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Waste Analysis of Sugar Production Process Using Lean Six Sigma Method

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ABSTRACT

The Sugar factory is a manufacturing company that produces sugar. The product produced is Super High Sugar (SHS) white crystal sugar. In the production process, there are still several problems that occur in the form of waste including product defects, excess storage, delay, and other problems that cause a very long lead time of 1410 minutes or equivalent to 23.5 hours. This study aims to determine the type of waste that occurs through the calculation of Defect Per Million Opportunity (DPMO) and sigma level and provide suggestions for improvement. The results showed that the biggest waste occurred in defects, waiting, and unnecessary inventory with a waste weight of 3.0; 2.9; and 2.5, respectively. The DPMO value is 55188 and the sigma level is 3.096. The Failure Mode Effect and Analysis (FMEA) method and Risk Priority Number (RPN) value were applied to analyze the causes of waste and provide suggestions for improvement. Recommendations for the company are to carry out routine machine maintenance and control raw materials before entering the production process. This research contributes other solutions to help management overcome waste during the production process.

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1. INTRODUCTION

Waste can disrupt the flow of the production process which can result in decreased company performance. In addition, the quality of the products produced must follow market demands and certain standards that have been applied by the company Wibowo (2021). Sugar Factory is a manufacturing company that produces white crystal sugar. The product produced is SHS (Super High Sugar) sugar. The process of processing sugar cane into white crystal sugar through a neutral sulfitation process which will produce White Crystal Sugar (GKP) type 2. In 2022 the machine section experienced a delay of about 3 hours due to waiting for the supply of supporting raw materials. In 2022 production lead time reached 1410 minutes or equivalent to 23.5 hours. Based on the observation data obtained, it shows that there are still products that do not meet the predetermined requirements. The number of unqualified products during the 2022 milling or cooking production period is 5% of the total production of 21,677.2 tons. The failed products are then re-processed (recycled). This requires multiple costs, including packing costs, storage costs, re-processing costs, and re-processing time. Excess storage, where there is a buildup of finished products in the warehouse because they have not been taken by the customer. There is unnecessary motion or non-value-added movement such as recording production data in one day manually and then entering it into the computer. the goal is to eliminate the waste generated, so in this study the method to be used is the Lean Six Sigma method. Gaspersz (2017) explains Lean Six Sigma is a quality control method that is a combination of Lean and Six Sigma which can be defined as a business philosophy, a systemic and systematic approach to identifying and eliminating non-value-added activities through radical continuous improvement to achieve a six sigma performance level. To provide suggestions for improvement, the Failure Mode Effect and Analysis (FMEA) approach is used to determine the level of failure and the impact that may occur in a product or production process. It is expected that using the Lean Six Sigma method can analyze waste in the sugar production process and can provide suggestions for improvement to overcome problems in the company's production process. This study aims to determine the type of waste that occurs through the calculation of Defect Per Million Opportunity (DPMO) and sigma level and provide suggestions for improvement.

2. LITERATURE REVIEW

2.1 Lean Six Sigma

Lean can be defined as an approach to identify and eliminate waste, or non-value-added activities in an operation (for services), which is directly related to the customer Gasperz (2007). Lean focuses on continuously improving customer value through the identification and elimination of non-value-added activities that constitute waste. Waste is any work activity that does not provide added value in the process of transforming inputs into outputs along the value stream. Lean manufacturing is a process management philosophy derived from the Toyota Production System (TPS), which is famous for emphasizing the elimination of seven wastes to increase overall customer satisfaction Nani (2018). The lean concept is a streamlining or efficiency concept that can be applied to manufacturing and service companies. Efficiency efforts can be made by minimizing non-value-added activities called waste. Therefore, an approach is needed to eliminate waste that occurs, one of which is the lean manufacturing approach (Setiawan, 2021). Six Sigma is a method for improving quality towards a target of 3.4 failures per million opportunities (Defect Per Million Opportunities-DPMO) for each product transaction (goods or services) or an enterprising effort towards perfection (zero-zero defect failure). Six Sigma is a metric that can be translated as a measurement process using statistical tools and techniques to reduce defects to more than 3.4 DPMO (Defect per Million Opportunities) or 99.99966 percent, focused on achieving customer satisfaction. Six Sigma is a disciplined approach based on five stages, namely define, measure, analyze, improve, and control.

According to Huer et. al (2008) in the journal Wicaksono et al. (2017) the integration of 2 functional and complex approaches, namely Lean and Six Sigma, offers experts and practitioners to provide alternative solutions and eliminate products in the process of improving product quality. Lean Six Sigma is a combination of lean and six sigma defined as a business philosophy, a systematic and systemic approach to identifying and eliminating waste or non-value-added activities through continuous improvement to achieve a Six Sigma performance level. This method is carried out with the DMAIC stage by using several analytical tools such as Process Activity Mapping (PAM) and value stream mapping to identify waste. Kemudian diagram ishikawa dan Failure Mode Effect and Analysis (FMEA). The lean method is defined as a systemic and sequential approach designed in the process of solving waste-oriented problems with the main goal of simplifying the process flow Sanny, et.al (2015). The principle of Lean Six Sigma is that all activities that cause critical-to-quality to consumers and things that cause long waste delays in each process are excellent opportunities or opportunities to make improvements and improvements in terms of cost, quality, capital, and lead time.

3. RESEARCH METHOD

This study uses Lean and Six Sigma methods by integrating the two to analyze waste in the sugar production process. The total activities in the sugar production process are 80 activities with a lead time of 1410 minutes or 23.5 hours. Lean Six Sigma method can help determine the cause of product defects that require rework and additional cycle time during production. This research uses the comparison of cycle time on each activity in the sugar production process by measuring value-added activities (VA), non-value-added activities (NVA), and necessary but not value-added activities (NNVA). After all activities are measured, it can be seen that the value of lead time in the sugar production process is a long cycle.

The method used in this research was conducted non-experimentally using the data provided. The data used are secondary data derived from company data and primary data from questionnaires that have been distributed. Problem-solving using the Lean Six Sigma model, namely DMAIC (define, measure, analyze, improve, control). The control stage is not done, only limited to providing suggestions for improvements to the company to increase the productivity of the sugar production process.

Furthermore, analysis is carried out to answer the research objectives, and then draw conclusions and suggestions. Value Stream Mapping is used to find out in detail the activities that include Value-Added (VA), Non-Value-Added (NVA), and necessary but Non-Value-Added (NNVA). This map can identify waste in the value stream and optimize the process to be more efficient and effective by simplification, combination, or elimination. The purpose of this mapping is to help understand the process flow, and identify waste, identify whether a process can be reorganized to be more efficient, identify value-added flow improvements.

Big picture mapping is a tool used to describe the whole along with the value stream in the company. Big picture mapping, it is possible to find out the physical flow of information in the system and the implementation time of each process. The data comes from the results of interviews with officers and field observations (Pradana et.al., 2018). Womack & Jones (2003) stated that the value stream is a collection of several activities used to create a product (goods and/or services) through three critical management tasks, namely problem-solving tasks, information management tasks, and physical transformation tasks. Process capability shows the uniformity of a process, by measuring the level of CTQ variability of the process. Process capability is used to determine DPMO (Defects Per Million Opportunities).

$$DPO = \frac{number\ of\ defective\ units}{number\ of\ defective\ units \times CTQ} \text{ .... (1)}$$

$$DPMO = \frac{number\ of\ defective\ units}{number\ of\ defective\ units \times CTQ} \times 1000000 \text{.. (2)}$$

According to Hines & Rich (1997) in principle, the value stream analysis tool is used as a tool to map in detail the value (value stream) which focuses on the value adding process. The VALSAT rating scale is, H is a multiplier factor of 9, M is a multiplier of 3, and L is a multiplier of 1. According to Wirawati (2020) Failure Mode and Effect Analysis (FMEA) is a structured procedure to identify and prevent as many failure modes as possible

$$RPN = S \times O \times D \text{ .... (3)}$$

Fig. 1, shows the flow of the research problem solving process.

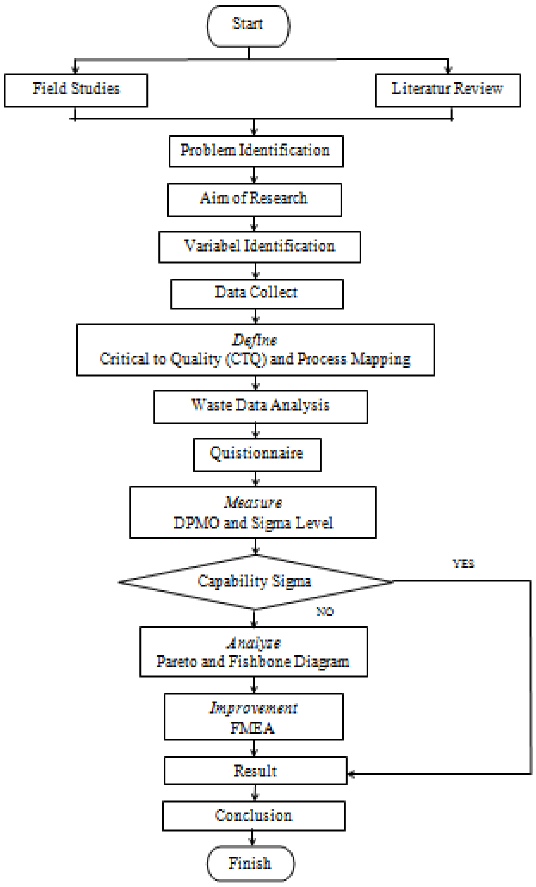

Fig. 1. Research flow process
Source: data processing

4. RESULT AND DISCUSSION

The initial stage is to identify the problems that occur in the sugar production process. Identification is done by describing the main process map which is divided into an information flow map and a physical flow map through big picture mapping. The drawing is done by identifying each material and physical flow of sugar production activities, then a table is made to distinguish value-added activities, namely operations, non-value-added necessary activities, namely inspection, and transportation, while non-value-added activities are waiting and delay activities that must be reduced.

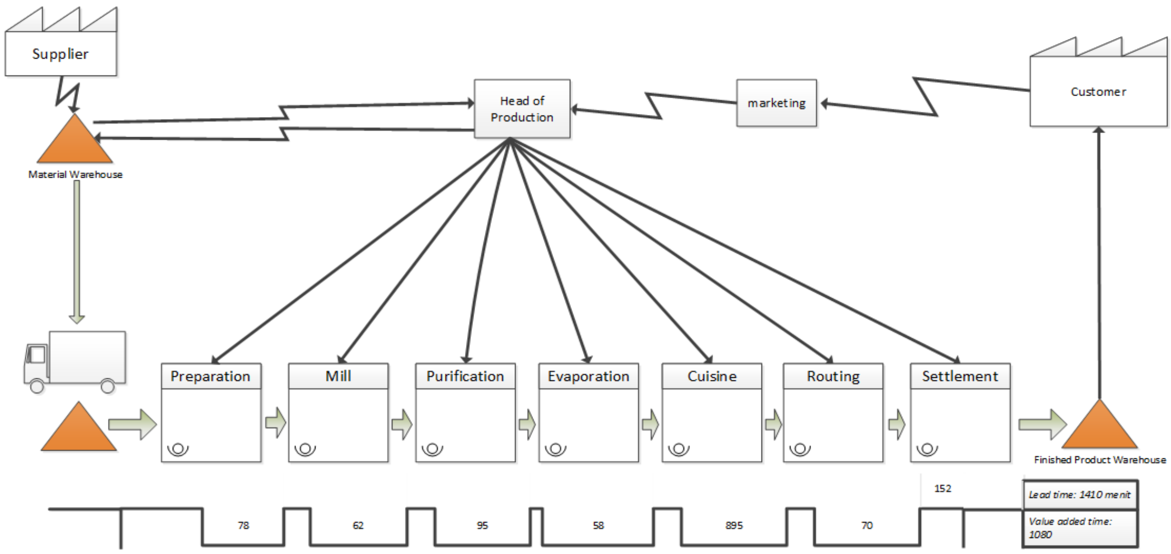

Fig. 2. Initial big-picture mapping

Initial identification of all current condition activities in the sugar production process. Figure 2 is a Big Picture Mapping that shows the state of the sugar production process at the beginning before analyzing the application of Lean Six Sigma. Based on Figure 2. Big Picture

Mapping obtained production time or production lead time of 1410 minutes or equivalent to 23.5 hours and value-added time of 1080 minutes or 18 hours. The total non-value added necessary time is 193 minutes, and the total non-value added time is 139 minutes. So it can be determined that the problem that occurs in the sugar production process is that the total lead time is too long at 1410 minutes or the equivalent of 23.5 hours. So the calculation of the Process Cycle Efficiency (PCE) value is as follows:

$$\mathbf{PCE} = \frac{value\ added}{lead\ time} \times 100\% = \frac{1078}{1410} \times 100\% = 76{,}45\% \ldots\ldots (4)$$

Based on the Process Cycle Efficiency (PCE) value, the result is 76.45%, which means that the sugar production process is still not running efficiently so improvements are needed in the production process. To identify the waste that occurs, a tool is needed in the form of a questionnaire that has the concept of seven wastes. This questionnaire was distributed to 6 respondents as a population of experts in the field of SHS (super high sugar) sugar production. The answer options are arranged with a weighting system, where the highest value is 5 (always occurs), 4 (often occurs), 3 (quite often occurs), 2 (rarely occurs), and 1 (very rarely occurs).

Table 1. Recapitulation of questionnaire results

No	Waste	Respondent										Weight	Ranking
		1	2	3	4	5	6	7	8	9	10		
1	Defect	3	3	3	3	3	4	1	2	4	4	3,0	1
2	Waiting	4	4	3	4	2	1	3	3	3	2	2,9	2
3	Unnecessary Inventory	2	1	3	3	2	2	3	4	3	2	2,5	3
4	Overproduction	3	3	3	2	2	4	2	1	2	1	2,3	4
5	Transportation	1	1	3	2	3	4	2	2	1	2	2,1	5
6	Unnecessary Motion	2	2	1	2	1	1	2	3	2	3	1,9	6
7	Innappropriate Process	2	1	1	2	2	2	2	2	2	2	1,8	7

Source: data processing

The questionnaire calculation is done by summing up the questionnaire results and then dividing by the number of respondents in the questionnaire. Table 1 shows that the results of waste identification provide results where there is waste that occurs in the production process. Defects with an average of 3.0, defects that

occur in the form of sugar granules that are too large or form coarse and powdery sugar, dark sugar color, and wet sugar because the water content exceeds the tolerance limit. Waiting with an average score of 2.9 comes from the length of time waiting for raw materials to support production and the length of time for re-production of products that experience defects during the production process. Unnecessary inventory with an average score of 2.5 occurs in the storage of finished goods because they are not immediately taken by consumers until the next milling period, causing finished products in the next milling period to lack storage warehouses. Overproduction with a score of 2.3 occurs during the production process because it causes losses in the pulp and in molasses. Unnecessary transportation with a score of 2.1 occurs in the process of moving finished products to a warehouse that is quite far away manually. Unnecessary motion with a score of 1.9 and inappropriate process with an average score of 1.8. The next process is to calculate the Value Stream Analysis Tools (VALSAT) The weight that has been obtained from the waste workshop results will be multiplied by the correlation value between the tools and the waste that occurs so that a score is obtained for each existing tool. Determination of tools is carried out based on the largest value to be obtained, in general, one tool with the largest score will be selected which will be continued in data processing.

Table 2. VALSAT results

Waste	Weight	VALSAT						
		PAM	SCRM	PVF	QFM	DAM	DPA	PS
Overproduction	2,3	2,3	6,9	0	2,3	6,9	6,9	0
Waiting	2,9	26,1	26,1	2,9	0	8,7	8,7	0
Transportation	2,1	18,9	0	0	0	0	0	2,1
Inappropriate processing	1,8	16,2	0	5,4	1,8	0	1,8	0
Unnecessary Inventory	2,5	7,5	22,5	7,5	0	22,5	7,5	2,5
Motion	1,9	17,1	1,9	0	0	0	0	0
Defects	3,0	3,0	0	0	27,0	0	0	0
Amount Weight		**91,1**	**57,4**	**15,8**	**31,1**	**38,1**	**24,9**	**4,6**

Source: data processing

Based on the results of the calculations that have been carried out in Table 2, the weighting is obtained based on the largest score with the first rank to the smallest with the seventh rank. So that the weighting results can be obtained the order of the most relevant tools to use is Process Activity Mapping (PAM).

Table 3. Number of defects

No	Type of Defect	Number of Defects (ton)
1	Sugar Color	1140
2	Sugar Granules	1322
3	Water Content	1127
	Amount	**3589**

Source: data processing

Based on the data, it can be seen that the largest number of defects is sugar granules with a total defect of 1322 tons, sugar color with a total of 1140 tons, and water content with a total of 1127 tons. Based on the data above, a histogram can be made.

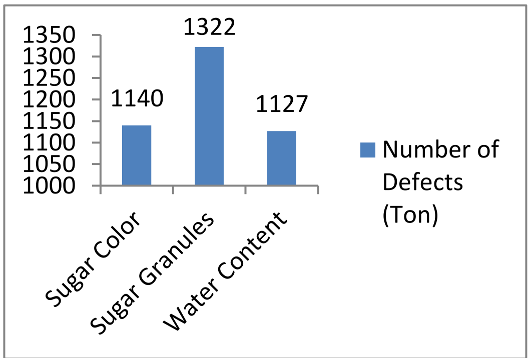

Fig. 2. Product defects of sugar production
Source: data processing

Based on the image of the histogram diagram, it can be seen that the number of defective block is the most defective sugar granules. As for the least number of defects is the water content defect.
Calculation of DPO, DPMO, and Sigma Level. The amount of sugar production is 21677.2 tons, so the value of defects per opportunity (DPO) and defects per million opportunities (DPMO) can be calculated as follows:

$$DPO = \frac{many\ defective\ product}{many\ defective\ product \times CTQ}$$

$$DPO = \frac{3589}{21677{,}2 \times 3} = 0{,}055188$$

$$DPMO = DPO \times 1000000$$

$$= 0{,}055188 \times 1000000 = 55188$$

Because there is no DPMO to sigma value conversion table with a value of 55188, it uses interpolation:

DPMO = 55917 (X2),
sigma conversion value = 3.09 (Y2)
DPMO = 57053 (X1),
sigma conversion value = 3.08 (Y1)
DPMO = 55188 (X),
sigma conversion value (Y) is?

$$\frac{x - x_1}{x_2 - x_1} = \frac{Y - Y_1}{Y_2 - Y_1} = \frac{55188 - 57053}{55917 - 57053} = \frac{Y - 3{,}08}{3{,}09 - 3{,}08}$$

$$\frac{-1865}{-1136} = \frac{Y - 3{,}08}{0{,}01} Y = \frac{-3517{,}53}{-1136} = 3{,}096$$

Table 4. Recapitulation of Six Sigma production results

No	Action	Similarities
1	Process of interest	Sugar Production Process
2	Number of units produced	21677,2 Ton
3	Number of defective units	3589 Ton
4	DPO	0,055188
5	DPMO	55188
6	Convert DPMO value to sigma	3.096

Source: data processing

Value Stream Tools Analysis With Proposed Process Activity Mapping. The results of processing using process activity mapping, obtained the number of activities and the number of each process with the percentage can be seen from the following bar chart:

Table 5. Proposed process activity mapping

No	Activity	Total Activity	Percentage of Activity (%)	Total Time (minutes)	Percentage of Time (%)
1	Operation	35	47,95%	1080	78,72%
2	Transportation	10	13,69%	86	6,27%
3	Inspection	19	26,03%	95	6,92%
4	Storage	1	1,37%	10	0,73%
5	Delay	8	10,96%	101	7,36%
	Amount	**73**	**100%**	**1372**	**100%**

Source: data processing

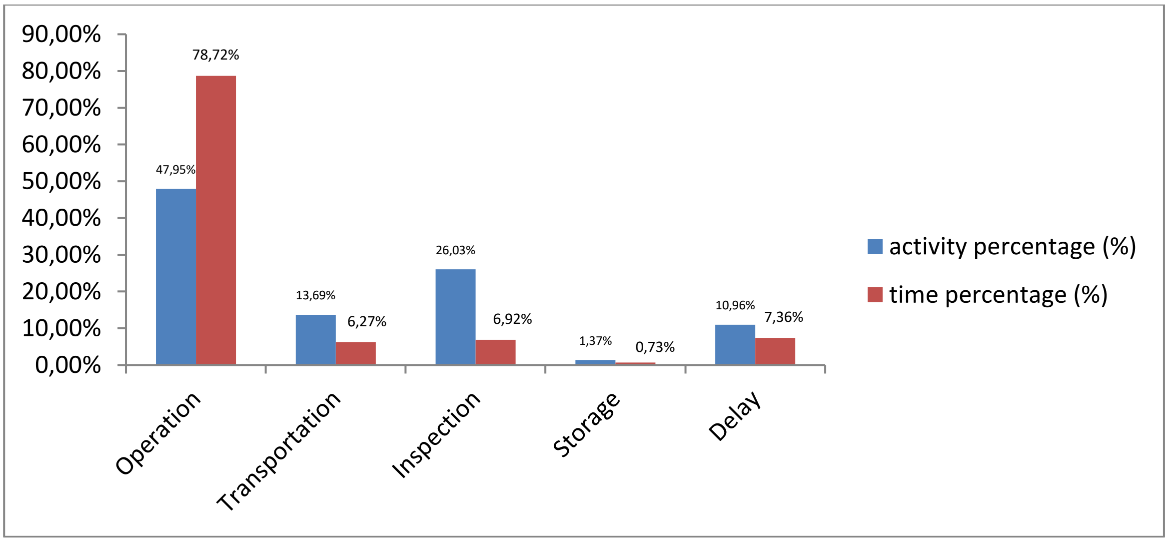

Fig. 3. Proposed process activity mapping
Source: data processing

It can be seen that the type of activity that has the largest percentage of time is operation activity of 47.95%, while for the largest amount of activity time is operation activity of 78.72%.

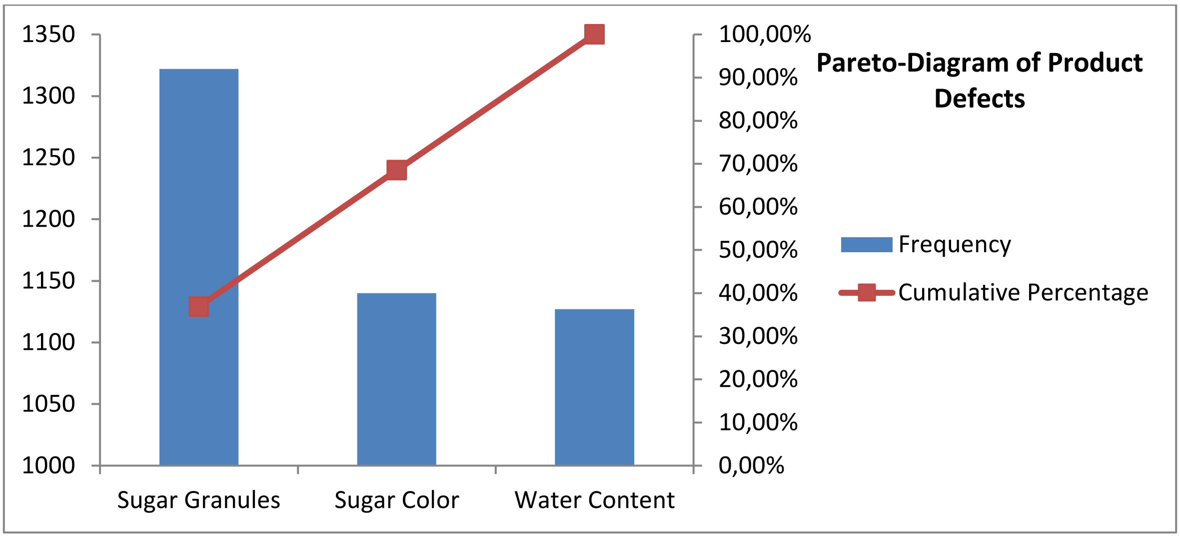

Fig. 4. Pareto diagram
Source: data processing

From the pareto diagram, it can be seen that the order of the highest types of defects is sugar grain defects at 36.9%, sugar color defects at 31.7%, and moisture content defects at 31.4%.

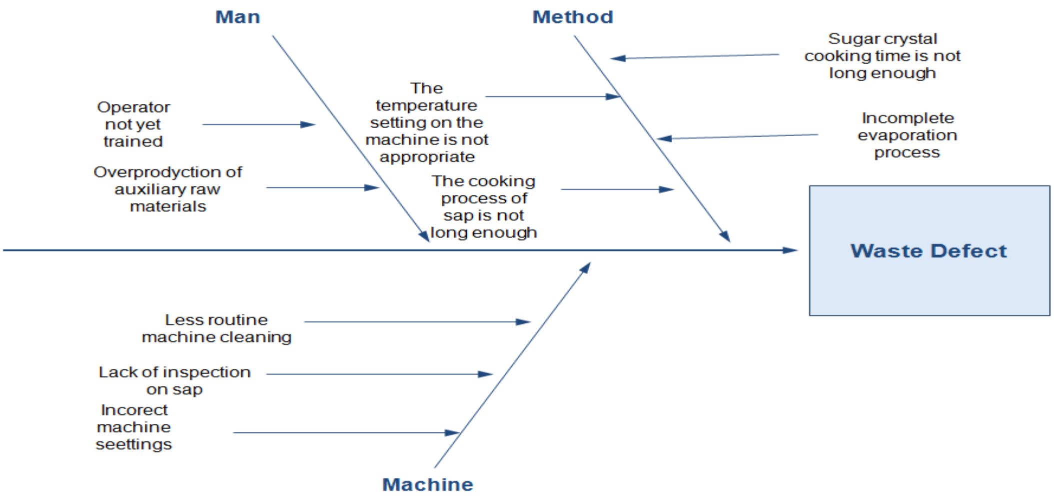

Fig. 5. Fishbone diagram

Based on Fig. 5, the types of defects are caused by methods, humans, and machines. The cause in terms of methods is that the temperature setting on the sugar dryer machine is not appropriate, causing the water content in the sugar to not fully dry, the second cause is that there is an incomplete evaporation process at the evaporation station, allowing the water content to remain. The cause in terms of humans is that the operator is not trained in setting the sugar dryer machine, causing the temperature to be inappropriate. The cause in terms of machinery is that machine cleaning is not carried out regularly, causing the machine to not be able to work optimally due to accumulated dirt, the second cause is the lack of inspection of sap before entering the next process.

Table 6. Calculation of RPN value

Potential Failure Mode	***Potential Effect of Failure***	**S**	***Potential Cause***	**O**	***Current Control***	**D**	**RPN**
Sugar Granules	Sugar Granules Coarse sugar granules cause consumers from large companies to not want to take their products so they have to be reprocessed	8	Machine rotation is not controlled in normal conditions	8	Perform routine machine maintenance	8	512
			Operator is not skilled enough to set up the machine	4	Conduct training for operators	6	192
			Less careful in observing sugar crystals	4	Perform scheduling of sugar crystal control	7	224
			Cooking time of sugar crystals is not long enough	7	Conduct routine inspections on the machine during the process	6	336
Water Content	Moisture Content Wet sugar or sugar with excessive moisture content causes storage not to last long	7	Incomplete evaporation	6	Increase evaporation time	5	210
			Machine temperature setting is not appropriate	7	Set up the machine regularly	5	245
			Operators have not been trained	4	Conduct training for operators	6	168
			Less routine machine cleaning	5	Make a routine cleaning schedule for the machine	7	245
			Lack of sap inspection	3	Notify employees about routine inspection schedule	5	105
Sugar Color	Sugar color Darker color reduces aesthetic value	6	Cooking process of nira is less long	5	Increase cooking time	5	150
			Poor quality of raw materials	8	Conduct control before raw materials enter the process	8	384
			Addition of excess production process auxiliary raw materials	4	Make the right dosage for production process auxiliary raw materials	6	144
			Poor machine settings	6	Recalibrate	5	180

Source: data processing

Table 7. Proposed improvements to waste in the sugar production process

No	Type of Waste	*Rank Priority*	Root Cause
1	Defect	1	• Standardize the sugar production process • Provide training to operators so that human error does not occur
2	Unnecessary Inventory	2	• Perform good calculation or planning of raw materials • Provide additional costs to consumers who do not immediately take sugar from the warehouse beyond the time limit
3	Waiting	3	• Barter with sister sugar factories so as not to wait too long for the procurement of raw materials • Use one recording server such as through a computer so as not to work twice
4	Overproduction	4	• Conduct inspections during the production process so that there are not many losses
5	Transportation	5	• Procure transportation with a forklift
6	Unnecessary Motion	6	• Reducing non-value-added activities • Record in one computer only
7	Innappropriate Process	7	• Does not occur because the process is already running according to the company flowsheet.

Source: data processing

Proposed Big Picture Mapping, then a Big Picture Mapping proposal is made by distributing questionnaires to employees related to the production process to reduce the lead time of the sugar production process. The results of improvements obtained from the analysis and proposals on Big Picture Mapping can be seen in Fig. 6 .

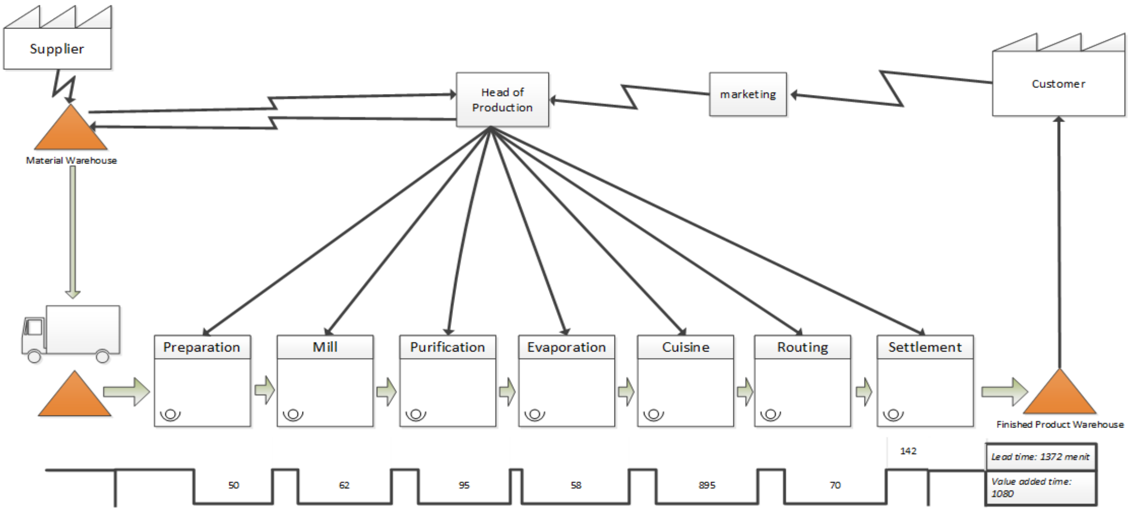

Fig. 6. Proposed big-picture mapping

From the big picture mapping picture, it can be seen that after processing the data using the Lean Six Sigma approach, the sugar production lead time value is faster than before. The initial sugar production lead time was identified as 1410 minutes, then identified again as 1372 minutes. So that the value for the percentage of efficiency improvement in the sugar production process can be described as follows:

$$\% \text{ Increase in Efficiency} = \frac{\textit{Lead Time} \text{ Awal} - \textit{Lead Time} \text{ Akhir}}{\textit{Lead Time} \text{ Awal}} \times 100\%$$

$$\% \text{ Efficiency Improvement} = \frac{1410-1372}{1410} \times 100\% = 2{,}7\%$$

Based on the calculation of the percentage of efficiency improvement, the result is 2.7%, so the value of the proposed Process Cycle Efficiency (PCE) can be determined using the following formula:

$$\textbf{PCE} = \frac{value\ added}{Lead\ Time\ l} \times 100\% = \frac{1078}{1372} \times 100\% = 78{,}57\%$$

Based on the proposed Process Cycle Efficiency (PCE) value, the result is 78.57%, which means that the sugar production process has improved from before the calculation using the lean six sigma method where the prose cycle efficiency value is obtained at 76.45% based on calculation 4.

From the results of data processing that has been carried out, the results can be obtained through the identification of waste, there are root causes of problems in the sugar production process, namely Defect occurs because the sugar production does not match the quality specifications determined by company standards and SNI. Unnecessary Inventory there are residual raw materials throughout the production process. Waiting occurs because there are raw materials that support the incomplete production process and result in waiting for the next process. Overproduction in the production process does not occur because the product is made according to customer orders. Transportation occurs because the process of moving materials or raw materials supporting production has a fairly far location. Unnecessary Motion occurs because there are activities that are carried out repeatedly. Innapropriate Process there is no waste of this type because the information flow process is following with the production process flowsheet.

5. CONCLUSION

The result of reducing lead time on wastage of non-value-added defects in the sugar production process which was originally worth 1410 minutes can be reduced to 1372 minutes through reduced activity in the form of a delay of 38 minutes, to reduce the cycle time in the sugar production process. The DPMO value obtained is 55188 with a sigma level of 3.096. Because the company has not previously implemented Six Sigma, it is not known how much the Sigma level has increased before and after using Lean Six Sigma. Process Cycle Efficiency has increased from 76.45% to 78.57%. Proposed improvements to reduce the level of waste through the help of Failure Mode Effect and Analysis (FMEA), obtained the highest Risk Priority Number (RPN) value of 512 with the cause of the rotary engine not being controlled under normal circumstances, the second highest Risk Priority Number (RPN) is 384 which is the cause of the poor quality of raw materials. Whereas the third highest RPN value of 336 was caused by less cooking time for sugar crystals. Future research is expected to further analyze the sugar production process so that production activities can be explained more clearly to reduce production lead time to the maximum.

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