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Analysis of the Defect Level of Paving Stone DC 06 Products Using Six Sigma and FMEA Methods at PT. Duta Beton Mandiri Pasuruan

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ABSTRACT

The rapid development of the industry requires companies to improve the quality of products to maintain competitiveness. PT. Duta Beton Mandiri Pasuruan faces the problem of the high defect rate of DC 06 paving stone products, reaching 30.75% in March 2020, which has an impact on financial losses and customer satisfaction. This study aims to identify the type and cause of defects, calculate sigma levels, and provide recommendations for improvement using Six Sigma and FMEA methods. A quantitative approach is used to calculate DPMO and sigma levels, while a qualitative approach is applied to analyze the causes of defects through observation and interviews. The results showed a sigma level value of 2.52 and a DPMO of 178,827, indicating low process performance. FMEA analysis identified gopel defects as the main problem with the highest RPN (245). Improvement recommendations include employee training, machine calibration, material supervision, and SOP refinement. The implementation of this proposal is expected to reduce the defect rate and increase production efficiency. This research makes a practical contribution to the application of Six Sigma and FMEA for quality improvement in the manufacturing industry

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1. Introduction

The rapid development of the industry requires companies to continue to increase their competitiveness in order to survive in global competition. One of the key factors that determine the success of a company is the ability to produce quality products, as this has a direct impact on profits and customer satisfaction. In a competitive business environment, quality improvement is not only a strategy, but a must to maintain the company's existence (Kifta & Munzir, 2018). However, the issue of product defects is still a serious challenge for many industries. Defective products not only lead to wasted costs, but also have the potential to cause customer complaints as well as significant financial losses for the company (Puspitasari & Martanto, 2014).

One of the companies that faces this problem is PT. Duta Beton Mandiri Pasuruan, a manufacturing company that produces a variety of concrete products, including paving stone. Initially focusing on the production of light bricks (baconcon), the company later expanded by adding product lines such as concrete fences (precast), paving stone, castin, and bricks. Even though the production system has been running well, PT. Duta Beton Mandiri still faces obstacles in quality control, especially in DC 06 paving stone products.

Table 1. Paving Stone DC 06 Defect Data in March 2020

Observation to-	Production Quantity	Number of Samples	Number of Defects
1	27936	100	27
2	27600	100	30
3	24240	100	31
4	26028	100	28
5	27488	100	30
6	26088	100	34
7	27888	100	33
8	26148	100	28
9	23952	100	33
10	26424	100	29
11	27681	100	30
12	18588	100	36
Sum		**1.200**	**369**

Source: PT. Beton Mandiri Ambassador

Based on observations, a number of defective products were found in the storage section, which indicates a problem in the production process. Production data in March 2020 showed that the defect rate in paving stone DC 06 was 369 out of 1,200 samples inspected as many as 1,200 paving DC 06, or defective products were found to be 30.75% of the total samples examined. This figure is relatively high and has the potential to reduce the company's profits and reputation. Therefore, an in-depth analysis is needed to identify the root of the problem and formulate a solution to the problem.

One approach that can be used to analyze and reduce product defects is to combine Six Sigma and FMEA (Failure Mode and Effect Analysis) methods. Six Sigma is a quality improvement methodology that focuses on reducing process variations to achieve a very low defect rate, which is a maximum of 3.4 DPMO (Defects Per Million Opportunities) (Gaspersz, 2002). Meanwhile, FMEA is a systematic technique to identify potential failures, causes, and impacts, so that preventive measures can be taken (Syauqi & Susanty, 2016).

This study aims to identify the types and causes of defects in DC 06 paving stone products at PT. Duta Beton Mandiri, calculates the company's level sigma value to assess the performance of the production process, and provides recommendations for improvements based on FMEA and Six Sigma methods to reduce the level of product defects. Thus, this research is expected to make a real contribution in improving the quality of production and operational efficiency of PT. Ambassador of Beton Mandiri Pasuruan.

2. Literature Review

Defective Products

Defective products are defined as products that do not meet established quality standards, both in terms of technical specifications, functions, and aesthetics. Product defects can be classified into two main types, namely attribute defects and variable defects. Attribute defects refer to qualitatively measured product nonconformities, such as cracking, breakage, or uneven color, which are typically judged based on "good" or "bad" criteria. Meanwhile, variable defects relate to quantitative deviations from specified specifications, such as dimensions, weight, or material strength that does not meet tolerances (Selvamuthu & Das, 2018) (Goetsch & Davis, 2016) (Pyzdek & Keller, 2014)

Quality

Quality is a multidimensional concept that includes product suitability to customer needs, durability, reliability, and consistency. In the context of manufacturing, quality is not only focused on the final product, but also on an efficient production process and minimal defects. According to , quality can be achieved through three main approaches, namely: (Garvin, 1987) (Wahyuni & Sulistiyowati, 2020) Prihandoko et al (2020)

a. Quality planning
b. Quality control
c. Quality improvement

Six Sigma

Six Sigma is a quality improvement methodology that focuses on reducing process variations and defects through a data-driven approach. This method uses the DMAIC (Define, Measure, Analyze, Improve, Control) framework to identify and resolve quality issues. The main goal of Six Sigma is to achieve a process performance level with only 3.4 defects per million opportunities (DPMO), which is equivalent to sigma level 6 (Gaspersz, 2002) (Ekoanindiyo, 2014) (Pyzdek & Keller, 2014)

Failure Mode and Effect Analysis (FMEA)

FMEA is a risk analysis technique used to identify potential product or process failures, along with their causes and impacts. This method involves three main components: (Budiarto, 2017)

a. Severity – the level of impact of failure,
b. Occurrence – how often failures occur, and
c. Detection – the ability to detect failures before they reach customers.

By calculating the Risk Priority Number (RPN), companies can prioritize corrective actions in the most critical areas (Sugiantara & Basuki, 2019)

3. Methodology

Research Location

This research was conducted at PT. Duta Beton Mandiri which is located in Sawur Hamlet, Pucangsari Village, Purwosari District, Pasuruan Regency, with a focus on the DC 06 paving stone production department.

Types of Research

This study uses a case study approach with a combination of quantitative and qualitative methods. A quantitative approach is applied to calculate the degree of disability and sigma level, while a qualitative approach is used to identify the cause of disability through in-depth interviews and field observations. Research data was obtained from two main sources. Primary data is collected through direct observation of the production process, interviews with the head of *Quality Control* and production operators, and documentation of defective products. Secondary data were obtained from monthly production reports and literature reviews related to quality management, Six Sigma, and FMEA.

Data Processing

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Data processing is carried out by applying the Six Sigma methodology through the DMAIC (*Define, Measure, Analyze, Improve, Control*) and FMEA approaches.

a. Define, namely by determining *the Critical-to-Quality* (CTQ) of the product
b. Measure, namely the calculation of *Defect Per Million Opportunities* (DPMO) and Sigma Level.
   The formula used to find DPMO is as follows:

$$DPMO = \frac{Jumlah\ cacat}{Jumlah\ yang\ diperiksa\ x\ CTQ}\ x\ 1.000.000$$

   DPMO = *Defect per million Opportunities*
   CTQ = *Critical to Quality*
   The formula used to calculate the sigma level is as follows:

$$Sigma\ Level = NORMASINV = \frac{1.000.000 - DPMO}{1.000.000} + 1,5$$

c. Analyze, At this stage the FMEA method is used to determine the priority cause of the defect that occurs. In addition, at this stage also use the Pareto Chart and Fishbone Diagram to find the root of the problem.
d. Improve, namely by producing improvement solutions according to the results of the analysis carried out
e. Control, namely by ensuring the sustainability of improvements through the improvement of SOPs.

4. Results and Discussion

Data processing in the research uses stages (Define, Measure, Analyze, Improve and Control) with the following steps:

1. Define

At this stage, the purpose of improvement is determined, in the form of CTQ identification according to the company's standard specifications. The following is a table of the types of defects, attributes and variables of the DC 06 paving stone product along with the description of each defect:

Table 2. Data on the type of defect paving stone DC 06

Variable Defects	Thickness	Swollen paving conditions, so the thickness is not the same
Attribute Defects	Gopel	The condition of the paving on the sides or ends of the paving
	Crack	The condition of the paving that is cracked so that it cannot be sold
	Porous	Porous paving condition so that it is easily damaged and broken

Defects of DC 06 paving stone products are categorized into 4 types:
C1 = Gopel
C2 = Crack
C3 = Keropos
C4 = Thickness

Table 3. DC paving stone defect data March 06, 2020

Observation to-	Production Quantity	Number of Samples	Types of Defects				Number of Defects	Percentage Disabled
			C4	C1	C2	C3		
1	27936	100	6	7	10	4	27	0,270
2	27600	100	6	11	7	6	30	0,300
3	24240	100	4	13	8	6	31	0,310

Observation to-	Production Quantity	Number of Samples	Types of Defects				Number of Defects	Percentage Disabled
			C4	C1	C2	C3		
4	26028	100	5	11	8	4	28	0,280
5	27488	100	5	11	9	5	30	0,300
6	26088	100	7	12	10	5	34	0,340
7	27888	100	5	11	10	7	33	0,330
8	26148	100	4	13	6	5	28	0,280
9	23952	100	6	9	11	7	33	0,330
10	26424	100	4	12	8	5	29	0,290
11	27681	100	5	10	8	7	30	0,300
12	18588	100	7	12	9	8	36	0,360
Total	**310061**	**1200**	**64**	**132**	**104**	**69**	**369**	**0,3075**
			64	**305**				

Source: Data processing results

Table 4. Variable defect data of paving stone DC 06 March 2020

Observation to-	Sample (size in cm)					Total
	X1	X2	X3	X4	X5	
1	6.00	5.75	6.00	5.90	6.00	29,75
2	5.85	5.80	6.00	6.05	6.00	29,70
3	6.10	6.00	5.95	6.00	6.05	30,10
4	6.10	6.10	6.15	6.10	6.00	30,45
5	6.15	6.00	5.90	6.00	6.05	30,10
6	5.90	6.00	6.05	6.10	6.00	30,05
7	6.20	5.90	6.00	6.10	6.00	30,20
8	6.00	6.05	5.85	5.95	6.05	29,90
9	5.95	6.00	6.05	6.00	5.95	29,95
10	6.00	6.15	5.90	6.05	6.05	30,15
11	6.10	6.00	6.05	5.95	6.00	30,10
12	6.05	5.95	6.00	5.95	6.05	30,00

2. Measure

In the second stage, the calculation of Defect Per Million Opportunities (DPMO) and Sigma Level was carried out.

a. Data sufficiency test for variable defects

Table 5. DC 06 paving stone thickness data

Observation to-	Sample (size in cm)					∑X	Sample (size in cm)					∑X2
	X1	X2	X3	X4	X5		X12	X22	X32	X42	X52	
1	6,1	5,75	6	5,9	6	29,75	37,21	33,0625	36	34,81	36	177,0825
2	5,85	5,8	6	6,05	6	29,7	34,2225	33,64	36	36,6025	36	176,465
3	6,1	6	5,95	6	6,05	30,1	37,21	36	35,4025	36	36,6025	181,215
4	6,1	6,1	6,15	6,1	6	30,45	37,21	37,21	37,8225	37,21	36	185,4525
5	6,15	6	5,9	6	6,05	30,1	37,8225	36	34,81	36	36,6025	181,235

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Observation to-	Sample (size in cm)					∑X	Sample (size in cm)					∑X2
	X1	X2	X3	X4	X5		X12	X22	X32	X42	X52	
6	5,9	6	6,05	6,1	6	30,05	34,81	36	36,6025	37,21	36	180,6225
7	6,2	5,9	6	6,1	6	30,2	38,44	34,81	36	37,21	36	182,46
8	6	6,05	5,85	5,95	6,05	29,9	36	36,6025	34,2225	35,4025	36,6025	178,83
9	5,95	6	6,05	6	5,95	29,95	35,4025	36	36,6025	36	35,4025	179,4075
10	6	6,15	5,9	6,05	6,05	30,15	36	37,8225	34,81	36,6025	36,6025	181,8375
11	6,1	6	6,05	5,95	6	30,1	37,21	36	36,6025	35,4025	36	181,215
12	6,05	5,95	6	5,95	6,05	30	36,6025	35,4025	36	35,4025	36,6025	180,01
Sum							**360,45**					**2165,833**
Average							**30,0375**					**180,486**

N = 60
∑X = 360.45
∑X2 = 129924.2
K = 2
S = 0.05

$$N' = \left[\frac{\frac{k}{s}\sqrt{N(\Sigma X)-(\Sigma X)}}{\Sigma X}\right]^2$$

$$N' = \left[\frac{\frac{2}{0,05}\sqrt{60(2165,833)-(360,45)}}{360,45}\right]^2$$

N' = 0.72

Because of the value of N' < N, the collection of observation data for the height of the paving stone DC 06 as the high variable defect data is considered sufficient.

b. X and R Control Chart

The creation of the X control map and the P control map is used for variable defect data while the P control map is for attribute defect data. According to the product specifications of paving stone DC type A is 5.70 – 6.10 (cm), then:

- Control map X chart

  Mean / X Bar (CL) = 6

  In the table of factor A2 in the sub group or sample size n = 5 a value of 0.577 is obtained, then:

  UCL/BKA = X Bar + A2. R
  = 6 + 0.577 (0.2)
  = 6.1154

  LCL/BKB = X Bar – A2. R
  = 6 – 0.577 (0.2)
  = 5.9

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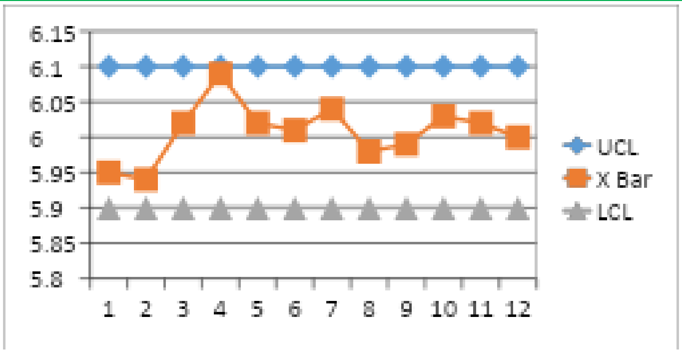

Figure 1. Variable defect X control map

- For R Chart control map

  Mean/ R (CL) = 0.2

  In the table of factor D4 in the sub group or sample size n = 5 the value of 2.114 is obtained and in the table of factor D3 in the sub group or sample size n = 5 the value of 0 is obtained, then:

  UCL/BKA = D4. R
  = 2.114 (0.2)
  = 0.4228

  LCL/BKB = D3. R
  = 0 (0.2) = 0

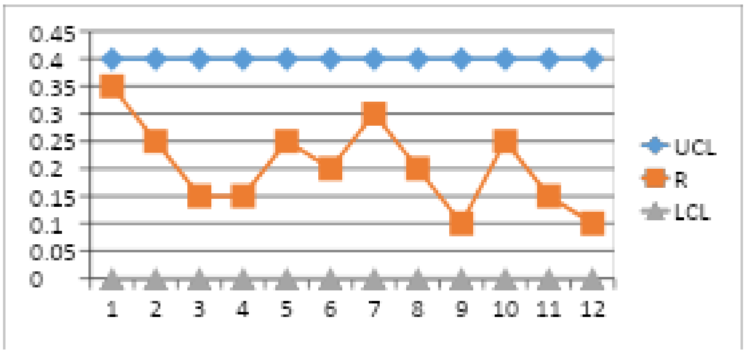

Figure 2. Variable defect R control map

c. Control Map P

Table 6. Control map P

Obbservasike-	Production Quantity	QuantitySample	Types of defects		∑P	P
			C1	C2		
1	27936	100	7	10	17	0,17
2	27600	100	11	7	18	0,18
3	24240	100	13	8	21	0,21
4	26028	100	11	8	19	0,19
5	27488	100	11	9	20	0,2
6	26088	100	12	10	22	0,22
7	27888	100	11	10	21	0,21
8	26148	100	13	6	19	0,19
9	23952	100	9	11	20	0,2
10	26424	100	12	8	20	0,2
11	27681	100	10	8	18	0,18
12	18588	100	12	9	21	0,21
Sum		1200	132	104	236	2,36

The calculation is as follows:

P $= = 0.197 = 0.2 \frac{236}{1200}$

UCL $= \overline{P} + 3\sqrt{\frac{\overline{P}(1-\overline{P})}{n}}$

UCL $= 0,2 + 3\sqrt{\frac{0,2(1-0,2)}{12}}$

UCL $= 0.5$

UCL $= \overline{P} - 3\sqrt{\frac{\overline{P}(1-\overline{P})}{n}}$

UCL $= 0,2 - 3\sqrt{\frac{0,2(1-0,2)}{12}}$

UCL = -0.142

Since the number of samples examined is the same, the UCL and LCL values are the same according to n per day. The results of the calculation of UCL and LCL values for attribute defects can be seen in the figure below:

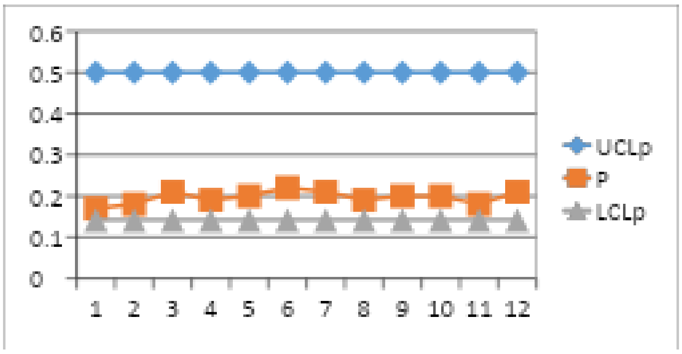

Figure 3. Attribute-defect P control map

d. Calculation of DPMO and Sigma Level Values

- Variable Defects

For the calculation of standard deviation (using the formula SD = R/d2, where for d2 is the coefficient for estimating the standard deviation, for n = 5, then d2 = 2.326. For the calculation of the DPMO value, it can be searched with the help of the Microsoft Excel program using the formula:

=1000000normsdist((USLXbar)/S)*1000000+normsdist(LSLXbar/S)*1000000,

The sigma level calculation is carried out using the help of the Microsoft Excel program using the formula:

= normsinv ((1000000 -DPMO)/1000000)+1.5

Table 7. Sigma and DPMO values of variable defect data

Observation -	Paving Thickness Data DC 06								
	∑X	X Bar	UCL	LCL	R	SD	Cp	Sigma Value	DPMO
1	29,75	5,95	6,1	5,9	0,35	0,150	0,005	2,497	159416,928
2	29,7	5,94	6,1	5,9	0,25	0,107	0,004	2,989	68291,096
3	30,1	6,02	6,1	5,9	0,15	0,064	0,002	2,741	107389,096
4	30,45	6,09	6,1	5,9	0,15	0,064	0,002	1,655	438384,380

5	30,1	6,02	6,1	5,9	0,25	0,107	0,004	2,244	228341,452
6	30,05	6,01	6,1	5,9	0,2	0,086	0,003	2,547	147618,981
7	30,2	6,04	6,1	5,9	0,3	0,129	0,004	1,965	320894,119
8	29,9	5,98	6,1	5,9	0,2	0,086	0,003	2,896	81417,491
9	29,95	5,99	6,1	5,9	0,1	0,043	0,001	4,059	5254,729
10	30,15	6,03	6,1	5,9	0,25	0,107	0,004	2,151	257432,878
11	30,1	6,02	6,1	5,9	0,15	0,064	0,002	2,741	107389,096
12	30	6	6,1	5,9	0,1	0,043	0,001	3,826	10009,275
Average								**2,692**	**160987**

- Attribute Defects

  Calculation of DPMO and sigma level values using the formula:

  DPMO = (Defect/(number of units inspected x CTQ)) x 1,000,000

Table 8. Sigma values and DPMO attribute defect data

Observation to-	Number of Samples	Number of Defects	DPMO	Sigma Value
1	100	17	170000	2,45
2	100	18	180000	2,42
3	100	21	210000	2,31
4	100	19	190000	2,38
5	100	20	200000	2,34
6	100	22	220000	2,27
7	100	21	210000	2,31
8	100	19	190000	2,38
9	100	20	200000	2,34
10	100	20	200000	2,34
11	100	18	180000	2,42
12	100	21	210000	2,31
Average			**196667**	**2,35**

- Total DMPO value and sigma value

Table 9. Total DPMO value and sigma value

Data Type	DPMO	Sigma Level
Variable Data	160987	2,69
Data Attributes	196667	2,35
Average	**178827**	**2,52**

3. Analysis

a. Analysis of the causes of defects

1) Crack

Cracks in paving occur due to several factors, especially human error and production process incompatibility. The lack of coordination between machine operators and field employees causes wet product checks to be suboptimal. Paving that is still soft should be carefully inspected, but because the process is continuous, workers often rush in manual patching, so small cracks are missed. In addition, a mixture of dough that does not comply with SOPs (e.g., improper ratio of cement, sand, and water) makes the paving brittle. Environmental factors such as unstable storage temperatures also trigger cracking due to uneven drying. If the paving is exposed to excessive heat or high humidity, the material wrinkles unevenly, aggravating cracks.

2) Gopel

Gopel occurs due to material handling errors and mechanical technical problems. When moving wet paving, employees are less careful, causing the paving edge to break or dent. In addition, printing machines that are used too often experience expansion due to heat, so that the size of the mold widens and the paving results are less symmetrical. The instability of this shape reduces the strength of the product, making it easy to break during transport or installation. Unregular machine calibration exacerbates the problem, as the size tolerance deviates further from the standard. The solution is scheduling machine maintenance and training employees in material handling.

3) Keropos

Keropos is caused by low material quality and suboptimal production processes. A mixture of cement, sand, and water that does not comply with the SOP (e.g., too much water) makes the paving hollow once it dries. Press downtime also plays a role—the reduced pressure as the machine begins to wear out causes the paving to not fully solidify. The lack of communication between the operator and the QC team resulted in porous paving passing inspection. External factors such as humid weather slow drying, while extreme temperatures trigger water evaporation too quickly, leaving pores inside the paving.

4) Thickness

The inconsistency of paving thickness is mainly affected by the pressure drop of the press machine. If the machine's compressive power is weakened (due to hydraulic faults or component wear), the dough is not compressed to the maximum, causing the paving to expand and the thickness to be uneven. Human error also plays a role during checking—employees may ignore thickness tolerances due to lack of supervision or inaccurate gauges. Long-term solutions include periodic machine pressure calibration and the use of digital measuring instruments to ensure dimensional accuracy.

b. Stages of the FMEA (Failure Mode and Effect Analysis) Method

1) Seveerity (S)

Table 10. Severity value

Potential Failure Mode	Potential Cause	Rating Severity
Deffect Attribute	Crack	6
	Gopel	5
	Keropos	7
Deffect Variable	Thickness	4

2) Occurrance (O)

Table 11. Occurrenceance Values

Potential Failure Mode	Potential Cause	Occurrence Rating
Deffect Attribute	Crack	6
	Gopel	7
	Keropos	5
Deffect Variable	Thickness	5

3) Detection (D)

Table 12. Detection value

Potential Failure Mode	Potential Cause	Detection Rating
Defect Attribute	Crack	6
	Gopel	7

	Keropos	5
Deffect Variable	Thickness	4

4) RPN (*Risk Priority Number*) Value

Table 13. RPN Value

Potential Failure Mode	Potential Cause	S	O	D	RPN
Defect Attribute	Crack	6	6	6	216
	Gopel	5	7	7	245
	Keropos	7	5	5	175
Deffect Variable	Thickness	4	5	4	80

4. Improve

Table 14. Recommended improvement proposals

Ranking	Potential Disruption	RPN	Proposed Improvements	5M
1	Gopel	245	1. Carry out supervision at the time of transportation and arrangement of newly molded paving	Human
			2. Calibrate every phase of the job	Machine
2	Crack	216	1. Provide direction to create harmonious relationships between employees in work behavior. 2. Provide training to employees on work productivity.	Human
			3. Control the dough mixing part in each printing phase	Material
			4. Create a storage area that can protect products from unpredictable weather	Milieu
3	Porous	175	1. Selecting materials that are in accordance with the company's specifications. 2. Tightening the check of materials coming out of the warehouse	Material
			3. Perform machine checks before operation 4. Perform maintenance on the machine once a week.	Machine
			5. Provide training to employees on work productivity.	Human
			6. Create a storage area that can protect the product from unpredictable weather.	Milieu
4	Thickness	80	1. Provide training to employees on work productivity	Human
			2. Checking the machine before and after operation	Machine

5. Control

In this control stage, an SOP (standard operating procedure) is made in a recommendation as a result of the proposed improvement, namely: SOP to reduce Gopel defects, including the form of paving according to the company's standard size and the paving in its entire state (no gopel or hair cracks). SOP to reduce crack defects: dough mixture according to the specifications of the company, inspection on each newly finished product, inspection on the printing machine each working phase and paving is not hollow and has great resistance. SOP to reduce porous defects: paving is not hollow and does not crumble, the mixture of dough according to the specifications of the company. SOP to reduce defects Thickness such as uniformity of size on each paving mold according to the standards of the company and pressure on the printing machine according to the standard.

5. Conclusion

Based on data in March 2020, there are four types of defects in DC 06 paving stone products, namely thickness, cracks, goples, and porous. And the biggest type of defect is in the defect of the gopel. And the factors that affect defects in DC 06 paving stone products come from human, machine, material, and environmental error. It is known that the company's level sigma value from the results of processing defective product data is 2.52, while the DPMO value on paving stone DC 06 is 178827. Based on the resulting improvement proposals, there is a need for improvement in the production process, especially in the human factor, namely the lack of communication about the work system so that work productivity is maintained so that work productivity is maintained, machine factors so that there is a need for more frequent control than usual, material factors to determine materials that are in accordance with the specifications of the company, and environmental factors, namely by making a storage place that is can protect the product from unpredictable weather.

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