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Combined Waste Assessment Model and Fuzzy-FMEA in Lean Six Sigma for Generating Waste Reduction Strategy: A Proposed Model

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Abstract: Lean Six Sigma is a method that is quite effective in solving waste problems in the production process, but it is often not optimal because of the tools used in the DMAIC process. Therefore, we developed a proposed model by combining the Waste Assessment Model and Fuzzy-FMEA in Lean Six Sigma to reduce waste in the production process. The Waste Assessment Model was used at the defined stage to identify waste, while the fuzzy-FMEA was used for priority waste risk analysis at the analysis stage. Based on the results of the Waste Assessment Model case study, defects were the most influential waste, with a percentage of 22.38%. At the analysis stage using Pareto diagrams, tearing was the dominant defect in the Nike Extreme. Based on calculations using the fuzzy-FMEA method, the highest cause of defects was errors in processes or missed processes that caused the failure. Improvement was carried out at the improvement stage, and we found it necessary to carry out intensive and periodic control or supervision of the Nike Extreme production process. Based on these results, the proposed Lean Six Sigma model can be used to identify and reduce waste in the production process.

Keywords: Lean six sigma, waste assessment model, fuzzy-FMEA, waste.

Introduction

The development of problem-solving methods in the current era is increasingly widespread; several new methods are created to solve problems that occur. In addition to new methods that have been developed, many method systems are integrated to support problem-solving to maximize the results. A continuous breakthrough in science and technology may make new applications incompatible with existing materials, so the need for new and sophisticated materials continues to increase [1]. This plays a critical role for the industrial sector in improving its work system. The industrial sector is an influential part of economic development because the industrial sector can increase economic growth properly by contributing to the growth of the productive component [2]. Therefore, companies must have a strategy for dealing with conflicts and making decisions on problems using several relevant methods to overcome these problems.

The company is inseparable from the production process, which is the core of the company's activities in a manufacturing company [3]. The production process is a series of activities on the production floor [4]. It is almost certain that there are many problems in the production process, and some problems may have a negative impact on the company both in terms of product quality and the effectiveness of a process [5]. These problems can cause several adverse effects such as a decrease in productivity and quality of the products, and thus there is a need for appropriate waste reduction methods to improve the efficiency, quality, and sustainability of the production process in a company. Some waste reduction methods have been employed, such as the application of Lean Six Sigma and VSM. However, this method still has some shortcomings, such as the lack of more specific waste identification, so the solution provided is less optimal [6]. Therefore, a company needs to have a strategy to deal with conflicts and make decisions on problems using several relevant methods to develop optimal solutions. This is done to improve the ability to find more specific types of waste which could have a significant effect, so it can provide recommendations on more optimal solutions. Apart from that, by using integrated methods, satisfactory results could be obtained, so the goal of addressing the existing problems could be achieved.

Lean Six Sigma is one method of solving the problem of waste in the production process [7]. In its solution, DMAIC (Define, Measure, Analyze, Improve, Control) is a step used to realize Lean Six Sigma ([8]; [9]; [10];

[11]; [12]; [13]), which often uses different tools in the DMAIC process. In DMAIC, there is a waste identification process, with several methods that are often used, one of which is Value Stream Mapping (VSM) [14], and the method used to evaluate the most abundant type of waste to manage based on several criteria is the Analytical Hierarchy Process (AHP). Value Stream Mapping is not always ineffective in highly dynamic or rapidly changing environments, where value streams may change significantly in a short time [15]. In addition to VSM, AHP can be used to determine the most significant type of waste to manage by going through various alternatives based on different criteria with the score results obtained for each alternative. This method has drawbacks because it depends on the main input in the form of an expert's perception. Similarly, the AHP method has disadvantages, which are pairwise comparisons, time consuming, and the use of consistency index. These drawbacks could be difficult to solve, requiring many alternative choices [16]. Therefore, a waste identification method must be used in all production process conditions in an industry. At the analysis stage, a method that can be used to analyze the risk of each waste occurring in the production process is needed. FMEA (Failure Mode and Effects Analysis) is a tool used to detect and eliminate the possibility (risk) of failure and damage in a system or product [17]. These risks can be identified, analyzed and categorized based on their level, and appropriate control measures can be proposed to reduce these risks [18]. However, FMEA is considered subjective because the use of this method involves the assessment of experts or respondents in determining three main variables, namely severity, occurrence, and detection rate of each failure risk. Therefore, there are no definite parameters in the process of collecting respondent data [19]. Still, in reality, the interests of the three are not the same [20]. Based on previous research on Lean Six Sigma, the Waste Assessment Model is usually combined with Traditional FMEA [21]. In addition, previous research also used a combination of Value Stream Mapping and Traditional FMEA [22]; [23]. Therefore, a proposed model in Lean Six Sigma was designed, which can be seen in Figure 1.

The Lean Six Sigma method using the Waste Assessment Model to identify waste in the production process can help find problems and provide objectivity in waste assessment. Based on Figure 1, the advantages of using the Waste Assessment Model in this proposed model are to facilitate the identification of waste and the specific weight of waste as well as the impact it has and how it is influenced by other wastes. By identifying the specific weight of waste priorities, recommendations for improvement can be made by analyzing the existing risks [24]. In addition, in minimizing the weakness of FMEA, which is subjectivity in risk level assessment, fuzzy logic is used. Fuzzy is a decision-making approach to solve problems that contain uncertainty [25]; [26]. Fuzzy FMEA can overcome the subjectivity and uncertainty inherent in the risk assessment process, which is often a challenge in FMEA. Fuzzy FMEA also enables a more flexible and adaptive risk assessment, which can be adapted to a variety of different situations and conditions [27]. This is evidenced by previous research which explains that the application of fuzzy logic can overcome uncertainty in decision making, so it can increase accuracy in the selection process by considering various factors. In addition, the application of fuzzy provides an objective assessment based on predetermined criteria [28]. Therefore, the application of fuzzy combined with FMEA can increase accuracy and objectivity in determining the type of waste that has a significant effect, which can be managed first. By implementing the proposed model by combining the Waste Assessment Model and Fuzzy FMEA, the company can solve problems appropriately and find solutions according to priority problems on the production floor.

Therefore, the incorporation of the Waste Assessment Model method to identify waste and Fuzzy Failure Mode and Effects Analysis to identify waste risks in Lean Six Sigma for waste reduction strategies on the production floor can be a proposed method. The combination of these methods can be used in overcoming various weaknesses of waste reduction methods that have been employed in previous studies. Based on latest studies ([7]; [8]; [9]; [10]; [11]; [12]; [13]), a combination of the Waste Assessment Model and Fuzzy FMEA methods has never been carried out on Lean Six Sigma, suggesting that there is a difference between the proposed models that we designed and those from previous research.

In implementing the proposed model of this study, case studies related to waste control in real industries were needed. The case study involved a strategy to reduce waste at a company. This company engaged in the make-to-order manufacturing industry, where it carries out production if there is an order from a customer or buyer. One company that is a customer of that company is Nike. Nike is a large company engaged in the manufacturing, garment, and textile industries, and it is competing with other large companies such as Puma and Adidas. Therefore, the company must be able to produce high-quality end products that provide a high level of satisfaction to buyers that Nike can sell. Implementing the proposed Lean Six Sigma model that we designed could help closely identify and control the waste on the production floor.

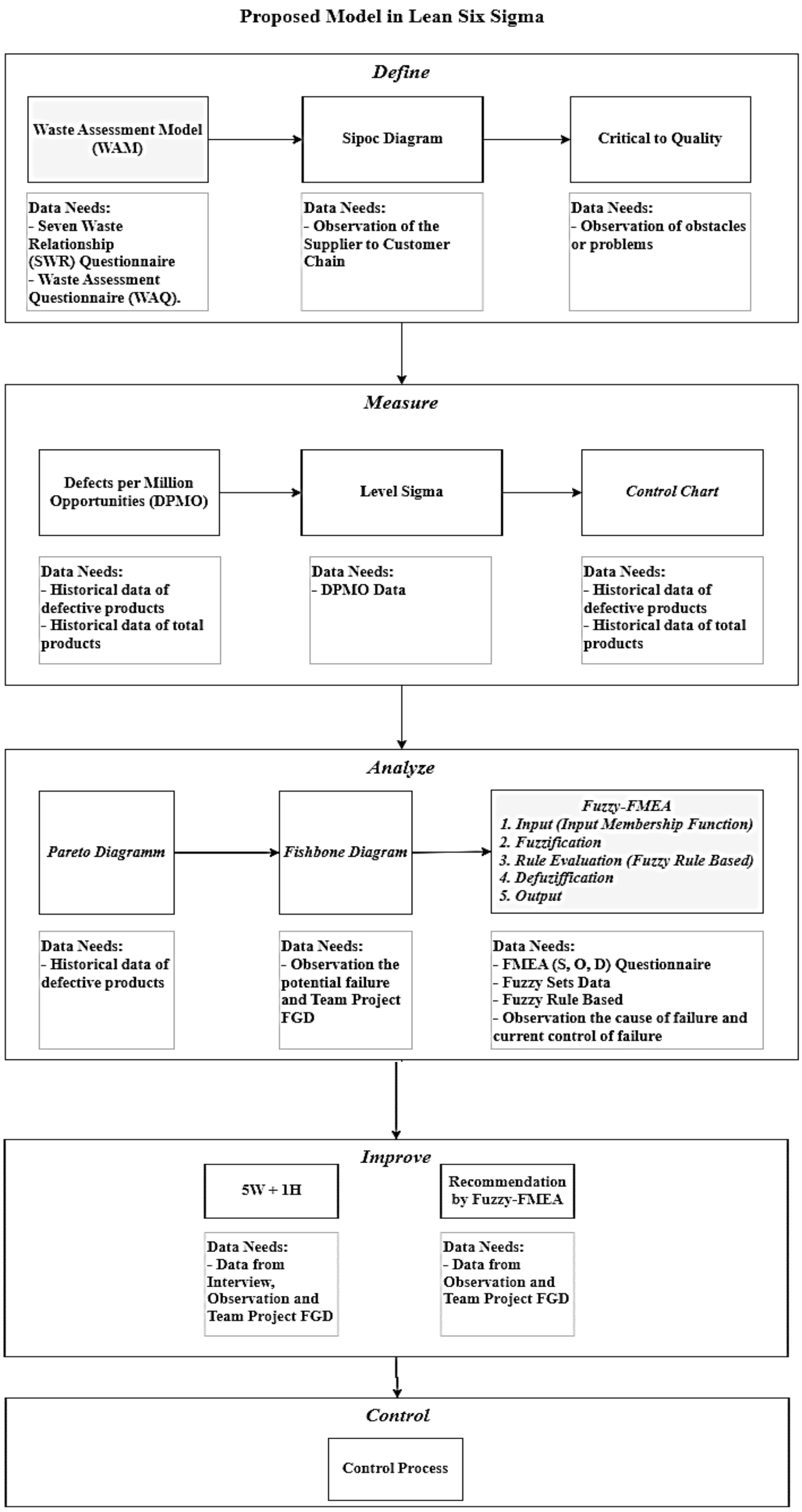

Figure 1. Proposed model in Lean Six Sigma

Methods

Research Object

This research focused on developing a Lean Six Sigma proposed model that could be used in the production process of the manufacturing industry. The case study in this research was THE COMPANY, located in Sleman Regency, Special Region of Yogyakarta. The object of this research was the Nike Extreme Glove production process. The data used in this study was data in 2022.

Data Collection

In this study, the secondary data were journals, books, and previous articles related to Lean, Six Sigma, and waste on the production floor. In addition, we used historical data on the number of production and defective products obtained from company data. The primary data were data on the number of Nike products produced within one year, as well as production process data. There were also data from interviews and questionnaires obtained from related parties (senior managers, managers, and operators).

The first step in this research was conducting a literature review to create a Lean Six Sigma proposed model. Then, observation was carried out at the location of the case study. Observation was used to see and observe everything that happened in the production process and production activities. The purpose of the observations was also to identify the causes and types of defective products. In addition, secondary data from the company and credible references were used in data processing. In addition to questionnaires, interviews with related parties were also conducted to obtain data about the problems they faced.

Data Processing Method

Define is a stage to identify Lean Six Sigma projects. At this stage, waste and a potential problem were identified. In its realization, the Waste Assessment Model method was used so that in the following stages, it could focus on problems or potential waste at the company and determine the goals to be achieved. After the problem was identified, a SIPOC diagram (Supplier, Input, Process, Output, and Customer) was created, and the product's Critical Quality was determined.

The second stage was measure. At this stage, current performance measurement was carried out, which was determined as a performance baseline at the start of the Six Sigma project. At this stage, 2 calculations were carried out to determine the value of Defects per Million Opportunity (DPMO) and the sigma level. A control chart (p-chart) was also used at this stage. In the analyze phase, the identification of the most dominant defect findings was carried out, and the root causes of the defect findings were analyzed. Several tools were used to assist the analysis, including Pareto diagrams, fishbone diagrams, and Fuzzy-FMEA. The Fuzzy-FMEA stage consisted of five critical stages, namely defining the input (input membership function). Fuzzification was carried out to change the input parameters into fuzzy sets, up to the stage of elaborating the fuzzy rules, and the defuzzification process to change the parameters of the fuzzy set into an output.

The next stage was improved. At this stage, the 5W + 1H tools were used. It was done by determining a repair plan that had known the root cause of the problem with processes that were considered to affect defective products. In the last stage (control), recommendations on how to control the existing problems and minimize defects for Nike Extreme products were made. These recommendations, which companies could implement, were made based on the results of the research.

Model Verification in a Case Study

In testing the proposed model, it was necessary to verify the model in a case study found on the production floor. This was done by testing the proposed model at the company to find out whether the model was feasible for quality improvement in a manufacturing industry.

Define

At this stage, data processing was carried out using the Waste Assessment Model (WAM) method to validate related problems on the production floor. Some data were collected by distributing questionnaires, including the Seven Waste Relationship (SWR) questionnaire and the Waste Assessment Questionnaire (WAQ). WAM was divided into 3 steps to determine waste ranking: Seven Waste Relationship (SWR), Waste Relationship Matrix (WRM), and Waste Assessment Questionnaire (WAQ) [29]. Table 1 are the results of the data processing of Waste Assessment Model.

Based on the Table 1, defects were the most critical waste in the production line of the company. This suggests that defective wastes were a serious problem in the production line of the company with a percentage of 22.38%. Based on these data, a follow-up was carried out to minimize defect wastes. Furthermore, a SIPOC diagram was made to describe the flow of the production process of a product produced by the company in an orderly and clear manner. The SIPOC diagram consisted of the production process flow starting from the supply of raw materials to the finished good, which was Nike Extreme, ready to send to Nike.

Table 1. Waste assessment model

	Overproduction	Inventory	Defect	Motion	Transportation	Excess processing	Waiting	Total
Score (Yj)	0.36	0.33	0.30	0.34	0.33	0.25	0.30	
Pj factor	262.27	216.66	342.09	189.47	164.03	90.79	148.24	
Final result (Yj Final)	93.37	71.35	101.23	64.45	54.02	22.83	45.04	452.29
Percentage	20.64%	15.77%	22.38%	14.25%	11.94%	5.05%	9.96%	100%

Note
Score (Yj) : Initial indicator of each waste
Pj Factor : Probability of influence between waste
Yj Final : The results of the influence between waste

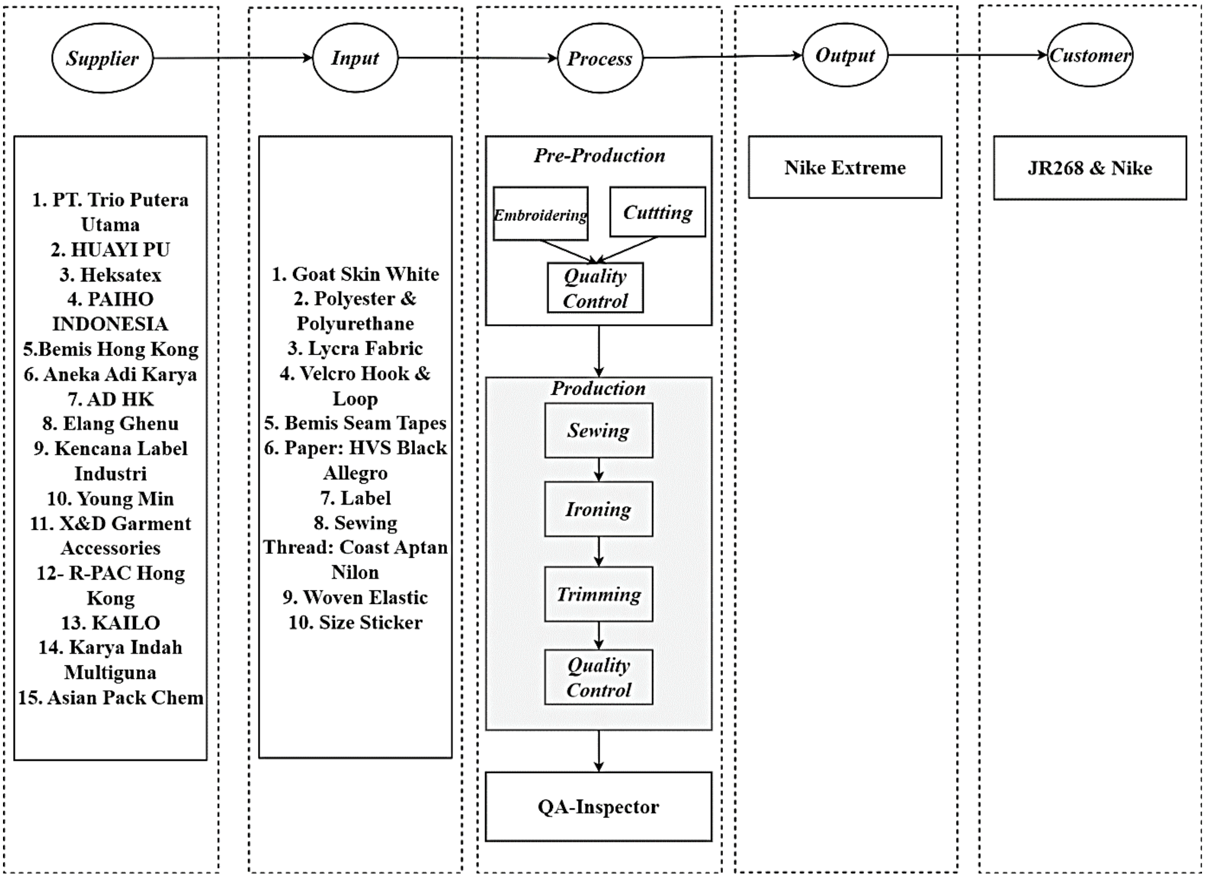

Figure 2. SIPOC Diagram

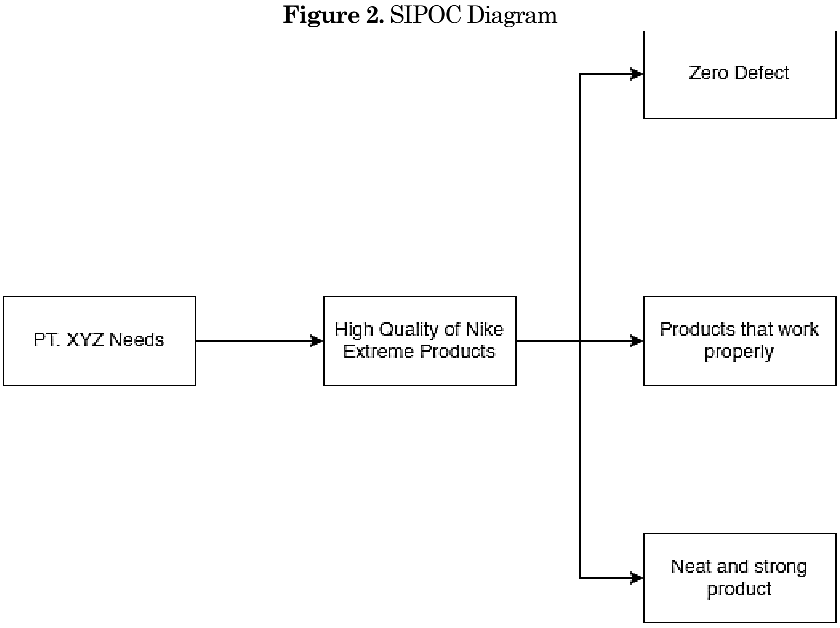

Figure 3. Critical to quality

As shown in Figure 2, the production process has a gray background. This shows that this area is the focus of this research. The next step was to determine Critical to Quality. Critical to Quality (CTQ) is a criterion for product quality standards that a company must achieve, or, more precisely, a minimum specification standard must be maintained for a product. Figure 3 shows the Critical to the Quality of Nike Extreme products.

A failure had to be defined first. At the define stage, Critical to Quality was used to categorize a product as a defective product more easily. Based on Figure 3, three categories were obtained in which the company achieved its goal of zero defects. In addition, there were 14 types of CTQ based on the historical data on Nike Extreme products.

Measure

Defects Per Million Opportunities (DPMO) is a performance measurement to assess the process capability [30]. DPMO is a method of measuring the performance of a process. DPMO measures the Probability of a defect occurring per million opportunities. The following is the formula for Defects Per Million Opportunities (DPMO):

$$\text{DPMO} = \frac{Total\ Product\ Defect}{Total\ Product\ Check\ x\ Total\ Types\ of\ Defects} \text{x } 1.000.000 \quad (1)$$

The next step was calculating the DPMO table for the Nike Extreme product. Table 2 presents the DPMO values of Nike Extreme products in 2022.

Table 2. DPMO

Period	Total product	Total defect	CTQ	DPMO
January	9014	1064	14	8431.329
February	21449	3259	14	10852.987
March	17704	2074	14	8367.762
April	6693	723	14	7715.951
May	6344	946	14	10651.234
June	14208	1688	14	8486.165
August	4775	625	14	9349.289
September	7654	924	14	8622.942
October	7498	1168	14	11126.777
November	5799	659	14	8117.163
December	7142	762	14	7620.914
Average				9031.137

As shown in Table 2, the period with the highest DPMO value was October 2022. The DPMO value in this period was worth 11,126.777. Meanwhile, the lowest DPMO value was in December at 7,620.9145. The average DPMO score in 2022 was 9,031.137549.

After the DPMO value was determined, the next step was calculating the sigma level. This was done using the sigma level table or by doing calculations in Microsoft Excel with the following formula:

$$\text{Sigma } (\sigma) = Normsinv\left(\frac{1{,}000{,}000-\text{DPMO}}{1{,}000{,}000}\right) + 1.5 \quad (2)$$

According to Gaspersz [31], the number 1.5 is a constant according to the Motorola concept, which allows a shift in the average values of 1.5 Sigma. Table 3 is a table for calculating the sigma level for Nike Extreme products.

Based on the results of Table 3, December 2022 was the period with the highest sigma level, with a sigma level of 3.93, while the lowest sigma level was in October 2022, with 3.79. Meanwhile, the overall average sigma level in 2022 was 3.87.

The next stage was creating a control chart which served as a tool for analysis. The analysis was carried out to find out whether there were deviations in the output of the products produced at a certain period. Control charts consist of many types, such as p-charts, u-charts, and other types of control charts. At this stage, a p-chart was chosen because the p-chart could be used to analyze the proportion of errors in the number of samples. Figure 4 is the p-chart control chart for Nike Extreme products.

Table 3. Sigma level

Period	Sigma Level
January	3.89
February	3.80
March	3.89
April	3.92
May	3.80
June	3.89
August	3.85
September	3.88
October	3.79
November	3.90
December	3.93
Average	3.87

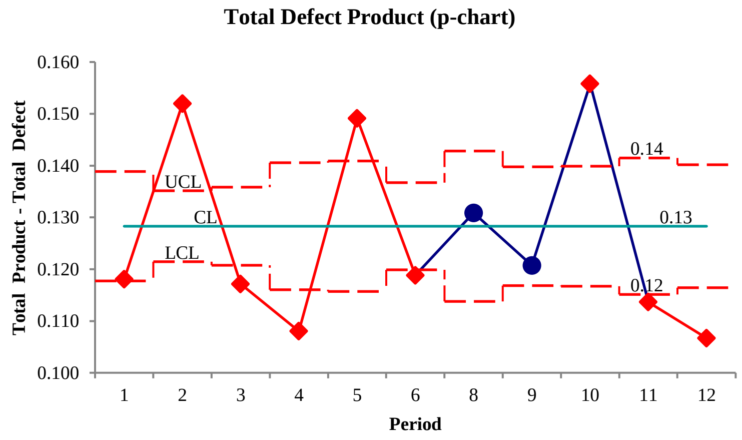

Figure 4. Control chart

Based on Figure 4, the production process for Nike Extreme products in 2022 seemed to fluctuate uncontrollably and was unstable. In February, March, April, May, June, October, November, and December, it was outside the control chart boundaries. This may indicate that the company needed to make improvements to the Nike Extreme production process.

Analyse

At this stage, the dominant defect in Nike Extreme products was determined using Pareto Diagram. Table 4 is a Pareto chart analysis chart for 2022.

Table 4. Defect type

Defect Type	Total	Percentage
Broken-down	1948	14.02%
Loose Stitches	1898	13.66%
Skipped Stitches / Falling Out	1769	12.73%
Broken Stitches	1565	11.27%
Jump stitch	1281	9.22%
Twisted Fingers	1002	7.21%
Wrinkled / Folded	1002	7.21%
Non-oval Fingers	903	6.50%
Trimming	857	6.17%
Uneven Stitches	815	5.87%
Hole/ Needle Container	327	2.35%
Others	268	1.93%
Auxiliary Stitches	141	1.01%
Oil/Sticker	116	0.84%
Total Defect	13892	

As can be seen from Figure 5, of the 14 types of defects in Nike Extreme in 2022, the most common defect were broken-down defects. Therefore, it became the focus of this research which aimed to identify the causes of the problems. Based on the results displayed in Figure 5, products broken-down were common defects in the production process of Nike Extreme. This type of defect had the highest percentage (14.02%) of all defects in Nike Extreme. From these results, an analysis was carried out to investigate factors that may cause these defects. This was done by creating a fishbone diagram that had six factors: man, measure, machine, method, material, and environment. A fishbone diagram was a tool used in stage 2 of the research process to analyze the root causes of a problem by starting with the consequences or problems that arose and then, in a structured way, looking for possible causes [32].

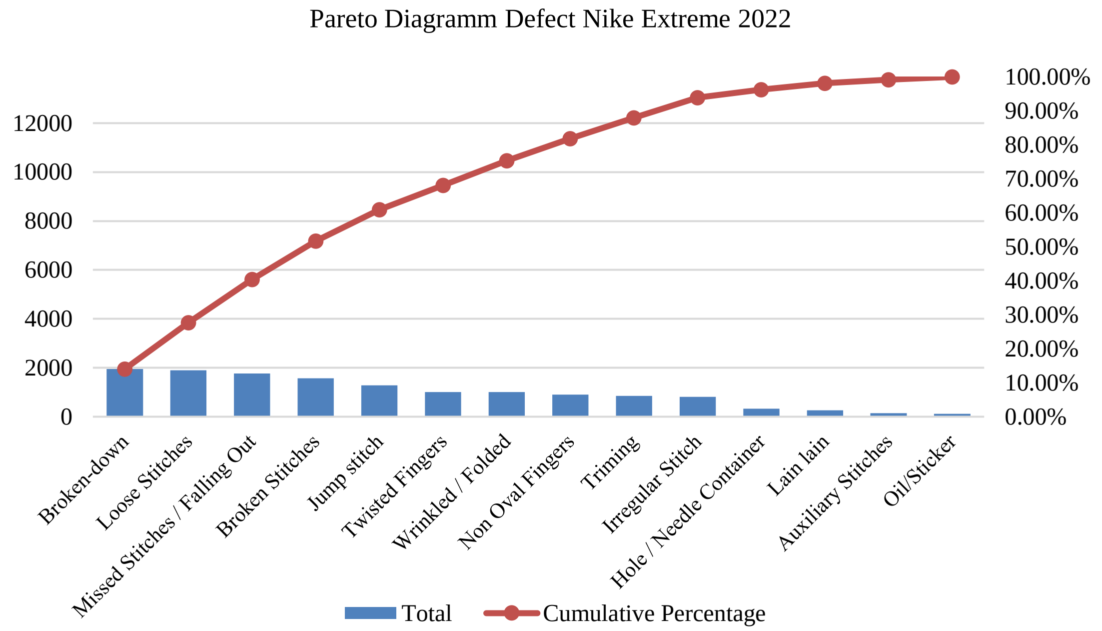

Figure 5. Pareto diagram

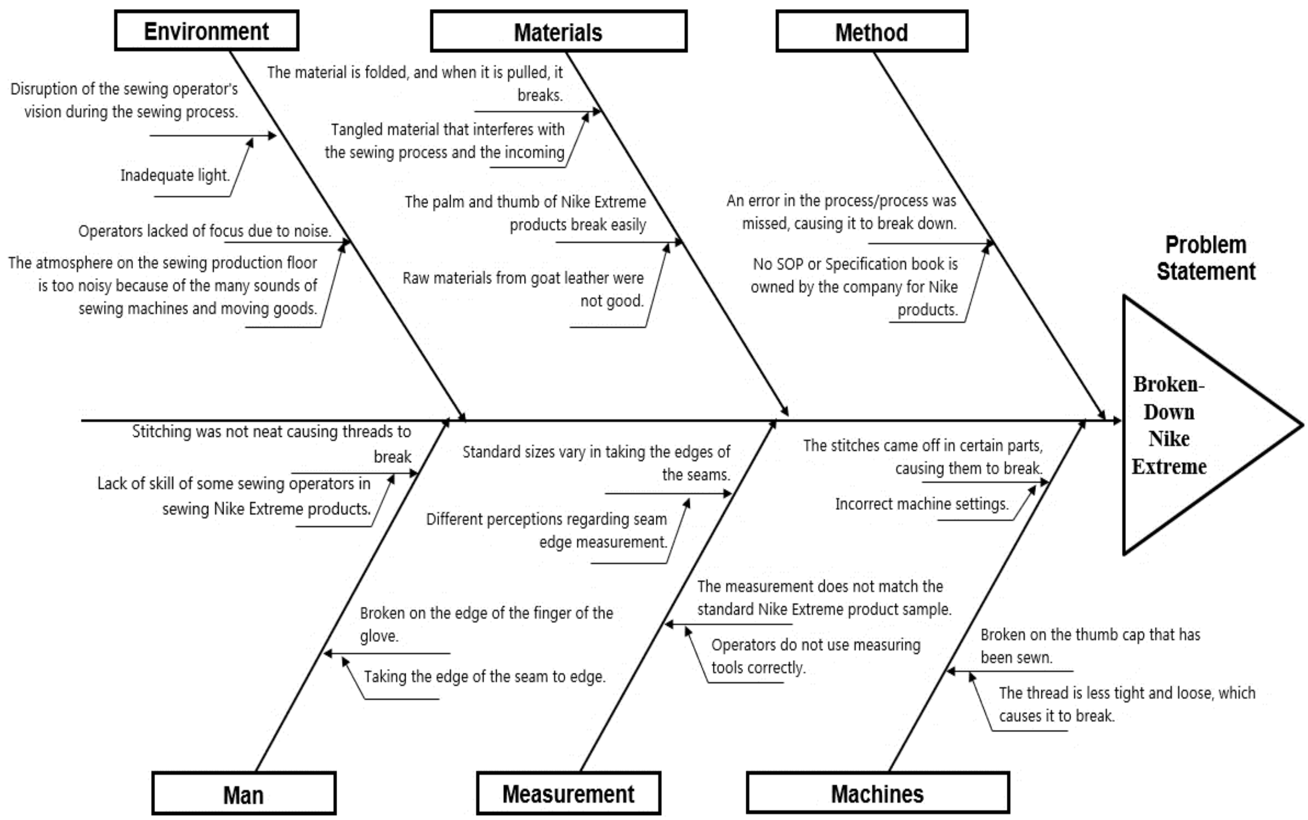

Figure 6. A fishbone diagram

Figure 6 shows the results of the analysis based on interviews with quality control and assurance personnel and the Nike Extreme product operators.

As seen in the fishbone diagram in Figure 6, defects were mostly caused by products broken-down. Table 5 gives a detailed explanation of the causes of the defects. The main causes of Nike Extreme product defects were identified using a fishbone diagram and has been enumerated in Table 5. Then, identification was carried out to measure the possibility of failure using the Fuzzy Failure Mode Effect and Analyze (Fuzzy-FMEA). In this method, there are 3 main assessment variables: severity, occurrence, and detection. A quality assurance manager and a QA inspector did this evaluation for the considered Nike product expert in the field. In addition, discussions and observations were carried out with experts during the research process. The discussions and observations were related to the factors that caused defects. This was then used as a reference control. Table 6 summarizes the failures, effects, causes, and control observed during the Nike Extreme production process. The results of the FMEA assessment questionnaire were obtained from the results of the questionnaires completed by the project quality assurance and control team, which comprised QA inspectors, QA and QC managers, and Nike Extreme sewing operators.

Table 5. Defect causes

Broken-Down Defect			
No	Factor	Reason	Explanation
1	Measure	Measurements were not up to standard sample of Nike Extreme products	During sewing, the operator made a measurement error, failing to meet the standard measurement sample of Nike Extreme products. This was usually because the operators were not careful and did not use the standardized measuring instruments that the company provided.
2		Standard sizes were inconsistent due to inaccurate seam allowance.	This often happened in the process of sewing because each operator had their subjective view, where the operator's perception tended to be different. If the seam allowance was too narrow, it could cause the fabric to rip open.
3	Man	Broken-down on the edge of the finger of the glove	Broken-down caused by an untidy sewing process was usually in the sewing section that connected one part to another
4		Stitching was not neat that caused it too broken-down.	Breaks caused by an untidy sewing process are usually in the sewing section that connects one part to another
5	Machine	The stitches came loose in certain parts, causing sewing damage.	Loose stitches often happened, which eventually caused sewing damage. This could be caused by wrong machine settings
6		Broken-down on the thumb cap that had been sewn	It might be caused by the thread not being tight enough. Poor thread tension setting could influence this
7	Material	The material was folded, and when pulled, it ripped.	Folded material could cause fraying. When the material was folded and the operator was not aware of it, it may result in material damage. When the material was pulled from the fold, it could affect the suture thread and caused it to break
8		The palm and thumb of Nike Extreme products were easily damaged.	The palm and thumb of Nike Extreme products were easily damaged due to the materials used. The palm and thumb of Nike Extreme products used goat leather. The quality of the goat leather varied. Different parts of the goat's body produced different leather. The damage usually occurred because the goat leather used was too thin.
9	Method	There was an error in the process/ process that was missed, causing defect to the product.	Errors in the process often caused this defect. This usually happened because a process was missed or forgotten. As a result, in some parts, it did not stick together and caused it to break. This was because of Nike Extreme product's guidelines and specifications.
10	Environment	Operator's disturbed vision during sewing process	Disruption of the operator's vision could cause product defect. As a result, some parts were considered good enough even though they were not. In addition, some processes may be missed because of this disruption.
11		Lack of operator focus because of noise	Operators were disrupted by noise from the sewing machines in the production floor. Because there were no countermeasures regarding this matter, it may disrupt the operators' concentration, resulting in defect to the product.

Table 6. FMEA assessment questionnaire

Potential Failure	Severity	Occurrence	Detection
There was an error in the process/ process was missed, causing product defect.	10	5	8
Broken-down on the edge of the finger of the glove	9	6	3
The stitches came loose in certain parts, causing sewing damage.	8	5	5
The measurement did not match the standard Nike Extreme product sample.	9	5	2
Broken-down on the thumb cap that had been sewn	8	4	3
Operators' disturbed vision during the sewing process.	8	5	2
Gloves were not stitched neatly and properly, resulting in product defect.	8	4	2
The palm and thumb of Nike Extreme products broken-down easily	9	3	2
The material was folded, and when it was pulled it ripped.	8	3	2
Operator's lack of focus because of noise	7	3	3
Standard sizes for seam allowance were inconsistent.	8	3	1

Table 6 shows the values obtained based on the questionnaire given to the respondents. In this study, FMEA calculations were carried out using fuzzy FMEA. FMEA (Failure Mode and Effect Analysis) is a method used to identify all possible risks of failure in a design or process [33], while fuzzy FMEA is a risk analysis method that uses fuzzy logic to account for uncertainty in risk assessment [34]. Fuzzy-FMEA in the DMAIC cycle is used to reduce the subjective side of FMEA. FMEA calculation is done simply by multiplying the input value (severity, occurrence, and detection) alone to produce RPN values regardless of the degree of importance of the input. By contrast, Fuzzy-FMEA produces FRPN values that consider the degree of importance in every input of Fuzzy-FMEA [27].

The first stage in Fuzzy-FMEA is to input the variables of Fuzzy-FMEA. This study used the fuzzy Membership Function to map data points into their membership values with intervals of 0 – 1. In this study, the triangle and trapezoidal curve function approaches were used. There are three Fuzzy-FMEA input variables: severity, occurrence, and detection. The three input variables each have a value between 1-10 which are classified into five categories: Very Low (VL), Low (L), Moderate (M), High (H), and Very High (VH). Each category has its type of curve and the parameters that are also input in Jupyter Notebook. Table 7 is the curves and parameters input for Fuzzy-FMEA.

Table 7. Types of curves and parameters *input*

Category	Curve Type	Parameter
Very Low (VL)	Trapezoid	(0; 0; 1; 2,5)
Low (L)	Triangle	(1; 2,5; 4,5)
Moderate (M)	Trapezoid	(2,5; 4,5; 5,5; 7,5)
High (H)	Triangle	(5,5; 7,5; 9)
Very High (VH)	Trapezoid	(7,5; 9; 10; 10)

The data is then presented in graphical diagrams, as shown in Table 7. Figure 7 shows the three Fuzzy-FMEA input variables (severity, occurrence, and detection).

Then, the output of the variable Fuzzy-FMEA is determined. This study used fuzzy membership function to show variables output. Variable output of Fuzzy-FMEA is an FRPN value or fuzzy risk priority number. The value of an FRPN membership is between 1 and 1000. Meanwhile, the parameters of the FRPN membership function can be seen in Table 8.

Figure 8 shows the fuzzy output membership function in the research of Nike Extreme products. Then, fuzzy rules are defined by entering the rules for the three inputs (severity, occurrence, and detection) to become Fuzzy-RPN. The rules are defined per one severity, occurrence, and detection values that the expert has previously determined. In this study, 125 were found rules for every possibility.

The last step is to make the Fuzzy-FMEA result function. In this study, a function in Python was used to calculate Fuzzy-FMEA automatically. When a certain value was entered on the variable input (severity, occurrence, and detection), the result value of Fuzzy-RPN was automatically computed and was compatible with rules which had been planned with the company's expert. Table 9 are the FRPN results based on data processing.

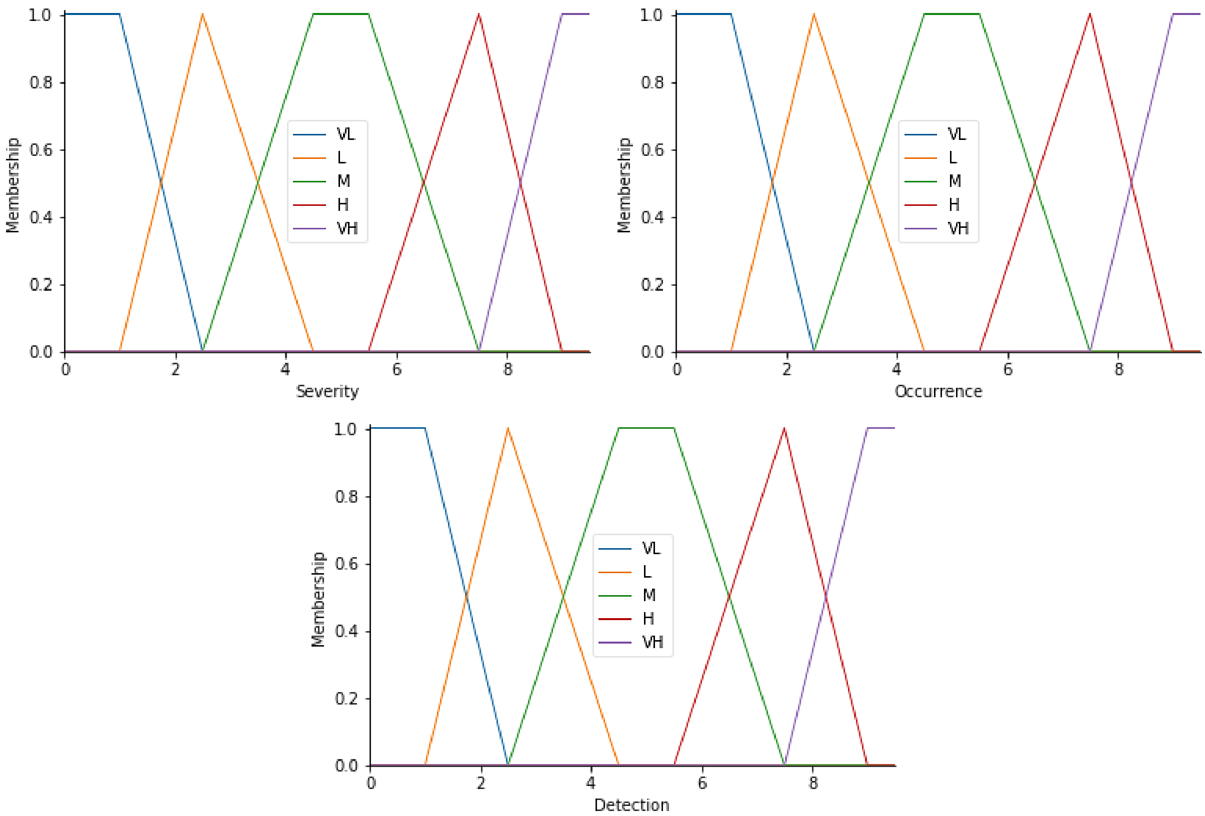

Figure 7. View input

Table 8. Types of curves and parameters output

Category	Curve type	Parameter
Very Low (VL)	Trapezoid	(0, 0, 25, 75)
Very Low (VL)-Low (L)	Triangle	(25, 75, 125)
Low (L)	Triangle	(75, 125, 200)
Low (L)- Moderate (M)	Triangle	(125, 200, 300)
Moderate (M)	Triangle	(200, 300, 400)
Moderate (M)- High (H)	Triangle	(300, 400, 500)
High (H)	Triangle	(400, 500, 700)
High (H)- Very High (VH)	Triangle	(500, 700, 900)
Very High (VH)	Trapezoid	(700, 900, 1000, 1000)

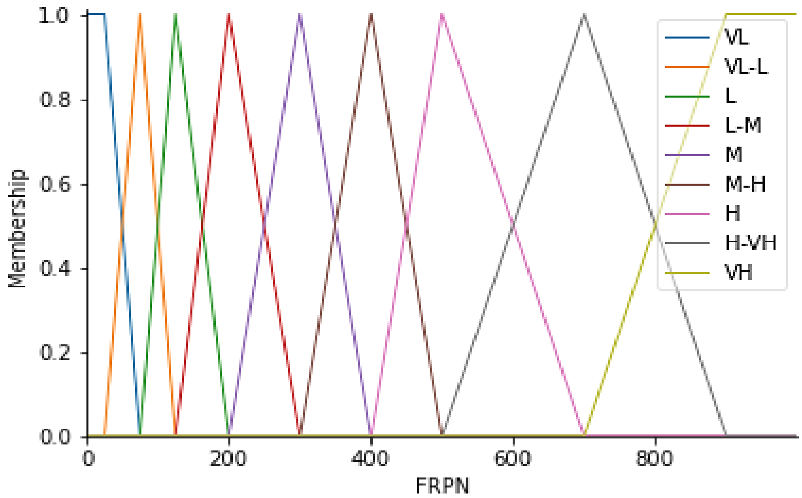

Figure 8. FFMEA output phyton

Table 9. Fuzzy-FMEA result

Potential Failure	Severity	Occurrence	Detection	Fuzzy-FMEA	Rank	Category
There was an error in the process/ process was missed, causing product defect.	10	5	8	612,96	1	High (H)- Very High (VH)
Broken-down on the edge of the finger of the glove	9	6	3	461	2	High (H)
The stitches came loose in certain parts, causing sewing damage.	8	5	5	400	3	Moderate (M)- High (H)
The measurement did not match the standard Nike Extreme product sample.	9	5	2	363,64	4	Moderate (M)- High (H)
Broken-down on the thumb cap that had been sewn	8	4	3	313.94	5	Moderate (M)
Operators' disturbed vision during the sewing process.	8	5	2	308.,13	6	Moderate (M)
Gloves were not stitched neatly and properly, resulting in product defect.	8	4	2	308	7	Moderate (M)
The palm and thumb of Nike Extreme products broken-down easily	9	3	2	301	8	Moderate (M)
The material was folded, and when it was pulled it ripped.	8	3	2	281	9	Moderate (M)
Operator's lack of focus because of noise	7	3	3	276,44	10	Moderate (M)
Standard sizes for seam allowance were inconsistent.	8	3	1	240	11	Low (L)- Moderate (M)

The severity, occurrence, and detection columns in Table 9 are the respondents' previously known scores. The data was obtained from several respondents. From the results of FRPN calculations with Jupyter Notebook in Table 9, the highest FRPN value was in the process errors or missed processes, which caused product defect, with FRPN of 612.96 with the category of High (H)-Very High (VH). Thus, this failure factor must be fixed immediately.

Improve

In this study, the focus was on repairing the type of broken defects in Nike Extreme products because this type of defect was the most common. The highest number of defects and their causes and factors were prioritized for improvement. The next step was to improve these priority factors at the improvement stage using the 5W+1H method. The main problem addressed in this method was the factor that caused the highest number of defects. The findings showed that the factor of process errors or missed processes caused the defects. Table 10 shows a corrective action plan for this problem using 5W+1H.

Table 10. 5W+1H

Type	5W+1H	Description
Objective	What	To improve the performance of workers in the sewing process of Nike Extreme, particularly to always pay attention to the provisions in the production process
Reason	Why	Employees understood the sewing process of Nike Extreme in detail, so they could perform according to the standard to avoid defects in the product and a delayed process.
Location	Where	Repairs were made in sewing lines where Nike Extreme production process took place.
Time	When	As soon as possible
People	Who	All workers in the production process such as line supervisors, sewing operators, quality control personnel, quality assurance personnel, and all quality and production departments
Method	How	By developing work procedures and specifications for Nike Extreme production process

After proposed improvements with 5W+1H for the highest number of defects were prepared, further identification was carried out to address other causes of defects. Based on the results of the discussion and brainstorming, several recommendations for improvement were obtained to reduce defects in Nike Extreme products. Of the 11 potential failures identified, six improvements were made to minimize or eliminate these defects. Six suggestions were given to minimize defective products.

First, the company must provide a work procedure or specification book, especially for Nike products. This way the operator could do the processing based on standard, and it also becomes the main reference to sewing in the production process. This book could also help the company minimize the five causes of product defects. First, the measurement did not comply with the standard sample of Nike Extreme products. With a reference book, it would be easier for operators to ensure that the size matches the expected size of Nike Extreme. The book may also provide information about the process, size, bill of material (BOM), and other needs that can support the production process in detail. Second, using the procedures and specifications the company can minimize errors in seam allowance because there are already rules regarding this in the book. Apart from that, the gloves had defects at the edges of the fingers, and the material was folded, but when it was pulled, it ripped. There were also process errors or missed processes. These problems can be resolved by having a process flow starting from tidying the material to the product entering the inspection process detailed in the work procedure or specification book.

Second, the company needs to hold training in Nike Extreme products for sewing operators periodically, especially for new operators. This needs to be done as a supportive means to improve the skill of operators in sewing. Nevertheless, these procedures and specifications may not be able to completely solve the problem if the operator does not have basic skills in sewing, especially because Nike Extreme is difficult to pattern.

Third, maintenance staff must also have a work procedure book and a maintenance SOP to minimize errors in the machine. This is because not all failures are due to human errors. Therefore, repairing and routine maintenance of machines could minimize errors in the production process and reduce excess and defective products. Thus, the causes of defects because of loose stitches and the defect on the thumb cap could be minimized and resolved.

Fourth, the company needs to choose high quality goat leather. Choosing raw materials is closely related to suppliers. The selection of suppliers greatly affects the quality of the raw materials for production in the company. Raw materials must undergo a quality control process on each arrival. All materials must be tested, not just the samples. In addition, it is necessary to assess supplier performance related to its reliability to control the existing raw materials to ensure that materials are continuously controlled. If the supplier has poor performance, and there is no improvement in each period, the company can change suppliers whenever possible. In addition, raw material checking also needs to be done. The company can choose goat skin with grade A or grade 1 to minimize occasional defects in palm and thumb.

Fifth, if lighting in the production floor was inadequate, usually the company replaced the lamp which wore out. There needs to be additional lighting on the production floor to improve the operator's vision in supervision and carrying out the production process. The lighting layout needs to be improved to maximize the existing lighting. In addition, the company also must replace the 8-watt lamps with 16-watt lamps. Without sufficient lighting, the number of defective products may increase. Additional lighting is needed in each line and on the inspection table. Thus, it can reduce the occurrence of defective products, and even defective products that are passed on and delivered.

Sixth, earplugs are needed to muffle disturbing sounds. Until now, no earplugs have been provided by the company, and this is because earplugs could become a barrier to communication. However, not all employees can adjust to field conditions with noise exposure because people have different levels of concentration. Therefore, it is necessary to have earplugs provided in each machine. Operators can use earplugs if the production floor has high noise levels, and for operators who are not exposed to noise, the earplugs do not have to be used.

Control

Control is the final stage in improving the quality of DMAIC (define, measure, analyze, improve, control). At this stage, controlling or intensive and regular supervision of the Nike Extreme production process was carried out. Check sheets were prepared as a tool for controlling to see whether the recommendations based on the project six sigma that had been designed were implemented. The check sheets were checked by the assistant manager of technical quality management (TQM). A control device that would become a supervisor's handbook before and during the production process was also designed to minimize the emergence of causes that could pose a risk of errors or defects. The cheek sheet supervisor carried out this daily control for an hour at regular intervals.

Apart from that, quality and production personnel periodically controlled the operator regarding the process production based on the recommendation action that had been designed, especially the work procedure book (covering the SOP of production process) and specification book for Nike Extreme which would later be made. This supervision should be carried out because if there were operators who did not carry out the production process correctly, they could be identified quickly, reprimanded, and given the correct directions. To minimize defects in the production process, check sheets were also prepared to control repairs to be made. After processing the checklist of ten production units, each operator signed the check sheet to ensure that no process was missed. This check sheet was designed according to the production process flow in the work procedures book.

Conclusion

From the results of the case studies conducted using the proposed Lean Six Sigma method by combining the Waste Assessment Model and Fuzzy FMEA methods, the method was quite successful, and it could provide recommendations on the problems in the production process. This model can be used as a strategy to reduce waste in small- and large-scale production processes. In addition, the findings of this study suggest that the proposed model is feasible and capable of reducing waste and controlling quality, as evidenced by the results of the model verification test. In this test the company could solve the problem correctly and found a solution according to the priority problems in the production floor. Based on the use of the Waste Assessment Model method, defective wastes were the main problem in the production process of the company. Defects had the highest percentage (23.38%) of all waste that affected or were influenced by other types of waste. This is in line with the company's statement that defects were one of the main problems in the Nike Extreme production process. In addition, the average DPMO value was 9,031, and the sigma level was 3.87 sigma in 2022, far from the company's target of 5 sigma. From the results of identifying the type of defect, broken-down was the most dominant type of defect with 14.02% of the total defects in Nike Extreme products. Based on the computational results using the Fuzzy Failure Mode and Effect Analyze (FFMEA), the most dominant cause of defects in the Nike Extreme production process was a process error or missed process, with an FRPN value of 612.96, which was in the High (H)-Very High (VH) category. In addition, there are six recommendations for improving the quality control system for Nike Extreme products.

Based on the results of the research, a priority type of waste was found, namely defects. However, this model may not be complete if it has to take other types of priority waste into account. Future research could make a waste assessment model that can be used for more types of waste as the industry develops. This model could also be used in other case studies, for example the case of defects in companies, not manufacturers. In addition, further research is also needed to study the quality costs of preventing defects.

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