Eliminating Production Process Waste with Lean Six Sigma in the Gresik Ceramic Industry

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Abstract— The Gresik Ceramic Industry is a company operating in the ceramic industry. In the ceramic production area at PT XYZ, waste is still found, namely waste defects, safety health environment (SHE), excess processing. and motion. This research aims to identify and reduce waste in the ceramic production process using the Lean six sigma (LSS) method and Failure Mode Effect and Analysis (FMEA) as proposed recommendations for improvement. Lean six sigma uses 5 stages, namely define, measure, analyze, improve, control. However, research is carried out to the improvement stage to provide recommendations for improvement. The results of reducing the lead time value in the ceramic production process, which was originally 1880 minutes, changed to 1816 minutes or decreased by 64 minutes, thereby reducing the cycle time in the ceramic production process. Then the DPMO value obtained was13311 with a sigma level of 3.71. The research results show that crack defects have the highest RPN value of 576 with the cause being that the punches on the press machine have reached their useful life, causing the printing process to be less than perfect. The proposed recommendation for improvement is replacing the punches components on the press machine

Keywords— Waste, Lean Six Sigma, Ceramics

I. INTRODUCTION

The ceramic industry produces a variety of goods, including sanitary ware, household utensils, roof tiles, and other ceramic products. The role of this industry is very important in providing domestic needs, increasing state income, and absorbing labor [1].The ceramic industry is a sector that is engaged in processing raw products in the form of clay into finished products in the form of ceramics which have high economic value [2] . Gresik ceramic factory is a company that operates in the ceramic industry sector. However, like other manufacturing industries, ceramic production often faces challenges in operations and resource management. In the ceramic production area at the Gresik ceramic factory, waste is still found occurring. First, namely waste defects, there are several types of defects identified, namely Powder Contamination (KPD), Gupil (GP), Bubble (BBL) and Cracks (RT). In the safety, health, environment (SHE) aspect, the waste that occurs includes a lack of attention to employee safety, as can be seen from the lack of differentiation between forklift and pedestrian paths, the unavailability of support belts for packing section employees, and many body prep workers are still found who do not wear footwear when working, this causes a high potential for work accidents. In the Excess Processing aspect, there is waste where the company will rework rejected products resulting from production, then these results are used in the composition of the next product at 4%. Then the next waste is in the motion aspect where workers clean up spilled powder on the spray dryer machine.

Lean Six Sigma combines the principles of Lean and Six Sigma, which are applied as a systematic approach to identifying and eliminating waste or activities that do not add value. This method focuses on significant continuous improvement, with the goal of achieving six sigma performance [3][4]. By implementing the Lean Six Sigma method, companies can improve product quality, shorten cycle times, and significantly reduce waste. Furthermore, to provide recommendations for improvement, the Failure Mode and Effect Analysis (FMEA) method is used. The Failure Mode and Effect Analysis (FMEA) approach is a method used to analyze and measure risks, as well as prioritize the highest risks that require improvement [5]. FMEA involves three main components, namely Severity, which identifies the severity of the failure impact on the operator; Occurrence, which assesses the possibility of failure during use; and Detection, which assesses the ability to detect failures before they occur [6].

Previous research regarding the elimination of waste in the production process was carried out by Rahayu et al in 2022. This research focused on the sheepskin tanning process, using the DMAIC stage and tools in the form of value stream mapping, as well as providing recommendations for improvements using FMEA [7]. Furthermore, research conducted by Fajar et al in 2023 focused on the shoe production process. This research also uses the DMAIC stages, determines critical waste using DPMO calculations, carries out analysis using fishbone diagrams, and provides recommendations for improvements using FMEA [3]. This research aims to identify and reduce waste in the ceramic production process at the Gresik ceramic factory, as well as provide recommendations for improvements using the Failure Mode and Effect Analysis (FMEA) approach. It is hoped that this research can contribute to companies by reducing waste and increasing the efficiency of the production process.

II. LITERATURE REVIEW

A. Lean

Lean is an approach applied in running an organization by supporting the concept of continuous improvement. This approach focuses on eliminating all things that are considered not to provide added value for customers, thereby increasing operational efficiency and effectiveness [8][9]. Lean is a method commonly applied by manufacturing companies to reduce waste and activities that do not provide added value. In the production process, activities are classified into three categories: Value Added Activities, which are activities that increase the value of the product; Non-Value Added Activities, namely activities that do not add value and are considered waste that must be eliminated; and Necessary Non-value Added Activity, namely activities that do not add value but are still needed in the production process [10].

In lean, waste is classified into 9 types of waste (E-downtime). Environment Health and Safety (EHS) refers to waste resulting from a lack of attention to safety, health and the environment. Defect is waste that occurs due to product defects. Over Production refers to production that exceeds customer orders. Waiting occurs when there is a delay in the process which causes a delay in the next stage. Non-Utilizing Employees' Knowledge, Skills, and Abilities refers to waste due to employees not having the necessary skills. Transportation is waste caused by excess delivery of goods. Inventory occurs when the stock of goods exceeds requirements, causing excess storage costs. Motion is waste caused by unnecessary operator movement. Excess Processing refers to more process steps than necessary [11].

B. Six Sigma

Six Sigma has an important role as a measurement system. In accordance with the meaning of sigma, namely the distribution or spread (variation) of the average (mean) of a process, Six Sigma is applied to reduce this variation [12]. Six Sigma is a quality control method that focuses on reducing process variations to reduce production defects through the application of statistical analysis. This quality control aims to increase the efficiency of the production process, with the hope of increasing consumer satisfaction [13]. Six Sigma is a statistical concept that evaluates the quality of a process in relation to the number of defects at the six sigma level, namely only 3.4 defects out of one million opportunities [14]. Steps to reduce defects are carried out systematically through five stages: identify, measure, analyze, improve and control. This systematic process is known as the 5 phases of DMAIC [15].

C. Value stream mapping

Value Stream Mapping (VSM) is a tool in lean manufacturing that is used to understand the flow of materials and information in a process [16]. Value Stream Mapping is used to visualize the production system, from ordering raw materials to finished products ready for distribution, as well as the value flow that exists in the company [17]. Usually, VSM is used to describe two conditions: Current State and Future State. When creating a VSM for Current State, we must understand what happens in each process. There are several data that need to be known and recorded at each stage, namely Number of Workers/Operators (O), Cycle Time (C/T), Changeover Time (C/O), Operation Time/Equipment Reliability (U/T), Equipment Availability (A/E), and Defect Rate (DR) [18].

D. Fishbone

Describing problems in the form of diagrams or pictures aims to make it easier for us to understand the whole problem and identify the causal factors visually in one diagram [19]. A fishbone diagram is a visual tool used to determine, investigate, and graphically map all the causes that contribute to a problem. In creating this diagram, quality improvement tools such as brainstorming can be used [20]. One of the advantages of a fishbone diagram is its ability to detail every problem that occurs, as well as allowing all parties involved to provide suggestions that might be the cause of the problem [21].

E. FMEA

FMEA is a method used to evaluate system design by analyzing various failure modes of its components and their impact on the overall reliability of the system [22]. Identification of potential failures is carried out by assigning a value or score to each failure mode based on three factors: occurrence rate, severity and detection rate [23]. The benefits of using the FMEA method include determining priorities for each corrective action, providing complete documentation of process changes to aid future developments, and minimizing time and costs [24]

III. METHODOLOGY

The data used includes primary and secondary data. Data collection was carried out through observation, interviews, literature study and documentation. Data processing follows the Six Sigma method with the Define, Measure, Analyze, Improve and Control (DMAIC) stages [25]. However, the control stage was not carried out because this research only reached the point of providing recommendations in the company. The following are the stages and tools used:

1) *Define*

   At this stage, the ceramic production process is described using value stream mapping. Next, a questionnaire was distributed to 10 experts from production, QC and RnD to identify and give critical weight to each type of waste according to actual conditions in the production area.

2) *Measure*

   In the measure stage, Process Cycle Efficiency (PCE), Defects Per Million Opportunities (DPMO), and Six Sigma levels will be calculated. PCE measures the overall efficiency of the process, DPMO calculates the number of defects per million opportunities, and Six Sigma levels assess the ability of the process to produce defect-free products

3) *Analyze*
   At this stage, an analysis will be carried out on the activities that occur throughout the VSM and the causes of defective products will be studied using a fishbone diagram.
4) *Improve*
   At this stage, researchers provide recommendations for improvements to the factors that cause waste that arise due to failures in the production process using failure mode effect analysis.

IV. RESULT AND DISCUSSION

A. Define

At this stage, identification of ceramic production processes in terms of time and activity classification. The flow of ceramic production processes is as follows:

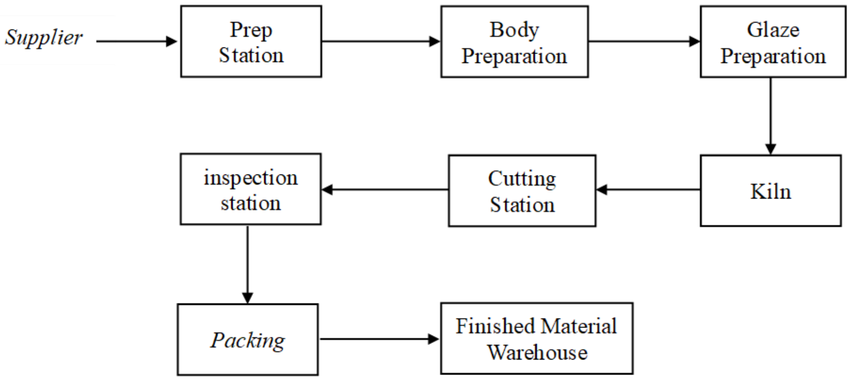


Figure 1. ceramic production process flow

In Figure 1, the ceramic production process can be known, which starts from the preparation station in the raw material warehouse then body prep, glaze prep, kiln, cutting, sorting, and packing.

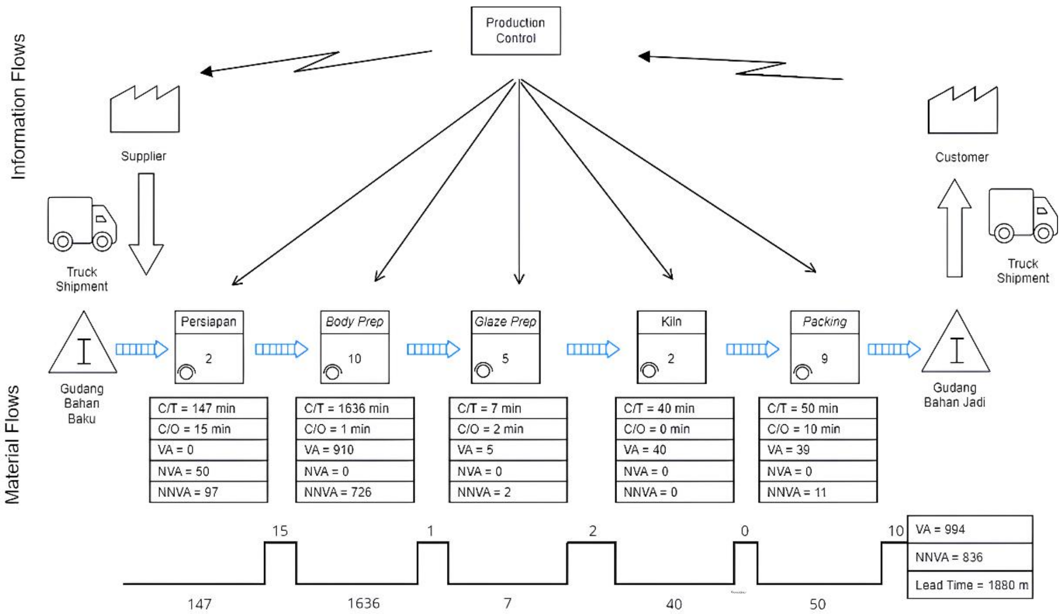


Figure 2. value stream mapping ceramic production processes

From this illustration, the total lead time is 1880 minutes, with activities that provide value added (VA) reaching 994 minutes, activities that do not provide added value but are required (non-value added/NNVA) for 836 minutes, and activities that do not provide added value (non-value added) of 50 minutes.

B. Measure

The aim of this stage is to assess the standard performance of the process in producing the product [26]. At this stage, the DPO and DPMO values are calculated, the DPMO value is converted into a sigma value, and the process capability (PCE) is measured.

1) Calculation of DPO and DPMO

Table 1. Ceramic production defect data 2023

Ceramic Production 2023						
No	**Month**	**Total Production (m^2)**	**Powder kontamination (KPD)**	**Bubble (BL)**	**crack (RT)**	**Gupil (GP)**
1	January	699634	12001	7325	6078	5767
2	February	638540	10328	8204	6429	4131
3	March	708672	10760	9523	5163	5473
4	April	664464	8755	5561	6546	5748
5	Mey	707098	10591	4427	10878	6894
6	June	514458	9276	5271	4359	6437
7	July	481008	8063	5126	10003	4517
8	August	337128	2352	444	4405	291
9	September	595130	7939	3247	6276	2336
10	October	635387	23179	9992	8830	16092
11	November	573282	15398	5284	12756	7843
12	Desember	614032	4060	5088	30478	11770
Total		7168833	122701	69492	112202	77298

Source: Data processing; unit m^2

The DPMO calculation according to table 1 is as follows:

$$DPO = \frac{Banyak\ keramik\ cacat}{banyak\ produksi\ keramik\ x\ CTQ} = \frac{381693}{7168833\ x\ 4} = 0{,}133109$$

$$DPMO = DPO\ x\ 1000000 = 0{,}133109\ x\ 1000000 = 13311$$

Because in the DPMO to sigma conversion table the value 13311 does not exist, we use interpolation :

DPMO = 13209 (X2), sigma conversion value = 3,72 (Y2)

DPMO = 13553 (X1), sigma conversion value = 3,71 (Y1)

DPMO = 13311 (X), sigma (Y) conversion value is ?

$$\frac{x-x1}{x2-x1} = \frac{y-y1}{y2-y1} \quad (1)$$

that

$$\frac{13311-13553}{13209-13553} = \frac{y-3{,}71}{3{,}72-3{,}71} \leftrightarrow \frac{-242}{-344} = \frac{y-3{,}71}{0{,}01}$$

-3,44Y + 1276,24 = -2,42

$$Y = \frac{-12788{,}66}{-344} = 3{,}717$$

So after calculating the sigma value above, the DPMO value is 13311 and the six sigma conversion value is 3.717.

2) Calculation of process cycle efficiency (PCE) values

Table 2. Classification of Ceramic Production Process Activities

No	Activity	Time (minute)	Activity Type
	Preparation station		
1	Queue of loaded trucks entering the factory	30	NVA
2	Checking documents/travel documents at the security post	10	NNVA
3	Truck weighing process	8	NNVA
4	Inspection process by Incoming QC on each truck load	35	NNVA
5	Identification of truck loads in the Raw Material Warehouse	4	NNVA
6	Queue for unloading process	20	NVA
7	Load unloading process at GBB	15	NNVA
8	Material weighing composition process	10	NNVA
9	Transfer material to Body prep	15	NNVA
	Total Time	**147**	
	Body Prep station		
10	Material Mixing Process	480	VA
11	Temporary storage process (ST Well)	20	VA
12	Slip tank inspection	10	NNVA
13	Filtering process	30	VA
14	Temporary storage process (DT Well)	20	NNVA
15	Daily Tank Inspection	10	NNVA
16	Spray Dryer Process	120	VA
17	Powder storage in powder silos	480	NNVA
18	Inspection of powder in silo	205	NNVA
19	Transfer ceramic to Glaze prep	240	VA
20	Drying process with High Dryer	20	VA
21	Transfer ceramic to Glaze prep	1	NNVA
	Total	**1636**	
	Glaze Prep station		
22	Water spray process	1	VA
23	Engobe coating process	1	VA
24	Glazing coating process	1	VA
25	Motif printing process	2	VA
26	Transfer ceramics to kiln	2	NNVA
	Total	**7**	
	Kiln		
27	Ceramic Firing Process	40	VA
	Total	**40**	
	Packing		
28	Ceramic cutting process	4	VA
29	Final inspection by QC Finish	1	NNVA
30	Packaging	35	VA
31	Delivery of finished products to the finished good warehouse	10	NNVA
	Total	**50**	
	Total Overall Time	**1880**	

The process cycle efficiency (PCE) calculation is as follows:

$$PCE = \frac{Value\ added}{lead\ time}\ x\ 100 = \frac{994}{1880}\ x\ 100\ \% = 52{,}31\ \%$$

Based on the Process Cycle Efficiency (PCE) value, the result was 52.31%, which means that the ceramic production process is still not running efficiently so improvements are needed in the production process.

3) Processing questionnaire data

A questionnaire is a data collection tool that contains a structured list of questions with various alternative answers, which allows respondents to choose the answer that best suits their views, perceptions, attitudes, circumstances or personal opinions [27]. The questionnaire consists of a list of questions related to the concept of 9 waste (E-Downtime) to evaluate waste intensity. To make things easier, answer choices are included in the questionnaire, where each answer is weighted according to the level of waste occurrence: 5 (always happens), 4 (often happens), 3 (quite often happens), 2 (rarely happens), and 1 (very rarely happens).

Table 3. Questionnaire Result Data

Waste	**Respondents**										**Total**	**weight**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
Defect	5	2	2	5	3	3	3	5	5	4	37	3,7
Excess Process	2	4	2	3	4	5	4	3	2	4	33	3,3
Motion	2	2	5	3	3	5	3	3	4	3	33	3,3
Environment, Health, Safety	3	2	3	4	3	4	3	4	2	4	32	3,2
Inventory	2	2	3	5	1	3	3	5	3	3	30	3
Non utilizing Employee	2	4	4	4	1	2	3	4	2	3	29	2,9
Waiting	1	3	3	5	3	3	3	3	2	3	29	2,9
Transportation	1	4	2	4	3	2	2	4	2	3	27	2,7
Over Production	2	3	2	4	1	2	2	4	3	3	26	2,6

C. Analyze

1) Identify waste

at the analysis stage, waste is identified in the ceramic production process using the 9 waste (E-downtime) method. The waste identified is as follows:

a) Defects occur because ceramic production results do not comply with the quality specifications determined by company standards. This usually occurs because the process does not comply with work standards, poor raw materials, and less than perfect printing and burning processes which occur because the press on the press machine has had a lifetime and the burning temperature is not well controlled.
b) Excess processing always occurs because defective products, from greentiles (raw ceramics) to finished ceramics resulting from the production process, will be reprocessed as a mixture of product composition during the next production with a composition of 4%.
c) Motion occurs when spray dryer and silo operators have to clean up spilled powder that is scattered on the production floor. Waste also occurs when packing operators have to re-unpack ceramic products that break when stacked on pallets.
d) Safety, Health, and Environment (SHE) occurs because the company does not have a safety department so that safety regulations are only limited to signs or signs attached to machines and places that are deemed to contain danger. SHE waste occurs in the packing section where the operator is not provided with a back support belt, this condition can cause injuries caused by lifting heavy goods/loads.
e) Inventory occurs when the finished material warehouse in departments A and B reaches maximum capacity, the forklift operator must move the finished product to department C.
f) Non-Utilizing Employee occurs because there are still many employees who ignore safety when working, such as not using footwear and masks during body prep.
g) Waiting occurs when trucks entering the factory have to take turns because the factory layout does not allow trucks to go in both directions.
h) Transportation occurs because the company uses a less efficient transportation fleet because forklifts and loaders emit black smoke when lifting heavy loads.
i) Over Production there is no waste in this type because the amount of chemical production runs based on orders from customers.

2) Pareto diagram

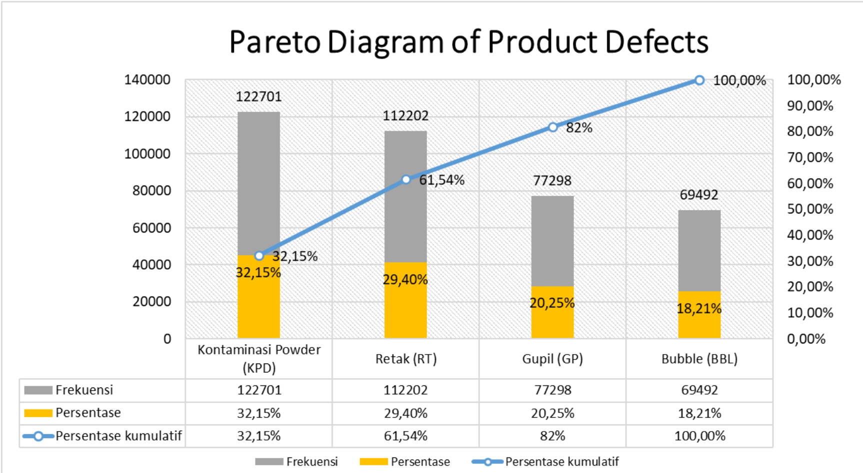
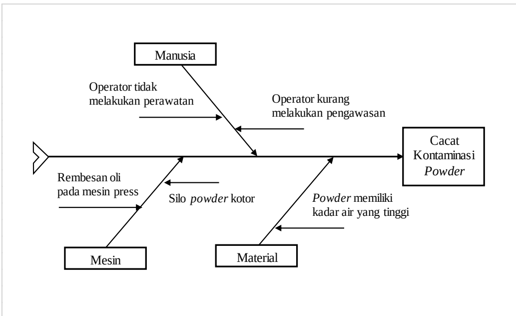


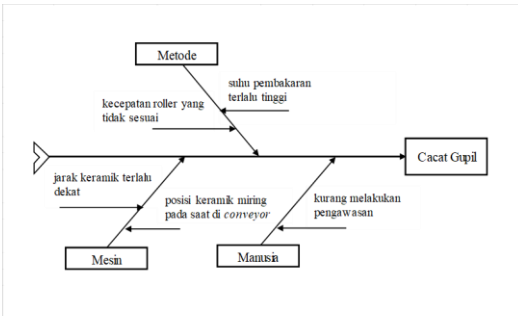
Figure 3. Pareto Diagram

From the Pareto diagram, it can be seen that the highest order of defect types is powder contamination defects (KPD) at 32.15%, crack defects (RT) at 29.40%, gupil defects (GP) at 20.25%, and bubble defects (BBL) of 18.21%.

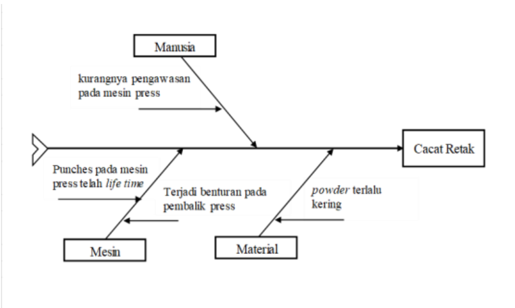
3) Fishbone diagram



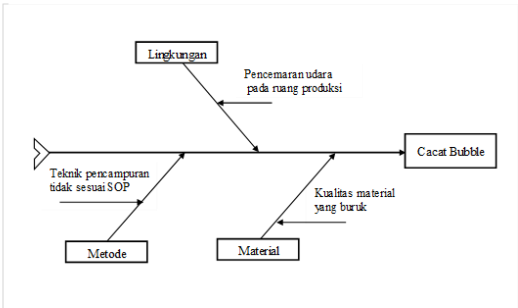
a. fishbone diagram Powder contamination (KPD)



b. gupil fishbone diagram (GP)



c. Fractured fishbone diagram (RT)



d. Bubble Fishbone Diagram (BBL) (BBL)

Figure 4. Fishbone Diagram

In figure 4.a. There is a powder contamination defect (KPD) with the main cause being oil seepage in the press machine, this causes the ceramic to crack when fired. Then in figure 4.b. there are crack defects (RT) with the main cause being the punches on the press machine which have reached their useful life, this causes the printing process to be imperfect and causes cracks in the ceramic. In figure 4.c. there is a gupill defect (GP) with the main cause being the inappropriate roller speed which results in a collision between the ceramics and causes gupil on the product. In figure 4.d. there is a bubble defect with the main cause being a defect in the mixing technique that does not comply with the SOP so that there are bubbles in the glazing and engobe.

D. Improve

1) Proposed value stream mapping

Table 4. Proposed Classification of ceramic production process activities

No	Activity	Time (minute)	Activity Type
	Preparation station		
1	Checking documents/travel documents at the security post	10	NNVA
2	Truck weighing process	8	NNVA
3	Inspection process by Incoming QC on each truck load	35	NNVA
4	Load unloading process at GBB	15	NNVA
5	Material weighing composition process	10	NNVA
6	Transfer material to Body prep	15	NNVA
	Total Time	**93**	
	Body Prep Station		
7	Material Mixing Process	480	VA
8	Temporary storage process (ST Well)	20	VA
9	Slip tank inspection	10	NNVA
10	Filtering process	30	VA
11	Temporary storage process (DT Well)	20	NNVA
12	Spray Dryer Process	120	VA
13	Powder storage in powder silos	480	NNVA
14	Inspection of powder in silo	205	NNVA
15	Transfer ceramic to Glaze prep	240	VA
16	Drying process with High Dryer	20	VA
17	Transfer ceramic to Glaze prep	1	NNVA
	Total	**1626**	
	Glaze Prep Station		
18	Water spray process	1	VA
19	Engobe coating process	1	VA
20	Glazing coating process	1	VA
21	Motif printing process	2	VA
22	Transfer ceramics to kiln	2	NNVA
	Total	**7**	
	Kiln		
23	Ceramic Firing Process	40	VA
	Total	**40**	
	Packing		
24	Ceramic cutting process	4	VA
25	Final inspection by QC Finish	1	NNVA
26	Packaging	35	VA
27	Delivery of finished products to the finished good warehouse	10	NNVA
	Total	**50**	
	Total Overall Time	**1816**	

From table 4, it can be seen that after processing the data using the lean six sigma approach, the lead time value for ceramic production was obtained which was faster than before. The lead time for ceramic production was initially identified as 1880 minutes, then identified again as 1816 minutes. So the value for the percentage increase in efficiency in the ceramic production process can be described as follows:

$$\%\text{Enhancement} = \frac{Initial\ Lead\ time - Proposed\ Lead\ time}{Initial\ lead\ time}\ x\ 100\ \% = \frac{1880-1820}{1880}\ \text{X}\ 100\ \% = 3{,}40\ \%$$

Based on the calculation of the percentage increase in efficiency, the result was 3.19%. So that the proposed Process Cycle Efficiency (PCE) value can be determined using the following formula:

$$PCE = \frac{Value\ added}{lead\ time}\ x\ 100\ \% = \frac{994}{1816}\ x\ 100\ \% = 54{,}73\ \%$$

Based on the proposed Process Cycle Efficiency (PCE) value, the results obtained were 54.73%, which means that the ceramic production process has increased.

2) Failure mode effect analysis (FMEA)

Risk Priority Number (RPN) is a relative indicator of risk level. RPN is calculated by multiplying the Severity, Occurrence, and Detection values [28]. The following is the formula used to calculate the RPN value

Table 5. Failure mode effect analysis (FMEA)

Potential Failure Mode	***Potential Effect of Failure***	**S**	***Potrential Cause***	**O**	***Current Control***	**D**	**RPN**
Powder Contamination (KPD)	The ceramic body cracks which can reduce the aesthetic value of the product, the strength and hardness of the ceramic	6	Operator does not perform maintenance	7	Create a routine maintenance schedule	5	210
			Oil seepage on press machine	9	Replacing the seal on the press machine	9	486
			Dirty powder silo	6	Carry out regular silo cleaning	7	252
			Powder has a high water content	4	Carry out inspections before press	6	144
Crack (RT)	Cracks in ceramics can reduce their resistance to pressure or other mechanical forces	8	lack of supervision on the press machine	6	Provide training to press machine operators	5	240
			The punch on the press machine has a life time	9	Replacing punches components on press machines	8	576
			There was an impact on the press turner	6	Recalibrate the machine	8	384
			Powder is too dry	4	Carrying out inspections on powder silos	5	160
Gupil (GP)	lack of oversight in the production process, which can harm brand reputation and customer trust.	8	Inappropriate roller speed	8	Recalibrate the speed of each roller	8	512
			The combustion temperature is too high	6	Monitor kiln temperature	7	336
			The ceramic distance is too close	7	Recalibrate the proximity sensor	8	448
			The position of the ceramic is tilted when on the conveyor	7	Adjusting the ceramic barrier to the conveyor	5	280
			Lack of supervision	6	Make a regular inspection schedule	4	192
Bubble (BBL)	Bubbles on the ceramic surface which affect the beauty and aesthetic value of the product	5	Pencemaran udara pada ruang produksi	4	Install the nets in the glaze prep area	6	120
			Operators work not according to SOP	7	Provide operator training	7	245
			Poor quality of materials	5	Carry out inspections upon arrival of materials	7	175

The results of the RPN calculation in table 7 show that the 3 highest orders come from crack defects (RT), gupil (GP), and powder contamination (KPD). The first sequence is from a crack defect with an RPN value of 576 with the cause being that the punches on the press machine have reached their useful life, causing the printing process to be less than perfect. The proposed recommendation for improvement is replacing the punches components on the press machine. Then in second place, namely from the gupil defect with an RPN value of 512 with the cause being the inappropriate roller speed which causes the ceramics to collide, the proposed recommendation for improvement is recalibrating the speed of each roller. Then in third place, namely from powder contamination defects with an RPN value of 486 with the cause being oil seepage in the press machine, the proposed recommendation for improvement is replacing the seal on the press machine.

V. CONCLUSION

Based on the results of the analysis and discussion, there is a reduction in the value of lead time for waste of non-value-added defects in the ceramic production process, which was initially 1880 minutes, which can be achieved by reducing activities that cause delays. Thus, the proposed lead time is 1816 minutes, reduced by 64 minutes, thereby reducing cycle time in the ceramic production process. The DPMO value obtained is 13311 with a sigma level of 3.71.

Proposed improvements to reduce the level of waste through the help of Failure Mode and Effect Analysis (FMEA), obtained the highest Risk Priority Number (RPN) value of 576 with the cause being that the punches on the press machine have had their life time, the recommendation for improvement given is replacing the punches components on the press machine. Then for the second highest RPN value of 512 with the cause of the roller speed being inappropriate, the recommendation given is to recalibrate the speed of each roller. Then for the second highest Risk Priority Number (RPN) value of 486 with the cause of oil seepage in the press machine, the recommendation for improvement is replacing the seal on the press machine.

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