it is then cut to the desired size. After cutting, the product is placed in a cooling area and then enters the finishing stage. The output obtained is sandwich panels, after which the product will be given to the consumer.

B. Measure

1. Determining CTQ

The CTQ for the sandwich panel production process is shown in Table 4. Based on Table 4, it was found that wavy or bubble panels are the most dominant problem in sandwich panel production.

Table 4. CTQ for Sandwich Panel Production.

No	CTQ	Total Defect
1	Wavy Surface or Bubbles	106
2	Hollow	70
3	Plate Marking	62
4	PU Leakage	40

2. Determining the Performance Baseline

The process of measuring the baseline performance involves calculating the DPMO value, which is then converted into a sigma level. The DPMO value and sigma level are shown in Table 5.

Table 5. Calculation of DPMO and Sigma Level.

Month	Sandwich Panel Production Quantity	Number of Sandwich Panel Product Defects	DPU	DPMO	Sigma Value
October	1.008	81	0,020	20.089	2,32
November	996	103	0,026	25.853	2,23
December	913	94	0,026	25.739	2,23
Average	972	93	0,024	23.894	2,26

Based on the calculation results, the DPMO value for these three periods is 23,894. This indicates that with a sigma value of 2.26, there are 23,894 opportunities out of a million for failure in the production of sandwich panels. Although this sigma value achievement is considered positive, there is still room for improvement to ensure high-quality products by minimizing the difficulties that arise.

C. Analyze

At the analysis stage, the causes of defects occurring in the production of sandwich panels are identified. The tool used for identification in this study is the Pareto diagram that was created in the seven tools method in Figure 4. Based on the Pareto diagram in Figure 4, the focus of improvement is on defects in the corrugated or bubble panels and voids. Next, identification was carried out using the fishbone diagram already present in the seven tools method, with an analysis of corrugated or bubble panels caused by sandwich panel products being stacked directly without cooling and the use of poor-quality raw materials (Figure 7). Inaccurate material calibration and clogged injectors are factors contributing to panel voids (Figure 8).

D. Improve

Basically, the plan will outline how resources are allocated, along with the alternatives and priorities considered during the plan's implementation. The findings from the cause-and-effect diagram analysis are used to improve all sources that could lead to defective goods.

a. Human factors

One of the reasons why sandwich panel products have shortcomings is human factors. Therefore, to prevent potential sources of failure, several improvements in human or operator performance are needed, specifically:

1. The production manager should conduct more frequent direct supervision and add CCTV cameras in the production area [2].
2. Inspect the PU injector nozzles to ensure smooth and even material output.
3. Check all parts of the pressing tool and mold for PU dirt before the production process.
4. When combining specific alloy elements, material calibration checks can be performed to ensure the finished product meets the company's quality requirements.

b. Method Factor

One of the factors causing problems with sandwich panel product defects is the method factor. The purpose of providing quality control suggestions and directions before the manufacturing process is to implement work standards during the briefing phase. [2]. To improve this factor, the company should design an appropriate production plan for each of its product types. This will prevent irregular schedules and disruptions to the production process caused by relying solely on high volume production.

c. Machine Factor

One of the causes of defects in sandwich panel products is related to the machine. Therefore, to ensure optimal performance and minimize potential sources of error, the machine needs to be improved in several ways as follows:

1. In addition to maintaining damaged machines, machine maintenance should always be performed once a week on Saturdays or Sundays. The machine should also be inspected before and after the production process. [2].
2. Perform routine maintenance on the bending machine and adjust each component to ensure the plate molds meet the required product standards.
3. Perform routine maintenance on the PU injector machine; if problems occur, replace machine components or nozzles to ensure maximum functionality during the production process.

d. Material or Raw Material Factor

One of the causes of defects in sandwich panel products is due to considerations regarding raw materials. Emphasis on suppliers regarding stable quality standards [20]. To ensure the final product meets business requirements and SNI (Indonesian National Standard), improvements were made by verifying that the coil plates and PU material were in good condition.

5. **Control**

The actions that must be taken to reduce excessive sandwich panel product defects are:

1. Materials
   a. Emphasizing to suppliers the importance of material quality requirements and the need for caution when conducting quality control (QC) inspections [20].
   b. Selecting materials that meet company standards, as this can affect the quality of the sandwich panel products produced.
2. Machine
   a. Maintenance and inspection tasks for machines or tools must be completed correctly according to the established schedule [20].
   b. Before starting the production process, the bending machine must be checked to ensure it meets the established standards by inspecting each component and cleaning the bending machine of dirt so that it does not affect the sheet metal entering the bending machine, preventing sheet marking or uneven bending.
3. Method
   a. The size of the sheet metal to be printed and the machine settings must be adjusted. [20].
   b. Perform proper material calibration checks during the mixing of specific alloy elements, ensuring the resulting product meets the company's established quality standards.
   c. Calculate control charts to periodically monitor process stability each period.
4. Humans
   a. The plate to be filled with PU (polyurethane) material requires the operator to inspect it more carefully [20].
   b. Before starting the production process, the PU injector equipment must be checked and routine maintenance performed. Replace machine components or nozzles if there are issues with the PU injector to ensure it functions optimally during the production process.

The following are the results of implementing the seven tools and Six Sigma methods for two months after improvements were made to address the issue of excessive product defect reduction.

Table 6. Data Check Sheet of Repair Results.

Month	Production Quantity (*Pcs*)	Types of Product Defects (*Pcs*)				Total	%
		Plate Marking	PU Leakage	Wavy Surface or Bubbles	Hollow		
January 2024	1.052	7	8	17	19	51	5

February 2024	985	10	10	15	13	48	5
Total	2.037	17	18	32	32	99	5

Based on the data analysis in Table 6 for two months after the repairs were made, the number of defective products decreased by 5% from the previous result of 10%. Therefore, the seven tools method and the six sigma method are very useful for a company experiencing problems with its products having a high defect rate.

Table 7. Data of Control Chart Calculation Results After Making Improvements.

No	Month	Production Quantity	Number of Samples	Number of Defects	Proportion	CL	UCL	LCL
1	January 2024	1.052	70	51	0,729	0,707	0,779	0,635
2	February 2024	985	70	48	0,686	0,707	0,779	0,635
	Total	2.037	140	99	1,414			

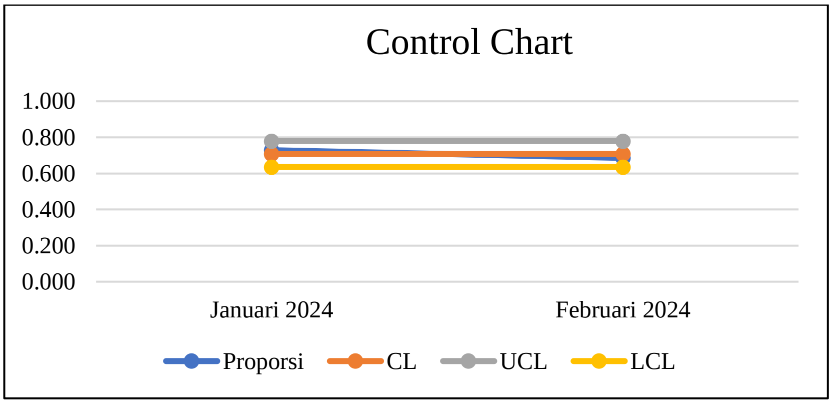

Figure 10. Graph of Control Chart Calculation Results (Control Chart).

Figure 10 shows two periods after the sandwich panel product quality improvement process was implemented, with the results remaining within control limits. This is evident in the p-control chart for January 2024 and February 2024.

CONCLUSION

Fundamental Finding : Conclusion can be drawn based on the results of data processing and analysis carried out as follows: 1. In the production process of sandwich panel products during the period of October to December 2023 with a total production of 2,917 pcs, it is known that the number of wave or bubble panel defects of 106 pcs is the most dominant type of defect occurring among the three types of defects, including hollow panel defects of 70 pcs, plate marking defects of 62 pcs, and leaking PU defects of 40 pcs. 2. Human, technique, machine, and material are the factors causing defects in sandwich panel products. Defects in sandwich panel products include bubble or wave panels, hollow panels, leaking PU, and plate marking. **Implication :** Suggestions to improve product quality standards include addressing all potential causes of defective products, including human factors to improve worker performance and method factors by conducting control chart calculations to ensure process stability periodically. Machine factors involve optimizing machine performance to prevent potential defect causes, and material factors include improvements such as ensuring the quality of each raw material meets standards before the mixing and production processes begin, in order to create high-quality products that comply with company specifications and satisfy customers. **Limitation :** In the production process of sandwich panel products during the period of October to December 2023 with a total production of 2,917 pcs, it is known that the number of wave or bubble panel defects of 106 pcs is the most dominant type of defect occurring among the three types of defects, including hollow panel defects of 70 pcs, plate marking defects of 62 pcs, and leaking PU defects of 40 pcs. **Future Research :** Human, technique, machine, and material are the factors causing defects in sandwich panel products. Defects in sandwich panel products include bubble or wave panels, hollow panels, leaking PU, and plate marking. Suggestions to improve product quality standards include addressing all potential causes of defective products, including human factors to improve worker performance and method factors by conducting control chart calculations to ensure process stability periodically. Machine factors involve optimizing machine performance to prevent potential defect causes, and material factors include improvements such as ensuring the quality of each raw material meets standards before the mixing and production processes begin, in order to create high-quality products that comply with company specifications and satisfy customers.

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