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ANALYSIS OF CORE SUPPLY CHAIN PROCESS PERFORMANCE BASED ON THE LEAN SIX SIGMA SUPPLY CHAIN MANAGEMENT APPROACH (Case Study: PT PG. CANDI BARU)

Krisna Ramadhian Arifano[1], Dira Ernawati[2], Sinta Dewi[3]
[1,2,3] Program Studi Teknik Industri, Fakultas Teknik Dan Sains, Universitas Pembangunan Nasional Veteran, Jawa Timur, Indonesia
Email: : 20032010170@student.upnjatim.ac.id, dira.ti@upnjatim.ac.id, sinta.dewi.ti@upnjatim.ac.id

ABSTRACT

PT. PG Candi Baru is a manufacturing company in Indonesia that produces sugar in the form of White Crystal Sugar (GKP) from sugar cane as raw material. Application of the supply chain concept at PT PG. Candi Baru is needed to fulfill the needs of end customers. The aim of the research is to integrate the lean six sigma supply chain management concept to design and measure performance measurement models and determine the causes of company performance failures and then provide recommendations for improvement according to the lean concept. This research was carried out only up to the improvement stage. The result of this research is an overall performance measurement of 66.6666 where this value can be categorized as "Average". This value shows that supply chain management activities at PT. PG Candi Baru is running moderately and obtained 9 KPIs that have not reached the target. Waste is the cause of the 9 KPIs not achieving the target, namely waste defects, waiting, not utilizing employee knowledge, skills and abilities and extra processing. Recommendations for improvement given to the company to reduce the occurrence of waste are: For defects in sugar quality, the proposed improvement is to carry out milling in accordance with established standards and use raw materials that comply with specifications. When waiting for raw materials to be late, the proposed improvement is that the plant department must carry out earlier purchasing planning to avoid waste waiting and prioritize TS suppliers because they have a higher weight than other suppliers. Not utilizing employees' knowledge, skills and abilities, the proposed improvement for the production department is training on how to forecast production scheduling. In extra processing, the proposed improvement is that the company can provide a quality control list when inspecting the finished product so that the inspection is more controlled.

KEYWORDS *Lean, Performance Measurement, Supply Chain, SCOR, Six Sigma, 9 Waste E-Downtime*

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INTRODUCTION

The rapid competition in the industrial world has led to increasingly intense competition among companies. This highlights the importance of improving company performance, urging companies to engage in management engineering by applying the concept of Supply Chain Management (SCM). One emerging supply chain issue recognized as crucial for companies to adopt is Lean Six Sigma Supply Chain Management. Lean Six Sigma in supply chain management aims to enhance efficiency and quality across the entire supply chain, identifying and eliminating waste or non-value-added activities and variations throughout the supply chain process through continuous improvement.

PT. PG Candi Baru is a manufacturing company engaged in sugar production. PT. PG Candi Baru, a subsidiary of Rajawali Nusantara, produces white crystal sugar as its main product. PT. PG Candi Baru is located at Jl. Raya Candi No.10, Candi Jaya, Candi, Sidoarjo Regency, East Java. The main product of PT. PG Candi Baru is white crystal sugar with a milling capacity of 3000 tons/day. Additionally, by-products such as molasses and bagasse are produced. To meet the raw material supply needs for sugar production, PT. PG Candi Baru sources from 3 raw materials: Own Sugarcane (TS), Partnership Sugarcane (TRK), and Independent Sugarcane (TRM).

In carrying out its supply chain activities, PT. PG Candi Baru has encountered challenges in procurement, production, and delays in delivering products to customers. In the procurement process (source), the company has experienced delays in providing raw materials caused by the failure to reach the supplier targets of independent sugarcane (TRM) due to competition with other sugar mills offering higher purchase prices to farmers during the milling season, which resulted in production delays and unmet production targets. This can be seen from PT. PG Candi Baru's operational production target for the years 2021, 2022, and 2023, which were successively set at 36,964 tons, 31,570 tons, and 31,160 tons. Based on production data, in 2021, 2022, and 2023, PT. PG. Candi Baru produced sugar amounts of 23,357 tons, 27,084 tons, and 30,871.4 tons successively. During the production process, the company faced issues such as low sugar production yield rates, averaging 6.94% compared to the target yield of 7.99%, as well as sugar product defects including fine sugar, lumps, and saponified sugar, along with delayed product deliveries to customers due to product quality issues. Moreover, the company is unaware of the necessary indicators for measuring supply chain management (SCM) performance and the required improvements to enhance Lean Six Sigma Supply Chain Management performance.

The emerging trend in measuring supply chain performance, recognized as beneficial for companies, is Lean Six Sigma Supply Chain Management using the Supply Chain Operations Reference (SCOR) method. Various methods are utilized to measure the effectiveness of manufacturing company performance, including the Balanced Scorecard (BSC), Performance Prism, Integrated Performance

Measurement System (IPMS), and Supply Chain Operations Reference (SCOR). In this study, the SCOR method was chosen because it encompasses supply chain activities from upstream to downstream, unlike other methods that focus solely on internal activities. In its evolution, the SCOR method is integrated with the Analytic Hierarchy Process (AHP). AHP is widely applied in decision-making systems compared to other methods like TOPSIS, Electre Promethee, and Saw because it hierarchically structures problems both qualitatively and quantitatively. The performance measurement results of the SCOR model will reveal the weakest points in PT. PG Candi Baru's core supply chain processes, which will be targeted for improvement using the Lean Six Sigma method. This method offers structured and efficient improvement steps. With Lean concepts, non-value-added activities can be identified, and waste can be reduced using the 9 waste concept. Meanwhile, Six Sigma is employed to enhance process capabilities along the existing value stream and strive for zero defects (Prasetyo, Emaputra, and Parwati 2021).

Previous research on measuring supply chain performance has been conducted using various methods, serving as important references. Some studies cover different industrial sectors such as furniture manufacturing, spray paint production, as well as poultry and cement supply chain management. For instance, a study by Firda Astria Oktasaputri et al. (2020) addresses the enhancement of core supply chain process performance at PT Gatra Mapan using the SCOR and Lean Six Sigma methods. Similarly, research by Tita Pratama Putri and Dede Rukmayadi (2022) at PT MGP employs SCOR and AHP. Furthermore, Windrawati et al. (2022) and Asep Ridwan et al. (2017) adopt a similar approach in analyzing supply chain performance using SCOR and Lean Six Sigma. Additionally, Safitri Ambarsari et al. (2020) integrate lean six sigma concepts to measure core supply chain process performance at PT Semen Indonesia (Persero) Tbk using SCOR-based AHP. All these studies provide significant contributions to understanding and improving supply chain performance across various industrial sectors.

This research aims to assist in solving company issues by determining whether the implementation of the Supply Chain Operations Reference (SCOR) method for each performance indicator has been effective. It also seeks to determine performance levels using the SCOR-based Analytical Hierarchy Process (AHP) approach, identify critical performance attributes in the company's supply chain, analyze and identify the causes of waste using the 9 waste concept, and implement improvements using the Lean Six Sigma approach to reduce waste. The findings obtained will be recommended back to the company for evaluation, providing useful insights for future improvements.

RESEARCH METHOD

This research was conducted at PT PG. Candi Baru, a sugar company based in Sidoarjo Regency, East Java, Indonesia, from February 2024 until data fulfillment. The dependent variable in this study is the level of supply chain management performance, while the independent variables include aspects such as planning, procurement of raw materials, production, delivery, and product returns. The problem-solving steps in this research begin with literature review, field study, problem formulation, and variable identification. Next, data collection is carried out, both primary and secondary, Key Performance Indicators (KPIs) are determined from the SCOR concept, weighting is done using the AHP method, and consistency tests are conducted. The data is then normalized using the Traffic Light System and given final values for supply chain performance. The next steps involve data analysis, waste identification, and providing improvement recommendations. The data analysis technique used is the Lean Six Sigma approach with DMAIC stages and SCOR method based on AHP. From the results of this research, waste identification is conducted using the E-DOWNTIME approach, consisting of 9 factors, such as Environmental, Health, and Safety (EHS), Defect, Over Production, Waiting, Non-Utilizing Employee, Transportation, Inventory, Motion, and Excess Processing. Improvement recommendations are provided for each perspective that does not meet the target supply chain management performance at PT PG. Candi Baru.

RESULT AND DISCUSSION

Data Collection

Data collection was conducted at PT PG. Candi Baru starting from February 2024. The methods used included interviews, observations, literature reviews, and data from company documents related to the research topic. Data was divided into primary and secondary. Primary data was obtained through interviews and questionnaire filling with the heads of procurement planning bureau, fabrication department head, fabrication staff, marketing department head, and Quality Assurance department head. Secondary data included various information, such as warehouse capacity, sugarcane land area, raw material delivery from suppliers, operational production targets, annual production data, sugar yield operational targets, and sugar product defect data. Warehouse capacity and sugarcane land area data in 2023 showed the conditions of the warehouse and sugarcane land area during that period. Raw material delivery from suppliers and operational production targets provided an overview of raw material supply and production targets. Annual production data indicated sugar production output during that period. Sugar yield operational targets indicated production efficiency. Meanwhile, sugar product defect data in 2023 recorded types of sugar product defects according to the standards applied by the company.

Company Overview

PT. PG Candi Baru Sidoarjo has a long history dating back to 1832 by the Goen Tjing family with the name N.V. Suiker Fabriek "Tjandi". After changing ownership several times, in 1962 the company's name was changed to PT. Pabrik Gula Tjandi. In 1992, PT. Rajawali Nusantara Indonesia (PT. RNI) took over the majority shares of the company, which then changed its name to PT. PG Candi Baru in 2004. The company has continuously increased its sugarcane milling capacity over time. Starting from the initial capacity in 1911 of 7,500 kw/day to reaching 2,700 tons per day in 2013. The company's location was chosen considering several strategic factors such as the availability of labor, adequate water supply, suitable conditions for sugarcane cultivation, and a strategic location on the Surabaya - Malang highway. The company's vision is to become the best company at the national level in the sugar industry and asset management, ready to face changes and challenges and excel in competition based on its own capabilities. The company's mission includes managing the sugar industry with the best performance, developing business in asset management professionally, increasing company value through innovation and human resources development, conducting business professionally to improve the welfare of employees and stakeholders, and making positive contributions to the environment, society, and local government.

Raw Materials

Raw materials are a key element in a company's or industry's supply chain because they form the basis for the final products produced. PT. PG Candi Baru uses sugarcane as the main raw material with a milling capacity of 3,000 Tons Cane per Day (TCD), obtained from several sources, including own sugarcane (TS), sugarcane from partnership farmers (TRK), and independent sugarcane farmers (TRM). Additionally, there are supporting raw materials used in the production process, including quicklime, imbisi water, phosphoric acid, sulfur, flocculant, calcium hypochlorite, alum, caustic soda flake, bactericide, fungicide, fondant, pheromone, MPQ, MCO, and Oxytrol. Each supporting raw material has a specific role in the production process, ranging from assisting in purification to maintaining plant environmental cleanliness.

Production Process

The production process is a technique of transforming inputs into outputs, so that the results obtained, whether goods or services, have higher added value.

Crushing Station

It is a production station aimed at obtaining as much juice as possible from the sugarcane stalks by crushing. Here are some explanations about the crushing station:

a. Preliminary Work Tools and Crushing
   Consists of 3 machines: cane cutter 1, cane cutter 2, and Crushing 1, Crushing 2, Crushing 3, Crushing 4, and HDHS (Heavy Duty Hammer Shredder).
b. Ambibisi Water Addition
   Water addition to bagasse coming out of Crushing 4 (temperature >80ºC).
c. Sanitation Cleanliness
   Maintenance of physical and chemical cleanliness.
d. Preparation Index (PI) Analysis
   Standard at PT. PG Candi Baru is 91%.
e. Juice Analysis
   To determine the brix value, pol, and Purity Content (PC).

To achieve the Standard Operational Procedure (SOP) quality control, the analysis is conducted on the Preparation Index (PI) or Preparation Value. If it doesn’t meet PT. PG Candi Baru's standard of ≤91%, the performance of the preliminary equipment is considered inadequate. Consequently, the Quality Assurance department will inform the installation department to recheck the settings of the preliminary equipment. The check includes examining the sharpness of the cane cutter 1, cane cutter 2, Crushing 1, Crushing 2, Crushing 3, Crushing 4, and HDHS (Heavy Duty Hammer Shredder) blades. If the blades are dull, they are sharpened or replaced. The % pol and % dry matter of the bagasse are influenced by the performance of the preparation equipment. Thus, if the performance of the preparation equipment is good or has a high PI value, the % pol of the bagasse will be lower, and the % dry matter will be higher.

Clarification Station

This clarification process aims to remove as many non-sugar components (impurities) and color from the juice efficiently and correctly, without damaging the sugar content in the juice. Heating in the clarification station is done twice, at PP1 and PP2. The temperature in PP 1 is 75ºC, and in PP 2, it is 105ºC - 110ºC. Then, hydrated lime is added to increase the pH of the juice and form the sediment nucleus. Mixing the juice with hydrated lime must be perfect by controlling temperature, time, and pH. The addition of SO2 gas aims to neutralize excess lime by forming perfect calcium sulfite sediment and lightening the color. This process must be controlled to maintain the pH at the standard level and the temperature at around 74ºC. The addition of this solution must be even and continuous to the juice. The sedimentation process must be controlled to achieve the specified brix.

Evaporation Station

The evaporation process carried out in the sugar production process at PT. PG Candi Baru aims to evaporate most of the water from the juice. This process is attempted to be fast, non-destructive to sugar, and economical. The success factors are the leftover steam, vacuum pressure, clear juice volume in each evaporator body, condensate, juice pipes, and leaks. Furthermore, the supervision of the crystallization process aims to prevent the occurrence of dark colors due to oxidation. Control is carried out by ensuring that SO2 gas is not contaminated and the thick sulfited juice temperature is around 55ºC. The pH value of the Clear Juice in the evaporator is analyzed to determine the efficiency of the evaporation process and the degree of thick juice, which is 30 - 32 Be. The standard for the brix value of the thick juice is 60-65%.

If there is a deviation, such as a decrease in the quality of the thick juice in the evaporation process, it can be caused by the fouling of the heating bodies in the evaporation station due to the buildup of scale on the heating body sides. This fouling can reduce quality because it prolongs the evaporation process and the thick juice produced is not optimal in terms of the % brix which is below the target. Therefore, a brief cleaning is needed to ensure the maximum operational time of the evaporator, with a minimum cleanliness result of 90%. Scale cleaning is done using effective and environmentally friendly scale softening agents. The agent used is caustic soda with a solution concentration of 15%.

Cooking Station

Several controls and Process Crystallization Controls are performed at the cooking station:

a. Crystallization process is carried out under vacuum as per the specified standard. One cooking body at the cooking station is controlled by one worker.
b. Cooking A must have a PC value >80 and %brix around 93-95. The crystal size in Cooking A is 0.8-1.1 mm.
c. Cooking C, the standard PC value is 72-74 and %brix is around 97. The crystal size in Cooking AC is about 0.5 mm.
d. Cooking D must have a PC value of 58-60 and %brix around ≥99. The crystal size in Cooking A is about 0.3 mm.
e. Before the addition of new cooking, the cooking body will be cleaned first with steam. This is intended to ensure the maximum optimal process result in achieving the above standards.

Furthermore, the Analysis of Cooking A, Cooking C, and Cooking D is intended to determine the %brix and %pol in each cooking result. When the analysis values have been obtained, the PC value for each cooking will also be known. This analysis also aims to determine the success of the crystallization process according to the specified standards. If there is a deviation from the analysis results indicating that the PC value of each sugar in A, C, and D is below the set standard, the QA department will inform the processing department to check and provide solutions. The solution is to add klare D to Cooking D. However, if the PC value in Cooking D or C is too high, the klare D in Cooking D must be withdrawn to ensure that the PC value in Cooking A does not exceed the standard limit of 81.0.

Centrifugation Station

The purpose of the Centrifugation Station process is to separate crystals in their solution from Cooking A, Cooking C, and Cooking D. This centrifugation process works based on rotational force (centrifugal force). Quality control and analysis conducted at the centrifugation station are as follows:

a. HGF (High-Grade Centrifugal) control, the centrifugation process must use water at the specified temperature. In addition to temperature, the time factor must also always be adjusted according to the specified standard.
b. LGF (Low-Grade Centrifugal) control must be maintained and monitored to be continuous, and the process must be continuous. Water addition uses cold water to prevent excessive erosion of sugar crystals. Then, the steam process is carried out to clean the sugar attached to the filter.
c. Analysis of Molasses or syrups is a by-product of the sugar processing industry, specifically in the separation process of D1 sugar with syrup in Cooking D. The syrup analysis aims to determine the % brix and % pol values, as well as the PC value in the syrup.
d. Stroop, Babonan, and Klare D analysis are carried out to determine the % brix, % pol, and PC values in Stroop A, Stroop C, Stroop D, Babonan C, Babonan D, and Klare D. This aims to maintain the quality of the sugar produced.

Finishing and Packaging Station

This finishing station has several objectives, namely drying the sugar that has undergone the centrifugation process to reduce the water content. Then, cooling the sugar to lower the sugar temperature after the drying process and before the packaging process. The next objective is to separate the small (fine), normal, and lumpy sugar, and then package the sugar properly according to company standards.

Define

This stage focuses on understanding the company's supply chain and determining the configuration of supply chain activities in the production process. It involves using the SCOR model to measure supply chain performance, determine KPIs, and assign weights to these KPIs.

The identification of PT. PG Candi Baru's Supply Chain starts from the arrival of raw materials to distribution to distributors. The depiction of the supply chain activity configuration is done to classify activities according to the five supply chain perspectives: plan, source, make, deliver, and return.

The Supply Chain activity configuration is the arrangement of a series of activities carried out by various entities in the supply chain. It considers the interaction between activities to ensure the overall process runs efficiently, responsively, and meets the quality standards expected by customers.

The identification of KPIs is based on the SCOR framework model, which divides the supply chain into five perspectives and five dimensions. Initially, there were 44 KPIs, which were then validated to ensure validity and measurement capability in line with company conditions. KPI validation is done to ensure the validity and consistency of the identified KPIs by the company. This process also ensures that the weighted results are in line with company conditions. Out of 38 initial KPIs, only 38 KPIs are considered valid.

KPI weighting is done to determine the relative importance level across all KPIs. The Analytical Hierarchy Process (AHP) method is used in the weighting process, with data collected through questionnaires divided into three levels: perspective, dimension, and KPI. The weighting results of the KPIs are obtained from the multiplication of weights from these three levels, which are then used to determine the overall supply chain performance achievement of the company.

Measure

Measure is the second stage in the DMAIC cycle related to performance measurement in the supply chain. In this stage, several measurements are made along the supply chain, including the calculation of Snorm de Boer normalization and evaluation of overall supply chain performance.

Snorm De Boer normalization is a technique used to standardize the value units of various performance metrics used in measuring a company's supply chain performance. Each performance metric has a maximum value (Smax) and a minimum value (Smin). If the measurement is "larger is better," the normalization formula is ((SI-Smin))/(Smax-Smin) X 100%. If the measurement is "lower is better," the formula is ((Smax-SI))/(Smax-Smin) X 100%. These normalized values are then used to evaluate performance according to the established standards.

Standard values for supply chain performance are set in a table using a monitoring system with performance category indicators such as "Poor," "Marginal," "Average," "Good," and "Excellent" based on specific value ranges.

From the results of Snorm de Boer normalization and performance evaluation according to standards, it can be seen that some KPIs do not reach the set targets. These KPIs require improvement using a traffic light system that divides performance into red, yellow, and green categories, each indicating unsatisfactory, marginal, and satisfactory performance.

Furthermore, the final performance value of the company's supply chain is calculated by multiplying the overall weights by the performance process value from the Snorm de Boer normalization results. This final value reflects the overall performance of the company's supply chain and can be used to evaluate performance comprehensively.

From the results of measuring the supply chain management performance at PT. PG Candi Baru using SCOR, the final performance value can be categorized as "Average," indicating that the supply chain management activities are moderate. However, to remain competitive with competitors, continuous improvement and monitoring are needed to enhance supply chain management performance in the future.

Analysis

In the analysis stage, the causes of waste that lead to KPIs not meeting the company's targets are examined. The analysis is based on the 9 wastes found in lean manufacturing so that the factors causing KPIs to fall short of the company's targets can be more easily identified in detail and significantly.

Identification of Waste on KPIs

Waste identification is only carried out on performance that does not meet the company's targets. This identification aims to determine the waste causing these indicators to not be achieved. KPIs with performance far from the company's target are as follows:

1. P1 01 Percentage of conformity of raw material planning with the amount of raw materials received. Waste waiting is identified in this KPI due to the arrival of raw materials not matching the ordered quantity.
2. P1 02 Percentage of the gap between recorded and available stock. Waste not utilizing employees is identified in this KPI because of the inability of production department employees to reconcile the recorded stock with the available stock.
3. P2 01 Production schedule delays. Waste not utilizing employees is identified in this KPI because of the inability of production planning employees to schedule production.
4. S2 01 Time required for Purchase Order creation. Waste not utilizing employees is identified in this KPI due to the inability of plantation department employees to create Purchase Orders.
5. S2 02 Waiting time for ordering raw materials from farmers. Waste waiting is identified due to waiting for the quantity of raw materials to match the demand.
6. S3 01 Average time required for additional raw material delivery from farmers due to changes in raw material requirements. Waste defect is identified

in this KPI due to the presence of defective raw materials from the supplier, requiring additional raw materials. Inappropriate processing waste is also identified due to the raw material testing process to assess the quality of the delivered raw materials.

7. M1 03 Percentage of products that pass quality testing. Waste defect is identified due to the high number of defective products that do not meet the company's quality standards.
8. M1 07 Effectiveness of time for checking faulty machines. Waste waiting is identified for checking faulty machines due to insufficient maintenance.
9. D2 02 Waste waiting is identified due to loading and unloading time of Sugar, hindering the delivery process.

Waste identification for indicators that do not meet targets is shown in Table 4.18.

Table 4. 1 Waste identification

Based on the identification conducted, the following is a further analysis of the waste that occurs in the existing process KPIs at PT PG Candi Baru.

Defect

KPI	**P1 01**	**P1 02**	**P2 01**	**S2 01**	**S2 02**	**S3 01**	**M1 03**	**M1 07**	**D2 02**
EHS									
Defects						√	√		
Overproductions									
Waiting	√				√			√	√
Not Utilizing Employee		√	√	√					
Transportation									
Inventory									
Motion									
Extra Processing						√			

Defect represents imperfections or deviations of products from the established standards. The standards used by PT.PG Candi Baru are in accordance with SNI 3140.4-2010. The standard for white crystal sugar (GKP) includes parameters such as sugar color (ICUMSA) and grain density (BJB). The BJB size is set at 0.8 – 1.2 mm, and the sugar color (ICUMSA) should be < 300 IU. If it's smaller than 0.8 mm, the rejected sugar becomes fine sugar, and if it's larger than 1.2 mm, the rejected sugar becomes lump sugar. There's also a defect called sapon sugar, which is sugar mixed with impurities in the sugar bin.

From the observations made at PT. PG Candi Baru, data has been obtained which is crucial for management to maintain, improve, and sustain product quality, particularly towards achieving zero defects. The following is a processing using the Six Sigma method.

Table 4. 2 Data on the Number of Production and Defective Products in 2023

No	Month	Number of Production (Ku)	Number of *defects* (Ku)
1	May	46550	202,5
2	Juni	71225	246,5
3	Juli	50675	334,5
4	Agustus	56115	240,5
5	September	63285	286,5
6	Oktober	59900	207,5
Total		308.714	1.518

Source: Data of PT. PG Candi Baru

The above data represents the production quantity during the 2023 milling season from May to October 2023. From Table 4.19, it can be seen that there are still many defects occurring in the sugar production process produced by PT PG. Candi Baru. The high number of defects can cause losses for the company. There are several steps that can be taken to identify the main factors influencing these defects, such as creating a fishbone diagram. The following is a fishbone diagram created based on the analysis to determine the main factors causing defects in the sugar production process produced by PT.PG Candi Baru.

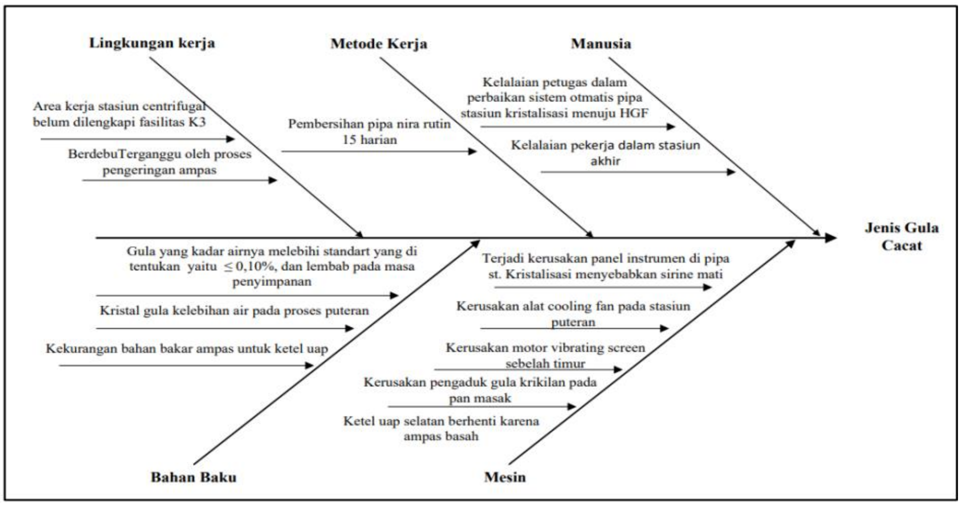

Figure 4. 1 *Fishbone diagram* of causes of sugar defects

The explanation of the fishbone diagram for the production defects of PT PG Candi Baru above is as follows:

a. Human: Labor plays a primary role in carrying out the production process. Factors such as negligence of officers and workers can lead to defects, such as negligence in repairing the automatic system for pipes from the crystallization station to the HGF and final stations.

b. Machine: Machines support the production process but can also hinder it if they malfunction. Some machine failure factors that can cause defects include instrument panel damage, cooling fan tools, lump sugar stirrers, and steam boilers.

c. Raw materials / Material: The quality of raw materials affects product quality and the smoothness of the production process. Factors such as sugar water content exceeding standards, excess water crystal sugar, and insufficient bagasse fuel can lead to defective products.

d. Method: Proper working methods can reduce the impact of defective products. PT PG Candi Baru uses production report collection methods to control quality, but factors such as routine pipe cleaning and inappropriate inspection methods can cause defects.

e. Working Environment: An unmanaged work environment can affect comfort and raw material quality. Factors such as the work area of the belung centrifugal station equipped with K3 facilities and the dusty bagasse drying process can affect product quality.

Quality defects that cause sugar to fail quality tests can also be a waste factor. Contamination, poor consistency, and unstable water content are some factors that can cause sugar to not meet quality standards.

The following is the conversion of DPMO calculation results and the Six Sigma table Defects that occurred in the sugar products produced by PT PG. Candi Baru during the 2023 milling season can be seen in Table 4.20

Tabel 4. 3 Konversi Hasil Perhitungan DPMO dan Tabel *Six Sigma*

Months	Number of Production (Ku)	Number of *defects* (Ku)	CTQ	DPU	TOP	DPO	DPMO	*Sigma*
Mei	46550	202.5	3	0.00435016	607.5	0.33333	333333.3	1.930727
Juni	71225	246.5	3	0.00346086	739.5	0.0164	16400	3.634523
Juli	50675	334.5	3	0.00660089	1003.5	0.0138	13800	3.702925
Agustus	56115	240.5	3	0.00428584	721.5	0.0085	8500	3.886708
Sep-tember	63285	286.5	3	0.00452714	859.5	0.0977	97700	2.794769
Oktober	59900	207.5	3	0.00346411	622.5	0.0085	8500	3.886708
Total		308.714	18	0.026689	4554	0.47823	478233.3	19.83636
Rata Rata							79705.56	3.30606

From the recap of sugar *defect* data during the milling season in 2023, it is found that the average DPMO is 79705.56 with *a sigma level of* 3.30 which shows that it is still less than the value of 6 *sigma*. For this reason, it is necessary to improve the quality of sugar produced by PT. PG New Temple.

Number of *defects* from refined sugar, gravel sugar, and sapon sugar in May – October 2023. In the picture data above, refined sugar and gravel sugar experience quite a lot of *defects*, while sapon sugar has a small *defect*. It is known that the number of sugar defects is 1604.5 quintals, the types of defects that occur are refined sugar types of 828 quintals, gravel sugar of 638.5 quintals, and sapon sugar of 138 quintals.

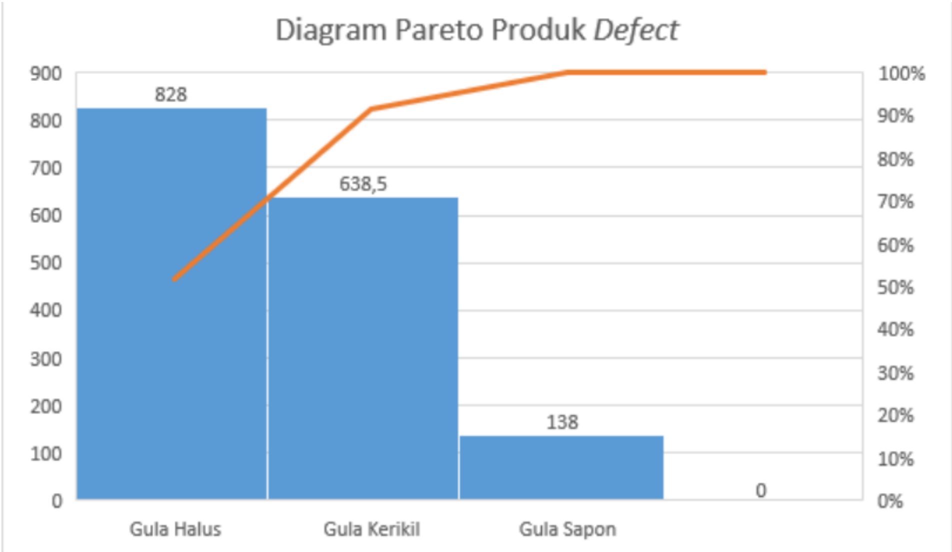

Figure 4. 2 Pareto Diagram Number of Defects

Based on figure 4.6 of the pareto diagram above, it can be found which priority of improvement comes first. The results of the pareto diagram above can be seen that the type of *defect* that requires the most attention is refined sugar with a total of 828 quintals and will be a priority for repair by the company.

Waiting

Waste waiting is a common waste associated with waiting for the arrival of materials, information, or equipment that does not add value. It is usually characterized by idle workers or idle machinery. Waiting at PT. PG Candi Baru is due to several factors, namely waiting for raw materials from suppliers, waiting for machine repairs, and waiting for the return of sugar packaging. The waiting data for 2023 obtained from the company is shown in Table 4.22.

Table 4.22 Total Waste Waiting in 2023

Year 2023	**Late Raw Materials (Menutes)**	**Machine Repair (Minutes)**	**Return of Sugar Packaging (Minutes)**
May	400	0	0
June	0	0	72
July	200	0	140
August	144	96	288
September	0	0	0
October	144	0	144

(source : PT.PG Candi Baru)

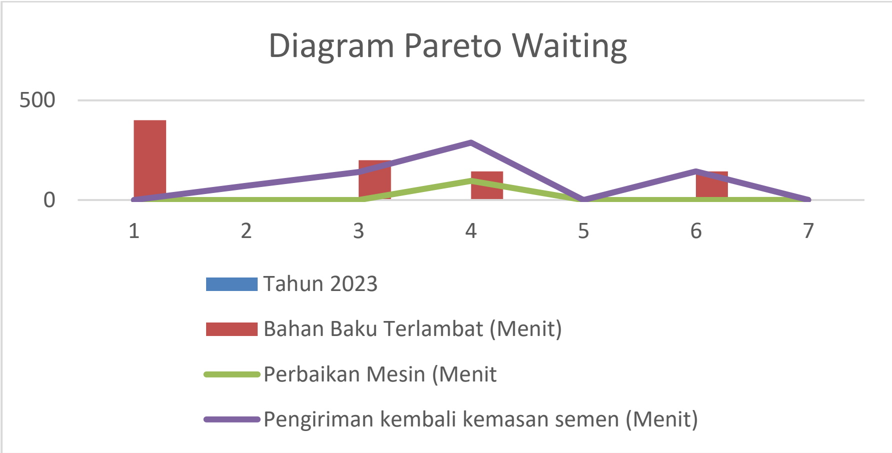

Figure 4. 3 Pareto *Waiting Diagram*

To determine the most influential type of waiting waste, calculations are shown in the Pareto diagram in Figure 4.7. From the Pareto diagram, it can be seen that the main cause of waste is late raw materials. It can be concluded that the delay in raw materials is a critical waste that occurs in waiting waste.

Not Utiliting Employee Knowledge, Skill and Abilities

Employees are the main factor in carrying out the production process to produce quality products. Employees require knowledge, skills, and abilities to perform activities well and be more responsive to problem causes, so the company sets education criteria for employees who want to work at PT. PG Candi Baru. By looking at the education criteria, employees are considered capable of performing activities well in their field.

Another factor besides educational background criteria is the lack of training provided to employees. The lack of training provided results in poor employee performance and also prevents employees from improving their skills. The inability of employees to forecast the determination of production quantities accurately is one consequence of the lack of training provided by the company.

Table 4.24 Root Cause Analysis of Waste Not Utilizing Employee Knowledge, Skill, and Ability

Waste	KPI	Root Cause
Not Utilizing Employee, Knowledge, Skill and Ability	**P1 02** Percentage Gap between recorded and available stock **P2 01** Production schedule delay **S2 01** Time required for making a purchase order	1. Educational background of employees 2. Lacking employee ability in establishing appropriate demand forecasting methods.

Extra Processing

Waste measurement by identifying Extra processing during observations in the production process that occurred at PT.PG Candi Baru throughout the 2023 milling season. From the observations, two types of activities included in Extra processing were quality testing of sugar and reworking of products that did not meet quality standards. The data can be seen in Table 4.25.

Table 4.25 Total Waste Extra Processing in 2023

Month	Sugar Quality Testing (Hours)	Rework Products (Hours)
May	89	1
June	24	2
July	23	1
August	39	1
September	31	2
October	30	1

(Source: PT.PG Candi Baru)

It can be seen from the above data that the most significantly impactful extra processing waste is sugar quality testing. Therefore, it can be concluded that sugar quality testing is considered a critical waste that causes failure in Extra processing waste.

Improvement

The improvement stage is conducted to identify and follow up on corrective actions that can reduce waste in the production process. In this stage, various improvement recommendations are provided based on the identification of significant wastes, such as waste defect, waiting, not utilizing knowledge, skill, and abilities, as well as extra processing.

To address waste defect, improvements need to be made in several aspects. First, in terms of human resources, increasing employee qualifications through training and placing them in positions that match their skills can reduce errors. Regular inspection and maintenance of machines are also important to prevent machine damage that can lead to product defects. Additionally, strict monitoring of raw material quality and the implementation of appropriate work methods are also required. Finally, maintaining a clean work environment can minimize the risk of contamination.

Waste waiting can be reduced by better purchase planning, including the use of safety stock and safety lead time to anticipate delays in raw material delivery. Selecting the right suppliers is also crucial, considering various factors such as cost, quality, technical capabilities, organizational profile, service level, supplier profile, and risk factors. To address waste not utilizing knowledge, skill, and abilities, training is needed for production employees, especially related to the effectiveness and efficiency of production processes, as well as demand forecasting methods and production scheduling. This will improve operators' skills in using machinery and production planning capabilities.

Finally, waste extra processing can be reduced by controlling the quality of raw materials and delivery schedules from suppliers. Evaluation of supplier performance is also necessary to ensure good quality and considering alternative suppliers if needed. By implementing these improvement recommendations, it is hoped that

PT PG Candi Baru can reduce waste in the production process and improve efficiency and the quality of the products produced.

Results and Discussion

SCOR fundamentally aligns the supply chain with business strategy. Its aim is to assess the performance of a company's business strategy in line with its vision and mission. Therefore, in this study, process maps and strategic planning were conducted, namely identifying the supply chain at PT. PG. Candi Baru, which leads to the five perspectives in SCOR: plan, source, make, deliver, and return, which will be used to identify Key Performance Indicators (KPIs) in each perspective. The identified KPIs were then measured according to the company's targets. A strong, data-driven approach to lean problem-solving can help identify the root causes.

After measuring the KPIs, the next step is to analyze the root causes of the failure to achieve the KPIs using the concept of 9 waste. There are four types of waste that hinder the achievement of targets, thus the company's performance is not optimal, namely waste defect, waiting, not utilizing skill, knowledge, and ability, and extra processing. Handling was conducted for these four wastes to reduce the impact of the generated waste, and improvement recommendations were provided according to the handling of each waste to achieve continuous improvement and improve supply chain performance.

With the improvement recommendations provided, an analysis can be conducted regarding the predicted results of the recommended corrective actions. The following are the results of the analysis of the provided improvements.

Analysis of Corrective Actions on Waste Defect

The improvement recommendation for waste defect is to implement improvements using the 5M method. From the factors of human, machine, material, method, and environment, it is expected that defects can be significantly reduced so that the resulting sigma level increases. With the proposed improvement, regular inspection and maintenance of machines and installing a strict quality monitoring system throughout the sugar factory to ensure consistent sugar quality. This may include routine testing of sugar content, moisture, and other contaminants. Another proposed improvement is training for employees to further enhance their work skills and supervision of employees before engaging in production activities, which can also minimize defects.

Analysis of Corrective Actions on Waste Waiting

The improvement recommendation for waste waiting is to plan safety stock and use safety lead time with earlier release order planning than stated in the requirement. This is done to anticipate raw material deliveries exceeding the promised lead time to overcome delays in raw material delivery.

Analysis of Corrective Actions on Waste Not Utilizing Knowledge, Skill, and Abilities

The improvement recommendation for waste not utilizing knowledge, skill, and abilities is to provide training for production and purchasing employees to be able to use production equipment and make accurate forecasts. As discussed earlier, one of the factors causing product defects is related to the lack of skills in employees. With the training provided by the company to employees, this will certainly minimize errors caused by the inability of employees and improve production results. This shows that the recommendations provided are expected to minimize several waste amounts at once.

Analysis of Corrective Actions on Waste Extra Processing

The improvement recommendation for waste Extra Processing is to control the quality of raw materials from suppliers and conduct monitoring or performance assessments of suppliers. Through assessment or education to suppliers, it is expected that suppliers can provide maximum results according to the company's demands, allowing the company to minimize inspection processes to reduce production lead times.

CONCLUSION

The research results on measuring the performance of core processes at PT PG Candi Baru using the lean six sigma supply chain management approach show an overall performance value of 66.6666, which can be categorized as "Average". This value indicates that the supply chain management activities in the company are running at a satisfactory level, although there are still 9 KPIs that have not reached their targets. As a solution to reduce waste and improve performance, several improvement recommendations are provided. First, for sugar quality defects, standard milling and the use of raw materials that meet specifications are needed. Second, for late raw material waiting, the plant department is advised to plan purchases earlier and prioritize suppliers with the highest weights. Third, for not utilizing employees' knowledge, skill, and abilities, training on production scheduling forecasting methods is required. Finally, for extra processing, the company is recommended to provide quality checklist during final product inspection. Recommendations for the company and future researchers include evaluating SCM performance, the need for continuous monitoring by management, and the use of other performance measurement methods to obtain broader and more specific solutions in determining outcomes and providing more ideal solutions across various industries.

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