JOURNAL LA LIFESCI

VOL. 06, ISSUE 02 (172-195), 2025
DOI: 10.37899/journallalifesci.v6i2.2197

Waste Reduction in Fertilizer Manufacturing Through Lean Six Sigma and 5S Implementation

Ruro Wiranti Meisufi[1], Rr. Rochmoeljati[1]

[1]*Departement of Industrial Engineering, National Development University "Veteran" East Java, Surabaya, Indonesia*

**Corresponding Author: Ruro Wiranti Meisufi*
Email: rurowirantimeisufi@gmail.com

Article Info

Article history:
Received 9 May 2025
Received in revised from 27 June 2025
Accepted 20 July 2025

Keywords:
Quality
Defect
Lean Six Sigma

Abstract

This study aims to analyze the waste that occurs in the fertilizer production process at PT XYZ and provide suggestions for improvement with the Lean Six Sigma approach and the 5S method (Seiri, Seiton, Seiso, Seiketsu, Shitsuke). Data was collected through observation, interviews, and questionnaires, then analyzed using the DMAIC stages and tools such as Value Stream Mapping, RCA, and VALSAT. The results showed the three highest wastes were defects, motion, and transportation, with an average DPMO value of 32,706.67 and a sigma level of 3.43. The proposed improvements focused on implementing 5S to increase work efficiency and reduce non-value-added activities. After the improvement, the process efficiency value increased by 6.86%, indicating the effectiveness of the applied method.

Introduction

The fertilizer industry has an important role in increasing agricultural production and supporting national food security. However, in the fertilizer production process, there are often various forms of waste that can hinder operational efficiency (Widiarta et al., 2025; Irahman & Rayhan, 2024). The impact of this waste not only affects productivity, but can also reduce the quality of the final product. Therefore, it is important for companies to implement effective methods to identify and reduce waste (Manzouri et al., 2014).

PT XYZ is one of the companies engaged in manufacturing the fertilizer industry and dolomite rock mining materials since 2018. Product testing is carried out according to the specifications set, namely MgO content of 18-22%, CaO content of 29-30%, H2O content <1%, and passing mesh at least 95%. In the fertilizer production area at PT XYZ, there is still waste that occurs. One of the waste that often occurs is product defects. The defects identified are coarse fertilizer texture, clumping, mismatches in CaO and MgO levels, and product weight that is out of tolerance.

Suryanti et al. (2020) and Helmold, (2020) said that not only defects, the waste that often occurs is waste motion, waste that occurs in the movement during production which is not value-added in the fertilizer production process. In the aspect of waste transportation, there are many delay processes that occur during the in/out of trucks that enter the weighing area (Hadavi et al., 2018). Controlling the production process is an important step to reduce waste, and one method that can be applied is Lean Six Sigma. Lean Six Sigma combines lean and six sigma principles. Lean Six Sigma is a methodology that aims to eliminate waste, reduce variation, and improve quality in business processes (Irahman & Rayhan, 2024).

In addition, it can improve the quality of products produced and minimize product variance (Putri et al., 2021). In its improvement method, the 5S method (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) is an effective strategic tool for optimizing production processes with a focus on

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

maintaining and structuring the work environment in a sustainable manner (Ariesta et al., 2023).

Seven Waste

Waste is an activity that uses a lot of resources but does not produce value. The waste in question includes: human activities that use a lot of resources that do not produce value, errors that require correction, unwanted production results that become inventory and scraps that accumulate, processes that are not actually needed, movement of labor and anchorage from one place to another without much purpose, waiting activities because the previous activity was not completed on time, and services that are not in accordance with customer needs. There are 7 types of waste used, namely defects, motion, overprocessing, overproduction, transportation, inventory, waiting (Annisa, 2023).

Lean Six Sigma

Lean Six Sigma was advanced by using combining key elements or characteristics from non-stop improvement theory and medical control. Lean methodology gets rid of waste by using extracting on-introduced behavior, while Six Sigma specifically specializes in disposing of best-related problems by calculating the wide variety of chances a manner can produce a illness earlier than it turns into a defect. Lean methodology is usually centered at the glide of statistics among the two processes, and 6 Sigma focuses on improvements inside the system (Kinariyanti & Sulaksono, 2025). Six Sigma is a vision of high-quality improvement in the direction of a goal of 3.4 failures in a millionth of a hazard for each product transaction (goods or offerings), an attempt toward perfection (Ramadhan, 2021). So this mixed method entirely emerges as a technique to achieve quality-in-class high-quality, value, manufacturing, and purchaser delight (Putri, 2022).

DMAIC

The Six Sigma improvement process, known as DMAIC, follows a systematic approach based on science and facts, consisting of five stages: Define, Measure, Analyze, Improve, and Control. In the Define stage, Critical to Quality (CTQ) is identified (Andriani & Sabardi, 2022). The Measure stage involves quantifying problems by calculating DPU (Defect per Unit), DPMO (Defect Per Million Opportunities), and sigma level to assess defect rates (Hidajat & Subagyo, 2022) DPMO is calculated using the formula:

$$DPMO = \frac{Total\ Damage}{Total\ Production}\ x\ 1.000.000$$

The Analyze stage focuses on identifying root causes, often using Pareto diagrams to highlight dominant defects (Anggraini et al., 2019). In the Improve stage, steps include experimental design, developing solutions, setting tolerances, testing improvements, and re-evaluating solutions. Finally, the Control stage involves evaluating and standardizing processes to maintain improvements and monitor progress (Adiasa et al., 2024).

VALSAT

In lean implementation, value stream mapping aims to eliminate waste and enhance efficiency by analyzing information such as takt time, downtime, production activities, personnel, and lead times. This analysis provides a static view of current conditions, allowing for the creation of future value stream maps that identify potential improvements (de et al., 2021). The lean concept categorizes activities into three types: Value Added (VA), Necessary but Non-Value Added (NNVA), and Non-Value Added (NVA). VA activities create value for consumers and should be maintained for competitiveness (Jusmani & Oktariansyah, 2021). NNVA activities

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

are necessary but do not add value from the customer's perspective (Nurdiansyah et al., 2022) NVA activities are inefficient and can be improved. Companies aim to eliminate NVA activities to enhance overall efficiency (Jusmani & Oktariansyah, 2021). The selection of the appropriate tool can be done using VALSAT (Value Stream Analysis Tools), because each mapping tool has a relationship of suitability with each waste (Hines & Rich, 1997) This relationship can be shown in Table 1 below:

Table 1. VALSAT Assessment Scale

Mapping Tools							
Waste/ Structure	**Process Activity Mapping**	**Supply Chain Response Matrix**	**Production Variety Funnel**	**Quality Filter Mapping**	**Demand Amplification Mapping**	**Decision Point Analysis**	**Physical Structure (a)Volume (b) Value**
Overproduction	L	M	-	L	M	M	-
Waiting	H	H	L	-	M	M	-
Transportation	H	-	-	-	-	-	L
Overprocessing	H	-	M	L	-	L	-
Inventory	M	H	M	-	H	M	L
Motion	H	L	-	-	-	-	-
Defects	L	-	-	H	-	-	-

Source: (Hines & Rich, 1997)

Note:

H = High correlation and usefulness, multiplier factor 9

M = Moderate correlation and usefulness, multiplier factor 3

L = Low correlation and usefulness, multiplier factor 1

The VALSAT value is calculated as follows:

VALSAT = Waste Weight x Correlation Value (H, L, M)

Explanation:

Waste weight = Based on the waste weight value in the questionnaire summary calculation

5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke)

The 5S method is a work habituation method originating from Japan with five Japanese words (Seiri, Seiton, Seiso, Seiketsu and Shitsuke). The principle of seiri is sorting, that is, the necessary and unnecessary materials or items found in the workplace must be sorted and classified. In principle, seiton (neat) determines the place for everything needed by the workplace (Mu'adzah & et, 2020). The next step is seiso (cleaning) everything in the area and removing all trash (Restuputri & Wahyudin, 2019). Seiketsu is a procedure about the rules of how to do seiri, seiton, and seiso. Then inform all parties concerned (Fitriana et al., 2021) and the last stage is Shitsuke this is the last stage of 5S implementation at this stage employees are encouraged to do things the way they should be done.

From the results of this study, the application of the Lean Six Sigma method focuses on reducing variability and waste and further provides improvement recommendations with 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) which focuses on removing unnecessary elements. Through research entitled “Analysis of Waste in the Fertilizer Production Process with Lean Six Sigma and 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) Methods at PT XYZ” is expected

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

to contribute to the company in reducing waste and increasing efficiency in the production process.

Methods

This research initiative aims to identify and classify waste in PT XYZ using lean six sigma frameworks, measure the current Process Cycle Efficiency (PCE) to determine the ratio of value added and non-value added activities and also analyze the root causes of the most significant waste, including defects, overproduction, waiting, and transportation, using tools such as value stream mapping (VSM) and 5 why's so can reduce production lead time by at least 5% by eliminating bottlenecks and NVA activities. The main objective was to improve Process Cycle Efficiency (PCE) and eliminate all non-value-added activities (NVA) and shorten lead times in production as well as reduce the level of product defects that occur. Several stages in the development of this methodology integrate observational measures with analytical tools to create a data-focused process improvement approach.

Define

This stage aims to observe and establish the condition of the company. This involves creating a production process map that includes an information flow map and a physical flow map using Big Picture Mapping tools. To create a Big Picture Mapping, essential data includes: production process steps with cycle/wait times and bottlenecks; inventory levels and material flows; quality metrics like defect rates; information flows including order processing; equipment performance data; workforce details; and customer demand patterns. This comprehensive dataset enables visualization of the entire value stream. The resulting map reveals critical insights: value-added vs. waste activities, bottleneck locations, inventory excesses, lead time components, quality failure points, and information flow gaps. It facilitates calculation of key metrics like Process Cycle Efficiency and identifies improvement opportunities across the value chain, serving as a foundation for Lean implementation and cross-functional improvement initiatives.

Measure

In the measurement stage, process cycle efficiency (PCE), defects per million opportunities (DPMO), and six Sigma degree could be calculated. PCE is used to degree the general performance of the manner, DPMO calculates the wide variety of defects in line with million opportunities, and the Six Sigma degree evaluates the potential of the procedure to supply disorder-unfastened merchandise. The resulting lead time value is 350 minutes with a PCE value of 48.57%. While from the defect calculations that have been carried out, the DPMO value is 32,706.67 so that the resulting sigma value conversion is 3.43.

Analyze

This stage analyzes the mapping details that have been made by identifying the causes of waste and factors that affect the production process, then identifying waste and determining the potential causes of these problems using Root Cause Analysis (RCA) to design improvement solutions. At this stage, tables and histograms are presented regarding the total percentage of each activity that will be used to determine the waste that must be eliminated. the following is a table and histogram of the amount of initial time for each activity:

Table 2. The Amount of Initial Time for Each Activity

No	Activity	Total Time (Minute)	Percentage (%)
1	Operation	241	69%

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

2	Transportation	35	10%
3	Inspection	56	16%
4	Storage	0	0%
5	Delay	18	5%
Total		**350**	**100%**

Source: Data Processing Results

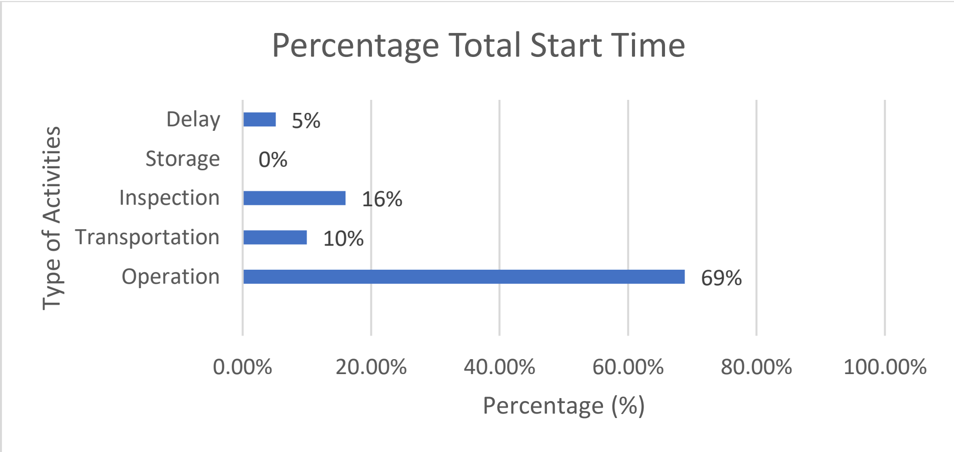

Figure 1. Histogram of Initial Time for Each Activity

Improve

Implementing effective solutions to overcome the problems that have been identified previously in the research conducted. The improvement method used is 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke). Making Value Stream Mapping (VSM) for future state will be carried out at this stage as a follow-up to the results of the proposed improvements that have been implemented. The proposed improvements will be identified from each root cause that has been analyzed using the 5 why's.

Results and Discussion

Data Collection

Researchers collect data and information from PT XYZ company to solve problems in production defects. The data collected are primary and secondary data. Primary data is obtained from direct interviews with field supervisors, while secondary data is data that has been collected in advance by someone and becomes company historical data. The data needed includes production yield data, data on the number of production defects, data related to waste and weighting questionnaires, and production activity data.

Table 3. Total Fertilizer Production Yield

Period	Month	Total Production (Ton)
1	August 2024	3.990
2	September 2024	7.531
3	October 2024	4.506
4	November 2024	3.446
5	December 2024	6.664
6	January 2025	6.825
Total		32.962

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Source: Internal Company Data

Table 4. Type and Quantity of Fertilizer Product Defects

Month	Production Result (Ton)	Coarse Fertilizer Texture Defects (Ton)	Defects Noncomformity CaO Content (Ton)	Defects Noncomformity CaO Content (Ton)	Fertilizer Caking Defect (Ton)	Nonconforming Product Weight Defect (Ton)	Total Defects (Ton)	Percentage of Defects Per Month
Agt-24	3990	91,92	67,64	57,67	74,85	95,75	387,83	9,72%
Sep-24	7531	159,66	145,19	105,29	242,08	226,66	878,87	11,67%
Okt-24	4506	92,83	64,10	62,89	115,83	130,27	465,92	10,34%
Nov-24	3446	62,46	66,54	83,06	73,74	65,69	351,49	10,20%
Des-24	6664	138,94	75,45	101,57	137,30	132,50	585,77	8,79%
Jan-25	6825	143,25	85,47	93,17	174,95	150,17	647,01	9,48%
Total	32962	689,05	504,38	503,65	818,75	801,05	3316,88	10,03%

Source: Internal Company Data

Table 5. Waste Data

Variable	Attribute
Inventory	Excessive storage of goods Delays in product/material information resulting in increased storage costs Decreased quality of service to customers
Overproduction	Too much production, too early and too soon
Overprocessing	Improper production process due to incorrect SOPs Errors in the use of equipment or machines that are not in accordance with work operating procedures
Motion	Unergonomic working environment and equipment conditions
Transportation	Poor production floor layout, and lack of understanding of production process flow
Waiting	Inappropriate or inefficient use of time Inactivity of workers, information, materials, products over a long period of time
Defect	Products do not meet the quality specifications set by the company

Define

This stage of identification is carried out by describing the main process maps which are divided into information flow maps and physical flow maps through big picture mapping of problems that occur in the fertilizer production process at PT XYZ.

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

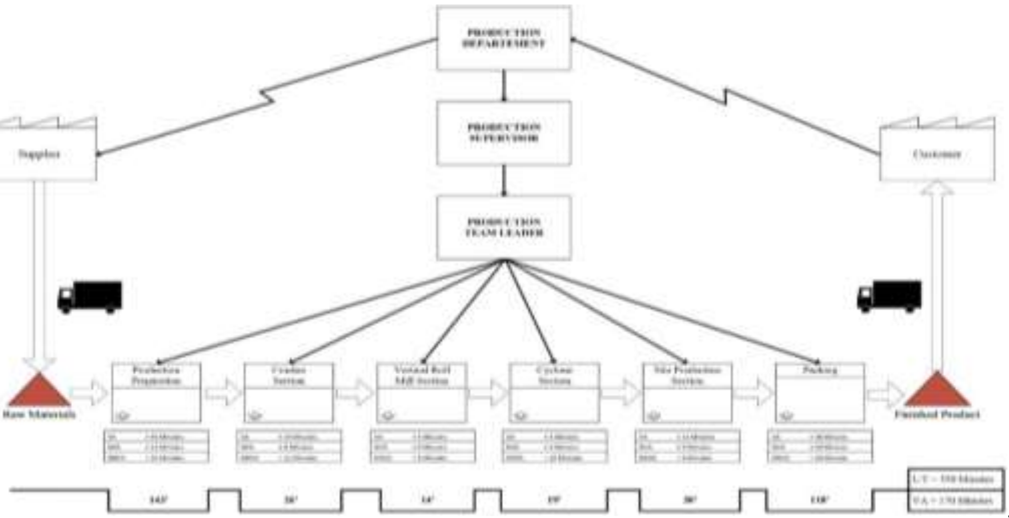

Figure 2. Initial Big Picture Mapping of Fertilizer Production Process

Based on the picture above, activities are obtained at 6 work stations, namely the raw material warehouse, crusher section, vertical roll mill section, cyclone section, product silo, and packing. It was also obtained that the total lead time for fertilizer production was 350 minutes with a total value added time of 170 minutes, a total necessary non-value added of 135 minutes, and a total non-value added of 45 minutes.

Measure

At the measure degree, essential waste may be decided based on the questionnaire that has been distributed and a mapping method may be made that gives a extra certain description of the waste that takes place the usage of the fee move tool according with the waste that takes place and calculates the sigma fee of the satisfactory of fertilizer production at PT XYZ.

Processing Questionnaire Facts

The dedication of critical waste is primarily based at the outcomes of the questionnaire that has been made and dispensed. the answer alternatives are organized with a weighting system, where the highest price is 5 (continually takes place), four (regularly takes place), 3 (quite often occurs), 2 (rarely happens), and 1 (very rarely occurs). primarily based at the calculations which have been completed, the outcomes of the questionnaire are proven inside the following desk:

Table 6. Recapitulation of Waste Questionnaire Outcomes in Step with Rating

No.	Waste	Respondents										Weight	Ranking
		1	2	3	4	5	6	7	8	9	10		
1	Defect	3	4	2	3	2	2	3	2	3	2	2,6	1
2	Motion	4	3	1	1	4	1	4	1	3	2	2,4	2
3	Transportation	3	3	2	1	3	2	3	3	2	1	2,3	3
4	Waiting	2	2	2	3	3	2	2	2	1	1	2,0	4
5	Overproduction	2	3	2	3	1	3	2	1	1	1	1,9	5
6	Inventory	1	1	2	2	2	1	2	2	2	3	1,8	6
7	Overprocessing	2	1	2	2	2	1	1	1	1	2	1,5	7

Source: Data Processing Results

Where is:

1 = Never happened

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

2 = Almost Never happened

3 = Occasionally occurs

4 = Frequent occurrence

5 = Always Happen

Based on this table, the weighting results obtained in order of ranking 1 to 3 are defects with a weight of 2,6; Motion with a weight of 2,4; and Transportation with a weight of 2,3.

Calculation of Process Cycle Efficiency (PCE)

Table 7. Fertilizer Production Process Time

No	Detail Activities	Time (Minute)	Type of Acvtivities
Production Preparation			
1	Receiving and weighing raw materials	15	NNVA
2	Data entry of raw material receipts and weighing	5	VA
3	Manual recording of raw material receiving and weighing forms	5	NNVA
4	Reporting of receipts form and weighing ofraw material and auxiliary materials to supply chain staff	3	NNVA
5	Inspection of raw material by warehouse operators	30	VA
6	Transferring raw materials from the truck to the raw material storage warehouse	5	NNVA
7	Test process for MgO, CaO, and H2O content in raw materials	20	VA
8	Manual recording of MgO, CaO, and H2O content test result data	12	NVA
9	Entering in the computer the data of MgO, CaO, and H2O content test results	5	VA
10	Reporting of MgO, CaO, and H2O test results of raw materials to supply chain staff	3	NNVA
11	Machine area cleaning	10	VA
12	Checking production machines	5	VA
13	Transferring auxiliary materials to the heating furnace by wheeloader	5	NNVA
14	Combustion process of auxiliary materials in the heating furnace	15	VA
15	Set up the machine and wait for the heating furnace to be ready	5	VA
Total Time		143	
Crusher Section			
16	Transferring dolomite raw materials to crusher machine by wheeloader	5	NNVA
17	Set up help sizes in the control room	5	VA
18	Crushing process of 1st stage dolomite raw materials	10	VA
19	Checking the results of crushing by the operator	3	NNVA

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

20	Flow of crushed product to vertical roll mill	3	NNVA
Total Time		26	
Vertical Roll Mill Section			
21	Dolomite flows to the loading hopper machine	3	NNVA
22	Flow of raw materials to feed hopper	3	NNVA
23	Weighing of raw materials on belt weigher (Hourly)	3	NNVA
24	Crushing process of 2nd stage dolomite raw materials and water content reduction	5	VA
Total Time		14	
Cyclone Section			
25	Weighing of raw materials on belt weigher	5	NNVA
26	Flow of raw materials to the cyclone	3	NNVA
27	Separation of dust and product	5	VA
28	Checking the temperature of the engine	2	NNVA
29	Texture checking by operator	4	NVA
Total Time		19	
Silo Product Section			
30	Product flow to the silo	3	NNVA
31	Sampling of production results	3	NNVA
32	The process of testing the MgO, CaO, and H2O content of the product	7	VA
33	Manual recording of MgO, CaO, and H2O test result data on products	4	NVA
34	Entering in the computer the data of MgO, CaO, and H2O content test results.	5	VA
35	Reporting of product MgO, CaO, and H2O test results to supply chain staff	3	NNVA
36	Reporting of production that goes into the silo	5	NVA
Total Time		30	
Packing			
37	Retrieval of sacks in the warehouse using a forklift	5	NNVA
38	Installation of fertilizer sacks in the packing house	3	VA
39	Flow of fertilizer product from hopper to weigher	3	NNVA
40	Automatic weighing when bagging fertilizer	2	NNVA
41	Product inspection by production operators	10	VA
42	Manual recording of inspection result data	5	NVA
43	Stitching of fertilizer sacks	5	VA
44	Manual process of arranging products onto pallets	7	NNVA
45	Stapling process using forklift to truck	30	NNVA
46	Transportation of products from plant area to warehouse	10	NNVA
47	Manual transfer of products to the woodpile using forklift tools	5	NVA
48	Product arrangement using a forklift	3	NNVA
49	Manual labeling of production results	10	NVA
50	Manual calculation and recording of rejected products	20	VA

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Total Time	**118**	
Total Overall Time	**350**	

Source: Internal Company Data

So the calculation of the Process Cycle Efficiency (PCE) value is as follows:

$$PCE = \frac{Value\ added}{Lead\ Time}\ x\ 100\% = \frac{170}{350}\ x\ 100\% = 48{,}57\%$$

Based totally on the Process Cycle Efficiency (PCE) value, the result is 48,57%, which means that the fertilizer manufacturing process is still not going efficiently so that upgrades are needed in the production process.

Calculation of DPO and DPMO

Based on monthly defect data, the value of defects per opportunities (DPO) and defects per million opportunities (DPMO) in each period (month) can be calculated as follows:

August 2024

DPO and DPMO calculation

$$DPO = \frac{Number\ of\ defective\ products\ per\ month}{Number\ of\ units\ produced\ per\ month\ x\ CTQ}$$

$$= \frac{387{,}828}{3990\ x\ 5}$$

= 0,01944

DPMO= DPO x 1.000.000

= 0,01944 x 1.000.000

= 19440

From the above calculations, it is known that in August 2024 there was a defect of 387,828 tons of fertilizer with a production volume of 3,990 tons. Meanwhile, there were 5 types of defects in terms of quality characteristics (CTQ), resulting in a failure rate of 19,440 per million products.

Sigma Levels calculation

Since there is no value of 19440 in the DPMO to sigma value conversion table, interpolation is used:

DPMO = 19.226 (X2), sigma conversion value = 3.57 (Y2)

DPMO = 19.699 (X1), sigma conversion value = 3.56 (Y1)

DPMO = 19.440 (X), what is the sigma conversion value (Y)?

Therefore,

$$\frac{x-x_1}{x_2-x_1} = \frac{Y-Y_1}{Y_2-Y_1} \leftrightarrow \frac{19.440-19.699}{19.226-19.699} = \frac{Y-3{,}56}{3{,}57-3{,}56} = \frac{-259}{-473} = \frac{Y-3{,}56}{0{,}01} = \mathrm{Y} = \frac{-1.686{,}47}{-473} = 3{,}57$$

So, after calculating the sigma value above, we obtain a DPMO value of 19.440 and a six sigma conversion value of 3.57.

September 2024

DPO and DPMO Calculation

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

DPO $= \frac{Number\ of\ defective\ products\ per\ month}{Number\ of\ units\ produced\ per\ month\ x\ CTQ}$

$= \frac{878,868}{7531\ x\ 5}$

= 0,0233

DPMO = DPO x 1.000.000

= 0,0233 x 1.000.000

= 23.340

From the above calculations, it is known that in September 2024 there was a defect of 878,868 tons of fertilizer with a production volume of 7531 tons. Meanwhile, there were 5 types of defects in terms of quality characteristics (CTQ), resulting in a failure rate of 23.340 per million products.

Sigma Levels Calculation

Since there is no value of 23.340 in the DPMO to sigma value conversion table, interpolation is used:

DPMO = 23.295 (X2), sigma conversion value = 3.49 (Y2)

DPMO = 23.852 (X1), sigma conversion value = 3.48 (Y1)

DPMO = 23.340 (X), sigma conversion value (Y) is?

Therefore,

$\frac{x-x_1}{x_2-x_1} = \frac{Y-Y_1}{Y_2-Y_1} \leftrightarrow \frac{23.340-23.852}{23.295-23.852} = \frac{Y-3,48}{3,49-3,48} = 3,49$

So, after calculating the sigma value above, we obtain a DPMO value of 23.340 and a six sigma conversion value of 3.49.

October 2024

DPO and DPMO Calculation

DPO $= \frac{Number\ of\ defective\ products\ per\ month}{Number\ of\ units\ produced\ per\ month\ x\ CTQ}$

$= \frac{465,920}{4506\ x\ 5}$

= 0,0207

DPMO = DPO x 1.000.000

= 0,0207 x 1.000.000

= 20.700

From the above calculations, it is known that in October 2024 there was a defect of 465,920 tons of fertilizer with a production volume of 4,506 tons. Meanwhile, there were 5 types of defects in terms of quality characteristics (CTQ), resulting in a failure rate of 20,700 per million products.

Sigma Levels Calculation

Since there is no value of 20,700 in the DPMO to sigma value conversion table, interpolation is used:

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

DPMO = 20.675 (X2), sigma conversion value = 3.54 (Y2)

DPMO = 21.178 (X1), sigma conversion value = 3.53 (Y1)

DPMO = 20.700 (X), what is the sigma conversion value (Y)?

Therefore,

$\frac{x-x_1}{x_2-x_1} = \frac{Y-Y_1}{Y_2-Y_1} \leftrightarrow \frac{20.700-21.178}{20.675-21.178} = \frac{Y-3,53}{3,54-3,53} = 3,54$

So, after calculating the sigma value above, we obtain a DPMO value of 20,700 and a six sigma conversion value of 3.54.

November 2024

DPO and DPMO Calculation

DPO $= \frac{Number\ of\ defective\ products\ per\ month}{Number\ of\ units\ produced\ per\ month\ x\ CTQ}$

$= \frac{351,492}{3446\ x\ 5}$

= 0,0204

DPMO= DPO x 1.000.000

= 0,0204 x 1.000.000

= 20.400

From the above calculations, it is known that in November 2024 there was a defect of 351,492 tons of fertilizer with a production volume of 3,446 tons. Meanwhile, there were 5 types of defects in terms of quality characteristics (CTQ), resulting in a failure rate of 20,400 per million products.

Sigma Levels Calculation

Since there is no value of 20,400 in the DPMO to sigma value conversion table, interpolation is used:

DPMO = 20.182 (X2), sigma conversion value = 3.55 (Y2)

DPMO = 20.675 (X1), sigma conversion value = 3.54 (Y1)

DPMO = 20,400 (X), what is the sigma conversion value (Y)?

Therefore,

$\frac{x-x_1}{x_2-x_1} = \frac{Y-Y_1}{Y_2-Y_1} \leftrightarrow \frac{20.400-20.675}{20.182-20.675} = \frac{Y-3,54}{3,55-3,54} = 3,55$

So, after calculating the sigma value above, we obtain a DPMO value of 20,400 and a six sigma conversion value of 3.55.

December 2024

DPO and DPMO Calculation

DPO $= \frac{Number\ of\ defective\ products\ per\ month}{Number\ of\ units\ produced\ per\ month\ x\ CTQ}$

$= \frac{585,766}{6664\ x\ 5}$

= 0,0176

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

DPMO= DPO x 1.000.000

= 0,0176 x 1.000.000

= 17.600

From the above calculations, it is known that in December 2024 there was a defect of 585,766 tons of fertilizer with a production volume of 6,664 tons. Meanwhile, there were 5 types of defects in terms of quality characteristics (CTQ), resulting in a failure rate of 17,600 per million products.

Sigma Levels Calculation

Since there is no value of 17,600 in the DPMO to sigma value conversion table, interpolation is used:

DPMO = 17,429 (X2), sigma conversion value = 3.61 (Y2)

DPMO = 17,864 (X1), sigma conversion value = 3.60 (Y1)

DPMO = 17,600 (X), sigma conversion value (Y) is?

Therefore,

$$\frac{x-x_1}{x_2-x_1} = \frac{Y-Y_1}{Y_2-Y_1} \leftrightarrow \frac{17.600-17.864}{17.429-17.864} = \frac{Y-3{,}60}{3{,}61-3{,}60} = 3{,}61$$

So, after calculating the sigma value above, we obtain a DPMO value of 17,600 and a six sigma conversion value of 3.61.

January 2025

DPO and DPMO Calculation

$$\text{DPO} = \frac{Number\ of\ defective\ products\ per\ month}{Number\ of\ units\ produced\ per\ month\ x\ CTQ}$$

$$= \frac{647{,}010}{6825\ x\ 5}$$

= 0,0948

DPMO= DPO x 1.000.000

= 0,0948 x 1.000.000

= 94.800

From the above calculations, it is known that in January 2025 there was a defect of 647,010 tons of fertilizer with a production volume of 6,825 tons. Meanwhile, there were 5 types of defects in terms of quality characteristics (CTQ), resulting in a failure rate of 94,800 per million products.

Sigma Levels Calculation

Since there is no value of 94,800 in the DPMO to sigma value conversion table, interpolation is used:

DPMO = 93.418 (X2), sigma conversion value = 2.82 (Y2)

DPMO = 95.098 (X1), sigma conversion value = 2.81 (Y1)

DPMO = 94.800 (X), sigma conversion value (Y) is?

Therefore,

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

$$\frac{x-x_1}{x_2-x_1} = \frac{Y-Y_1}{Y_2-Y_1} \leftrightarrow \frac{94.800-95.098}{93.418-95.098} = \frac{Y-2,81}{2,82-2,81} = 2,81$$

So, after calculating the sigma value above, the DPMO value obtained is 94,800 and the six sigma conversion value is 2.81.

Table 8. DPO, DPMO, and Sigma Level Value of Fertilizer from August 2024 to January 2025

Month	Total Production (Ton)	Total Defect (Ton)	CTQ	DPO	DPMO	Level Sigma
Aug-24	3990	387,83	5	0,0194	19440	3,57
Sept-24	7531	878,87	5	0,0233	23340	3,49
Oct-24	4506	465,92	5	0,0207	20680	3,54
Nov-24	3446	351,49	5	0,0204	20400	3,55
Dec-24	6664	585,77	5	0,0176	17580	3,61
Jan-25	6825	647,01	5	0,0948	94800	2,81

Source: Data Processing Results

Based on table 6. above, it can be seen that the average value of DPMO and the average value of sigma value from August 2024 to January 2025 are as follows:

Average value of DPMO $= \frac{Total\ DPMO\ from\ Aug-24\ to\ Jan-25}{6} = \frac{196.240}{6} = 32.706,67$

Average Value of Sigma $= \frac{Total\ Sigma\ from\ Aug-24\ to\ Jan-25}{6} = \frac{20,57}{6} = 3,43$

Based on the results above, it shows that PT XYZ is at a sigma level of 3.43 or can be said to be at the 3 sigma level with an average DPMO value of 32706.67 every 1,000,000 production carried out.

Analyze

At the analyze stage, an analysis will be carried out regarding the amount of waste that occurs, and its adverse effects on the company, so that later an effective and efficient improvement proposal can be determined to eliminate waste.

Identify Waste

The identification of waste that occurs in the fertilizer production process is as follows: (1) Defect, this waste occurs because fertilizer production does not meet the company's quality specifications, caused by processes that are not up to standard, the use of raw materials that are not optimal, and the lack of perfection in production; (2) Motion, this waste happens due to the fact there are many non-value-delivered sports that aren't wished in the manufacturing technique. furthermore, the fertilizer stapling process is executed manually, that's inefficient; (3) Transportation, this waste takes place due to the fact the fertilizer transfer method stories a loss of forklifts ensuing in process delays; (4) Waiting, this waste happens due to ready time because the recording activities are nevertheless executed manually which causes time inefficiency; (5) Overproduction, this waste occurs because of extra merchandise in the production method that don't meet manufacturing standards. this could result in the buildup of unsold inventory; (6) Inventory, this waste occurs because of the accumulation of products due to the fact clients are past due in selecting up orders for fertilizer products and defective merchandise which have not been further processed; (7) Overprocessing, this waste happens because there are excess merchandise that should be reprocessed, wherein the products that need to be reprocessed are faulty products which can be nonetheless possible.

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Pareto Diagram

Based on the CTQ that has been determined, an analysis is carried out to determine the cause of the highest defect using a pareto diagram according to the data that has been obtained:

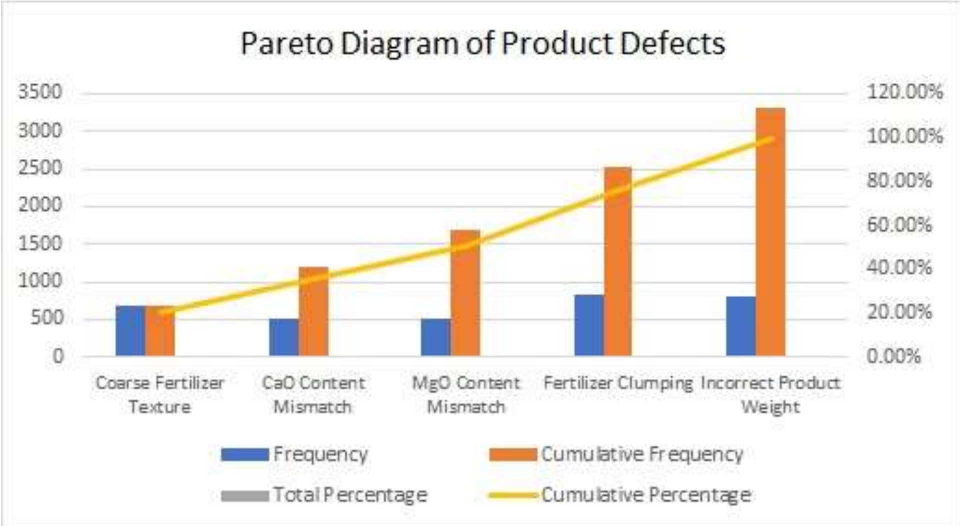

Figure 3. Pareto Diagram

From the pareto diagram, it can be seen that the order of the highest types of defects is the fertilizer clumping defect of 24.68%, the product weight defect does not match 24.15%, the rough fertilizer texture defect of 20.77%, the CaO level mismatch defect of 15.21%, and the MgO mismatch defect of 15.18%

5 Why's

Table 9. Root Cause Analysis using the 5 Why's

No	Defect	Why	Why	Why	Why	Why
1	Coarse Fertilizer Texture	Poor quality raw materials	High moisture content of raw materials	Improper storage of raw materials	Inadequate storage facilities	
		Inappropriate production methods	Suboptimal grinding process Wood burning is not hot enough	The machine is not being used to its full potential	Irregular machine maintenance	Lack of supervision of SOP implementation
		Lack of supervision of CCR operators in quality control	Lack of operator focus			
2	CaO Content Discrepancy	Dolomite raw material contains CaO below standard	Lack of inspection during product processing	Lack of operator supervision	Lack of operator focus	
		Inappropriate production methods	Suboptimal fertilizer processing	During the compaction process, the fertilizer was	The engine used is not optimal.	Lack of routine maintenance of the machine

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

			The temperature used is not appropriate	not evenly distributed, thereby reducing the solubility of CaO Contaminated by other materials		
		Product testing procedures are inconsistent.	The tools used are not accurate Lack of frequency in product quality testing	QC operators are not thorough enough in testing Operators do not follow SOPs during testing	Lack of training for operators	
3	MgO Content Discrepancy	Inappropriate raw material quality	Raw materials contaminated with other materials	Improper storage of raw materials	Raw material warehouse too open	Raw materials exposed to rainwater
		The method used in processing does not comply with SOP	Processing temperature and time are not appropriate	The grinding process is not fine enough		
4	Fertilizer Agglomeration	High moisture content of the product	Incorrect machine settings Lack of water content monitoring	Blowing machine not working optimally	Lack of regular machine maintenance	Lack of supervision of machine maintenance scheduling
		Product contaminated with other materials	Incorrect product storage procedures Dirty product silos	Lack of supervision of silo cleanliness	Operators unaware of their work	
		Lack of regular quality testing	Lack of awareness about quality control	Too much focus on production quantity		
5	Product Weight Not Compliant	The contents of the product inside the packaging are inconsistent	The filling machine does not dispense the same amount of product in each process	Machine maintenance is not performed regularly		
		The product has uneven density	The grinding process is uneven	There are mechanical problems that are not immediately repaired	There are no daily checks on the condition of the vertical roll mill	

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Improve

At this stage, steps are taken to reduce defects in the fertilizer production process, where improvements are made based on data analysis and findings from the previous stage.

Big Picture Mapping Suggestions

Figure 4. Big Picture Mapping Recommendation

From the big picture Mapping picture, it can be visible that when processing the information the use of the tilt six sigma method, the value of fertilizer manufacturing lead time is quicker than earlier than. The preliminary fertilizer production lead time became recognized as 350 mins, then recognized again as 305 minutes. In order that the fee for the percentage of performance development inside the fertilizer manufacturing technique can be defined as follows:

$$\%efficiency\ improvement = \frac{Initial\ lead\ time - Recommendation\ lead\ time}{Initial\ lead\ time}\ x\ 100\%$$

$$\%efficiency\ improvement = \frac{350-305}{350}\ x\ 100\% = 12{,}86\%$$

Primarily based at the calculation of the proportion of efficiency development, the end result is 6.86%. so that the fee of the proposed process Cycle efficiency (PCE) may be determined through the following method:

$$PCE = \frac{Value\ Added}{Lead\ Time}\ x\ 100\% = \frac{170}{305}\ x\ 100\% = 55{,}74\%$$

Based on the proposed Process Cycle Efficiency (PCE) value, the result is 55,74%, which means that the fertilizer production process has improved.

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Table 10. Comparison of Conditions Before and After the Proposed Improvements Were Implemented

Aspect	Detail Aspect	Before Repair	After Repair
Process Time	Lead Time	350 Minute	305 Minute
Time	Value Added	170 Minute	170 Minute
	Non Value Added	45 Minute	0 Minute
	Necessary Non Value Added	135 Minute	135 Minute
PCE Level	Process Cycle Efficiency (PCE)	48,57%	55,74%
Activity Type	Operation	32	27
	Transportation	6	5
	Inspection	6	5
	Storage	0	0
	Delay	6	6

Improvement Recommendation Using 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke)

Seiri

In its application, this principle can be done by using color labels or visual signs to distinguish areas for each raw material in order to maintain the quality of raw materials, evaluating and removing redundant work procedures that hinder quality control so that operators can focus more on maintaining product quality rather than just pursuing high production targets, and clearly identifying active and inactive machine maintenance schedules.

Seiton

In its application, this principle can be carried out by designing the flow of goods in and out so that the period of arrival of goods can be distinguished and prevent damage to raw materials, creating a special area to store production products that do not meet standards so that they are separated from good quality products to facilitate the re-sorting process before distribution, creating a daily check form to ensure that the machine settings and conditions are according to standards.

Seiso

In practice, this principle can be implemented by scheduling regular daily/weekly inspections to clean storage areas, adding waterproof covers/tents or moving raw materials to covered warehouses to prevent direct exposure to rain, and removing dolomite residue or debris that can clog or interfere with the fineness of the mill.

Seiketsu

In its application, this principle can be done by creating a pictorial SOP for machine checking and lubrication procedures, placed directly in the work area, setting a realistic maximum daily production limit according to machine capacity, so that the production process is not rushed and produces more controlled quality, and providing regular training to machine operators about the importance of machine cleanliness in ensuring the quality of dolomite fertilizer milling results so that operators are moved to clean without waiting for special instructions.

Shitsuke

In practice, this principle can be implemented by conducting pre-shift briefings to communicate daily targets, potential risks, increasing work awareness, as well as conducting regular internal

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

audits of the implementation of maintenance schedules and immediately discarding or updating schedules that are ineffective or ineffective.

Scientific Reflections on Waste Elimination and Operational Discipline through Lean Six Sigma and 5S Integration"

The fact that wastes in the form of defects, motion, and transportation are dominant in PT XYZ should raise the eyebrows to evaluate the fundamental structural and systemic natures of the manufacturing environment. These types of waste are far more than simply one or more isolated un-efficiencies, and instead indicate a higher level of misalignment between the inputs of production, process design and the interactions between humans and systems. Operation-science-wise, their persistence indicates a lack of systemic assimilation of quality at the outset, as well as the lack of predictive control. Instead of focusing on what was really observed (which is the role of the results section), the current discussion examines the theoretical implications: PT XYZ operates in a reactive quality-control mode where defects are handled ex post rather than predicted in advance, thus violating the principles of built-in quality was expressed in the lean production theory (Ishak et al., 2020; Meriton et al., 2021).

Scientifically, the application of Lean Six Sigma is useful since it generalises and controls the variability of processes via statistical rigor. With a process running at a 4-sigma level as demonstrated in this case, the process is operating within the unstable realm of quality where the trend with regard to defects is statistical in nature and it is exceptionally prone to tiny variations in inputs. The reliability engineering describes this level of sigma as non-trivial probability of failures that compound in a sequential operation and especially in chemical processing where the batch-to-batch variability needs to be heavily regulated (Thyregod et al, 2004). The larger implication is not just that the process is not performing well, but that it does not have the inherent ability to improve itself or adjust on its own, which is in large part why the capability maturity models and other continuous-improvement literature has accorded it so much attention (Marshall, 2010; Santally et al., 2020; Albliwi et al., 2014).

A permissible quantity is the entropy of processes which is used in the context of systems engineering to measure disorder or predictability in the sequences of work done internally (Alkan et al., 2018; Dulesov et al., 2018). Process cycle efficiency (PCE) has been identified to be the key indicator in the current study, and this diagnostic parameter meets all the required entropic criteria. The values of NVA and NNVA being high, as observed at the target facility, denote a workflow attributed to a regime of high entropy according to which production is not very restricted by directionality. The conditions lead to decreased variability responsiveness induced by the system, increased error detection, and less efficiency of the flow, which have been proved in empirical and theoretical studies in the past (Williams & Hoel, 2003; Çelebi, 2019). To put it more specifically, higher level of process entropy is not a capacity shortfall, per se, but shortfall of coherence across the system, and that is what lies the boundary between technical performance and organizational performance. It then follows that the discussion should not rest on the incremental improvement of the performance but rather on the fact that there is an explicit intention of moving out of the loosely coupled state to a tightly coordinated domain where a lean synchronization is in place.

Introducing the principles of 5S in such a situation does not only signify a step of the operational intervention but rather a shift in perception regarding the order in operation. Read into a scientific perspective, 5S actually functions as an inexpensive cybernetic feedback system: Seiri strains the outgoing dirty non-value-added activity; Seiton reduces signal delay; Seiso improves transparency in the system; Seiketsu lines in the operational parameters; and Shitsuke in-forces system feedback with a culture as well. Taken together these steps

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

sequentially introduce constraints on the degrees of freedom in which error can propagate effectively narrowing process control boundaries with little or no sophisticated automation involved. It is especially relevant to consider such systemic narrowing when attempting to archive the benefit of such a narrowing in medium-sized process industries, some of which include fertilizer manufacturing, in which digital monitoring is often primitive and human certainty is at the core (Burchette, 2025).

The implementation of the VALSAT within the scope of diagnostic tools alignment creates an opportunity of methodological rigor. The fact that the instrument is correlated with certain types of wastes augers well to precision in showing that the measurement instruments should be chosen based on the nature of the processing procedure and not inflicted absorbing any method (Sunheimer et al., 2011). When such practice is followed, it aligns with the systems-theory concept of industrial engineering that warns against diagnostic fragmentation, that is, the use of generic tools regardless of the process topology or waste taxonomy (Cromhout, 2023; Rodrigues et al., 2016). Through the use of VALSAT to identify areas of high impact, the study serves as an example of the scientific discipline received in the use of the tool thus achieving high levels of accuracy as well as the efficiency of the intervention.

One of the novel ideas of the field of science is to center human factors as limitations and facilitators in the process of the improvement. In quantitative lean assessments, this two-part can often be discarded to the periphery, but it is at the forefront of cultural change success. Human reliability literature (Kluger & DeNisi, 1996; Cervone & Wood, 1995) points to variability of performance, particularly, under standardised and cognitively taxing tasks, as being a result of flawed feedback processes, lack of task meaning and reinforcement. That is why, the visual SOPs, daily audits, and pre-shift briefings can be considered as empirically proven methods of behavior stabilization. The lack of sustainability of technical improvements also seems to be the contribution of their absence in process-intensive settings because it corresponded to the literature about failed Six Sigma rollouts that was empirically based.

The given study finds an empirical support of the theoretical effects postulated within the framework of Lean Six Sigma: constituent interventions of narrow focus can initiate statistically significant jumps in lead time as well as efficiency of the process cycle. Although the given gains are small, they represent an example of non-linear relationship as subject to the application of path-dependent network behavior (Colombelli & Von, 2011). The sequential increases in system performance, furthermore, fall very comfortably in the resilience engineering paradigm, whereby the site of performance improvement is linked to the (optimized) overall interactions and decreased feedback delays, and not due to the improved performance of individual components. It being so, the main value added of the given endeavor will be both working practice on the one hand and on the other hand the fact that scientifically-enhanced improvement frameworks, in this case, Lean Six Sigma in collaboration with 5S and VALSAT practices, can be termed as flexible mechanisms of developing higher intelligence of production systems as a whole.

Conclusion

Based on the analysis and evaluation, there is a reduction in the lead time value for activities that do not provide added value in the fertilizer production process, from 350 minutes to 326 minutes. This reduction is achieved by reducing activities that cause delays. Thus, the proposed lead time is reduced by 24 minutes, which also reduces the cycle time in the fertilizer production process by 6,86% with the DPMO value obtained is 32,706.67 and the sigma level is 3,43.

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Suggestion

Proposed improvements to reduce waste include the application of the 5S principles (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) to improve workplace tidiness and efficiency, as well as the rearrangement of facility layouts to reduce travel time between processes. In addition, the development of Standard Operating Procedures (SOPs) for each stage of production and training for operators to increase awareness of the importance of work efficiency. The implementation of these improvements is expected to minimize non-value-added activities, increase productivity, and reduce time.

References

Adiasa, I., Achmad, A. M. F., Busri, N. K., & Rabbani, R. (2024). Analisis Six Sigma Dmaic Dalam Mengurangi Defect Struktur Atap Pipa Baja Pada Proyek Perluasan Terminal Bandara Internasional Lombok. *Hexagon*, *5*(2), 115-129. https://doi.org/10.36761/hexagon.v5i2.4073

Albliwi, S. A., Antony, J., & Arshed, N. (2014, December). Critical literature review on maturity models for business process excellence. In *2014 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 79-83). IEEE. https://doi.org/10.1109/IEEM.2014.7058604

Alkan, B., Vera, D. A., Ahmad, M., Ahmad, B., & Harrison, R. (2018). Complexity in manufacturing systems and its measures: a literature review. *European Journal of Industrial Engineering*, *12*(1), 116-150. https://doi.org/10.1504/EJIE.2018.089883

Andriani, M., & Sabardi, W. (2022). Usulan perbaikan kualitas produk roti dengan menggunakan metode six sigma. *Jurnal Industri Samudra*, *3*(1), 11-11. Retrieved from https://doi.org/10.55377/jis.v3i1.5876

Anggraini, W., Kusumanto, I., & Sutaryono, A. (2019). Usulan peningkatan kualitas kain batik semi tulis menggunakan metode six sigma. *Jurnal Teknik Industri*, *5*(1), 48-55. http://dx.doi.org/10.24014/jti.v5i1.6765

Annisa, R. (2023). *Topik Khusus Analisis dan Perancangan Sistem Kerja Edisi Ke-1*. Malang: Media Nusa Creative (MNC Publishing).

Ariesta, Y., Rosita, S. H., Putri, N. H. D., Andra, R. M., Rachmadan, R., & Rohand, S. (2023). Meningkatkan Layanan Catering melalui Metode Lean dan Six Sigma (Studi Kasus UMKM Bilqis Catering). *Jurnal Logistica*, *1*(2), 22-29.

Burchette, T. (2025). What has the petroleum industry ever done for us? On the positive legacies from the petroleum industry and the role of carbonate and evaporite studies in the energy transition. *Geological Society, London, Special Publications*, *548*(1), SP548-2024. https://doi.org/10.1144/SP548-2024-103

Çelebi, D. (2019). The role of logistics performance in promoting trade. *Maritime Economics & Logistics*, *21*, 307-323. https://doi.org/10.1057/s41278-017-0094-4

Cervone, D., & Wood, R. (1995). Goals, feedback, and the differential influence of self-regulatory processes on cognitively complex performance. *Cognitive Therapy and Research*, *19*(5), 519-545. https://doi.org/10.1007/BF02230512

Colombelli, A., & von Tunzelmann, N. (2011). The persistence of innovation and path dependence. In *Handbook on the economic complexity of technological change*. Edward Elgar Publishing. https://doi.org/10.4337/9780857930378.00010]

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Cromhout, B. (2023). *A systems engineering approach: the application of lean thinking to support sustainability transitions in healthcare* (Doctoral dissertation, Stellenbosch: Stellenbosch University).

de Assis, R. F., de Santa-Eulalia, L. A., Ferreira, W. D. P., Armellini, F., Anholon, R., Rampasso, I. S., & Santos, J. G. C. L. D. (2021). Translating value stream maps into system dynamics models: a practical framework. *The International Journal of Advanced Manufacturing Technology*, *114*(11), 3537-3550. https://doi.org/10.1007/s00170-021-07053-y

Dulesov, A. S., Karandeev, D. J., & Dulesova, N. V. (2018, November). Determination of the amount of entropy of non-recoverable elements of the technical system. In *IOP Conference Series: Materials Science and Engineering* (Vol. 450, No. 7, p. 072004). IOP Publishing. https://doi.org/10.1088/1757-899X/450/7/072004

Fitriana, R., Sari, D. K., & Habyba, A. N. (2021). *Pengendalian dan Penjaminan Mutu*. Jawa Tengah: Wawasan Ilmu.

Hadavi, S., Verlinde, S., Verbeke, W., Macharis, C., & Guns, T. (2018). Monitoring urban-freight transport based on GPS trajectories of heavy-goods vehicles. *IEEE Transactions on Intelligent Transportation Systems*, *20*(10), 3747-3758. https://doi.org/10.1109/TITS.2018.2880949

Helmold, M. (2020). Waste and Value-Added. In *Lean Management and Kaizen: Fundamentals from Cases and Examples in Operations and Supply Chain Management* (pp. 31-44). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-46981-8_4

Hidajat, H. H., & Subagyo, A. M. (2022). Analisis Pengendalian Kualitas Produk X Dengan Metode Six Sigma (DMAIC) Pada PT. XYZ. *Jurnal Ilmiah Wahana Pendidikan*, *8*(9), 234-242. https://doi.org/10.5281/zenodo.6648878

Hines, P., & Rich, N. (1997). The seven value stream mapping tools. *International journal of operations & production management*, *17*(1), 46-64. https://doi.org/10.1108/01443579710157989

Irahman, M. S. (2024). Implementasi Prinsip Lean Six Sigma Dalam Meningkatkan Efisiensi Dan Efektivitas Proses Produksi Dan Distribusi Pada Makanan Dan Minuman. *LANDMARK:(Jurnal Pengabdian Masyarakat)*, *2*(2), 31-36. https://doi.org/10.32520/landmark.v2i2.3000

Ishak, A., Siregar, K., Ginting, R., & Manik, A. (2020, December). Analysis roofing quality control using statistical quality control (sqc)(case study: xyz company). In *IOP Conference Series: Materials Science and Engineering* (Vol. 1003, No. 1, p. 012085). IOP Publishing. https://doi.org/10.1088/1757-899X/1003/1/012085

Jusmani, J., & Oktariansyah, O. (2021). Activity Based Management Sebagai Instrumen Bagi Manajemen Dalam Efisiensi Biaya. *Jurnal Media Wahana Ekonomika*, *18*(3), 377-386. https://doi.org/10.31851/jmwe.v18i3.6658

Kinariyanti, M., & Sulaksono, A. G. (2025). Implementasi Metode Lean Six Sigma Dalam Digitalisasi Dokumen Iso Untuk Peningkatan Corrective Dan Preventive Action (Capa) Pada Pt. Xyb. *Jati (Jurnal Mahasiswa Teknik Informatika)*, *9*(1), 1088-1094. https://doi.org/10.36040/jati.v9i1.12612

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performance: a historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological bulletin*, *119*(2), 254.

Manzouri, M., Ab-Rahman, M. N., Che Mohd Zain, C. R., & Jamsari, E. A. (2014). Increasing production and eliminating waste through lean tools and techniques for halal food companies. *Sustainability*, *6*(12), 9179-9204. https://doi.org/10.3390/su6129179

Marshall, S. (2010). A quality framework for continuous improvement of e-Learning: The e-Learning Maturity Model. *International Journal of E-Learning & Distance Education/Revue internationale du e-learning et la formation à distance*, *24*(1), 143-166.

Meriton, R., Bhandal, R., Graham, G., & Brown, A. (2021). An examination of the generative mechanisms of value in big data-enabled supply chain management research. *International Journal of Production Research*, *59*(23), 7283-7310. https://doi.org/10.1080/00207543.2020.1832273

Mu'adzah, M. A., Ahmad, T. L., & Kusumawati, A. N. (2020). Systematic literature review: Implementasi metode 5s pada perusahaan manufaktur. *Jurnal Teknologi Dan Manajemen Industri*, *1*(2), 31-39.

Nurdiansyah, D., Fatimah, S. N., Nurwiyanti, H., & Fauzi, M. (2022). Usulan Efisiensi Waste Proses Produksi Bed Sheet di PT. ABC Menggunakan Metode Value Stream Mapping. *Jurnal Bayesian: Jurnal Ilmiah Statistika dan Ekonometrika*, *2*(1), 93-106. https://doi.org/10.46306/bay.v2i1.32

Putri, F. M., Profita, A., & Gunawan, S. (2021). Analysis of the application of the lean six sigma method to minimize waste in the plywood production process. *Teknika: Jurnal Sains dan Teknologi*, *17*(2), 174-182. http://dx.doi.org/10.36055/tjst.v17i2.11093

Putri, N. T. (2022). *Manajemen kualitas produk dan jasa*. Padang: Andalas University Press.

Ramadhan, M. (2021). Analisis Pengendalian Kualitas Untuk Mengurangi Cacat Pada Produk Sepatu Menggunakan Metode Six Sigma dan Kaizen. *Matrik: Jurnal Manajemen dan Teknik Industri Produksi*, *22*(1), 55-64. http://dx.doi.org/10.30587/matrik.v22i1.2517

Restuputri, D. P., & Wahyudin, D. (2019). Penerapan 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke) Sebagai Upaya Pengurangan Waste Pada Pt X. *Jurnal Sistem Teknik Industri*, *21*(1), 51-63. https://doi.org/10.32734/jsti.v21i1.903

Rodrigues, S., Martinho, G., & Pires, A. (2016). Waste collection systems. Part A: a taxonomy. *Journal of Cleaner Production*, *113*, 374-387. https://doi.org/10.1016/j.jclepro.2015.09.143

Santally, M. I., Rajabalee, Y. B., Sungkur, R. K., Maudarbocus, M. I., & Greller, W. (2020). Enabling continuous improvement in online teaching and learning through e-learning capability and maturity assessment. *Business process management journal*, *26*(6), 1687-1707. https://doi.org/10.1108/BPMJ-11-2018-0335

Sunheimer, R. L., Threatte, G. A., Pincus, M. R., & Lifshitz, M. S. (2011). Analysis: principles of instrumentation. *Henry's Clinical Diagnosis and Management by Laboratory Methods*, 37-63.

Suryanti, F., Sudiarno, A., & Sudarni, A. A. C. (2020, April). Combination of value stream mapping and house of risk methods to eliminate waste in productivity enhancement in

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)

production area of fertilizer company. In *IOP Conference Series: Materials Science and Engineering* (Vol. 847, No. 1, p. 012091). IOP Publishing. https://doi.org/10.1088/1757-899X/847/1/012091

Thyregod, P., Iwersen, J., & Melgaard, H. (2004). On monitoring processes and assessing process capability under a hierarchical model, Part 2. In *Frontiers in Statistical Quality Control 7* (pp. 150-167). Heidelberg: Physica-Verlag HD. https://doi.org/10.1007/978-3-7908-2674-6

Widiarta, I. P. G. D., Anindyasari, D., & Mayulu, H. (2025, January). Mengoptimalkan Limbah Sapi Potong untuk Energi Terbarukan dan Produksi Pupuk Organik dalam Kerangka Ekonomi Sirkular: Implikasi bagi Pengembangan Industri Peternakan Berkelanjutan. In *FORUM EKONOMI: Jurnal Ekonomi, Manajemen dan Akuntansi* (Vol. 27, No. 1, pp. 31-41). https://doi.org/10.30872/jfor.v27i1.2622

Williams, B. M., & Hoel, L. A. (2003). Modeling and forecasting vehicular traffic flow as a seasonal ARIMA process: Theoretical basis and empirical results. *Journal of transportation engineering*, *129*(6), 664-672. https://doi.org/10.1061/(ASCE)0733-947X(2003)129:6(664)

ISSN 2721-1304 (Print), ISSN 2721-1207 (online)