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Analysis Of Defects In White Crystal Sugar Products At XYZ Sugar Factory Using Fault Tree Analysis (FTA) And Failure Mode And Effect Analysis (FMEA)

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Abstract

XYZ Sugar Factory is a manufacturing company that produces processed sugar cane with the main product being white crystal sugar of the Super High Sugar (SHS) type. The problem found at the XYZ Sugar Factory was that there were defects in white crystal sugar products amounting to 7,359.1 tons with a defect percentage of 11.12%. This study aims to determine the types and causes of defects, as well as suggestions for improvements. The methods used are Fault Tree Analysis and Failure Mode and Effect Analysis. The results of the research show that the types of defects that occur in white crystal sugar products are sugar color defects and sugar grain size defects. One of the causes of sugar color defects is excessive levels of additional raw materials, while one of the causes of sugar grain size defects is the insufficient cooking duration of the sugar crystals. The results of FMEA calculations obtained the highest RPN value, namely sugar color defects with an RPN value of 140 and then grain size defects with an RPN value of 120. Proposed improvements for the company are to make appropriate measurements for additional raw materials to help with the production process and provide more routine training to employees regarding the use of machines production.

Keywords: defects, factory tree analysis, failure mode and mode effect analysis, sugar factory

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1. Introduction

Sugar cane (Saccharum spp.) is an annual grass that grows widely in tropical and snow-free areas. This plant requires hot temperatures, high exposure to sunlight, enough water, and fertile land with good irrigation. In Indonesia, sugar cane is widely cultivated on the islands of Java and Sumatra. The characteristics of sugar cane plants include the presence of hairs and thorns around the midrib and leaf blades (Setyawan, 2022). Sugarcane is the main ingredient for sugar production. White crystal sugar is sugar used for household consumption. Sugar (including white crystal sugar) is one of Indonesia's basic necessities according to the Presidential Regulation of the Republic of Indonesia (Perpres RI) Number 71 of 2015. Based on this regulation, the Central Government and Regional Governments are responsible for providing white crystal sugar in adequate quantities and an affordable price. This makes white crystal sugar a strategic commodity in Indonesia (Rachmadhan et al., 2020). The sugar industry sector in Indonesia has existed since the Dutch colonial era. As time went by, the need for sugar for the Indonesian people increased, so the Indonesian government nationalized the sugar industry.

XYZ Sugar Factory is a manufacturing company that produces various kinds of processed sugar cane which is located in Malang Regency. The main product produced by the XYZ Sugar Factory is white crystal sugar made from 100% pure sugar cane. Apart from white crystal sugar, several other products produced by the XYZ Sugar Factory are molasses which is known to have many benefits in various sectors, including the livestock industry, fisheries, agricultural fertilizer, food and the energy industry (ethanol). Brown Sugar which has lower carbohydrate and calorie content than white sugar, Hi Jus which is a sugar cane juice drink that is packaged hygienically, and sweet soy sauce.

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Of the several products produced by the XYZ Sugar Factory, the very high number of defects are crystal sugar products. This is supported by the higher production level of crystal sugar products compared to other products

Within a year, sugar production is carried out within a certain period of time or can be called a period. In one sugar production period there are 5 to 6 months of production. In 2023, the XYZ Sugar Factory will produce sugar from May to October 2023 with a total production of 66,157.8 tons of crystal sugar with a total number of defects of 7,389.1 tons. Quality control established by sugar products produced by the XYZ Sugar Factory refers to SNI. The problem that occurs is the different color of the sugar caused by the ICUMSA value of 6.7% which does not comply with the standard and the crystal sugar size (BJB) of 5.1% which does not comply with the standard

To overcome this problem, the Fault Tree Analysis method was applied to identify the root causes of product defects and Failure Mode and Effect Analysis (FMEA) to provide suggestions for improvement. According to Nugraha and Sari (2019) in their research, Fault Tree Analysis is a method in the form of a fault tree with a top-down approach, which begins by assuming an error or failure of an event, then detailed in more depth until it reaches the basic failure. The advantage of using the Fault Tree Analysis method is that it can identify the causes of product defects. According to Wicaksono and Yuamita (2022) in their research, Failure Mode and Effect Analysis (FMEA) is a structured procedure to identify and prevent as many risks as possible that play a role in a failure through a top down approach. FMEA (Failure Mode and Effect Analysis) is a method used to define, identify and eliminate defects and problems in the production process, both known and potential problems that occur in the system. FMEA is a systematic method that employs a solution table to guide engineers in identifying potential failure modes and assessing the impact of product defects (Lestari & Mahbubah, 2021).

2. Method

This research uses quantitative methods by processing data obtained from the company. The methods used in this research are Fault Tree Analysis and Failure Mode and Effect Analysis. Fault Tree Analysis is a technique used to identify risks that cause failure (Adrian et al., 2023). This method is carried out using a top down approach, which begins with an assumption of failure from a top event and then details the causes of a top event down to a basic failure (root cause) (Yuamita & Wicaksono, 2022). Fault tree analysis shows all the different relationships needed to generate top events explicitly (Khare et al., 2019). The basic concept of fault tree analysis (FTA) is to translate the failure behavior of a physical system into a visual diagram and logic model (Arsic et al., 2022). Meanwhile, Failure Mode and Effect Analysis is used to analyze and provide rating values for failures that frequently occur. The FMEA method is used to identify all activities that are at risk of causing accidents and analyze their severity levels (Hidayat & Rochmoeljati, 2020). The FMEA method provides benefits such as improving product quality and reliability, reducing risks and their impacts to acceptable levels and creating risk control plans, and increasing customer satisfaction (Mutlu & Altuntas, 2019). Potential failure identification is carried out by assigning a value or score to each failure mode based on the occurrence level, severity level, and detection level. Then, the Risk Priority Number (RPN) is obtained, which determines the priority scale of improvements that must be carried out first. he Risk Priority Number (RPN) is calculated by multiplying the severity, occurrence, and detection ratings. RPN helps prioritize failures. It is utilized to rank component failures, guiding actions to reduce criticality and enhance the process (Anthony, 2021). After determining the RPN in the Failure Mode and Effect Analysis (FMEA) process, recommendations for improvement are provided.

3. Result

There are some defects that occur in white crystal sugar products, where the produced products do not comply with predetermined standards. The list of types of defects shown on Table 1.

Table 1 shows that there are two types of defects in the production of white crystal sugar: color defects and grain size defects. According to the data collected and interviews with the production team, each white crystal sugar product has only one type of defect, and no product has more than one defect simultaneously.

Table 1. Data On The Number And Types Of Defects In White Crystal Sugar Products

Month	Type of Defect (Tons)		
	Sugar Color Defect	Grain Size Defect	Total
May	403.2	378.8	782.0
June	2001.4	405.7	2407.1
July	589.9	411.4	1001.3
August	470.2	896.4	1366.6
September	557.2	1044.7	1601.9
October	431.4	204.5	635.9
Total	4453.3	3341.5	7794.8
% Defect	57.1%	42.9%	100.0%
% Defect Kumulatif	57.1%	100.0%	

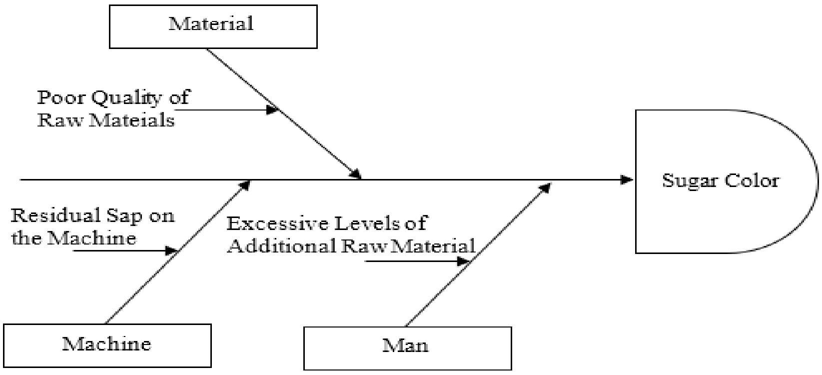

Figure 1. Cause And Effect Diagram Of Sugar Color Defects

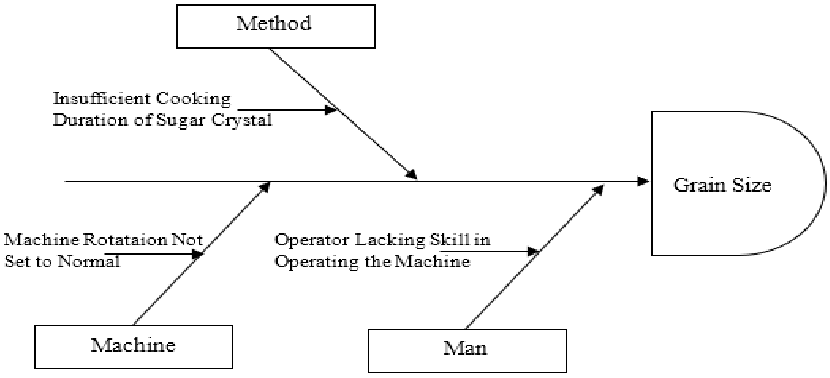

Figure 2. Cause And Effect Diagram Of Grain Size Defects

After identifying the cause of the top event for each defect, the next step is to identify the root cause or basic event that leads to undesirable events. The explanations of the root causes or basic events that result in undesirable events are as follows:

a. Excessive Levels of Additional Raw Materials

   Excessive levels of additional raw materials usually include excess sulfur, phosphoric acid, and other additives.

b. Poor Quality of Raw Materials

   The poor quality of raw materials refers to sugarcane that is not fresh and does not meet company standards.

c. Residual Sap on the Machine

   The presence of residual sap in the machine usually occurs because the process of extracting the sap is not optimal.

d. Insufficient Cooking Duration for Sugar Crystals

The cooking duration for sugar crystals is insufficient, usually because the cooking time does not meet factory standards.

e. Machine Rotation Not Set to Normal

Conditions If the machine rotation is not set to normal conditions, the sugar cannot dry completely and needs to be processed repeatedly.

f. Operators Lacking Skill in Operating the Machine

Operators lacking skill in operating the machine occurs due to insufficient training on the use of the machine.

3.1. Fault Tree Analysis

After identifying the causes of the defects, the next step is to create a Fault Tree Analysis (FTA) diagram for each type of defect.

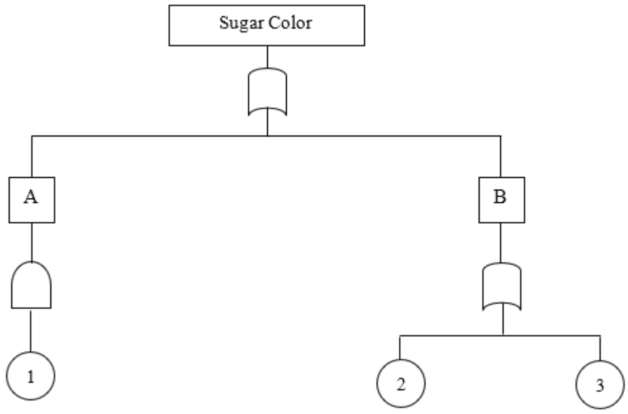

Figure 3. Fault Tree Analysis Diagram Of Sugar Color Defect

Description:

A : Bad Raw Materials
B : Human Error
1 : Poor Quality of Raw Materials
2 : Excessive Levels of Additional Raw Material
3 : Residual Sap on the Machine

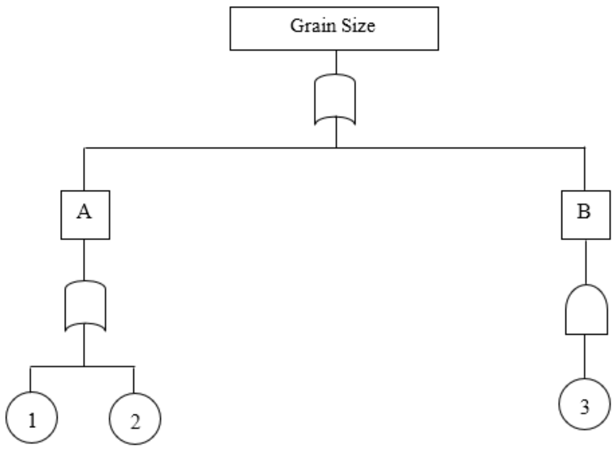

Figure 4. Fault Tree Analysis Diagram Of Grain Size Defect

Description:

A : Human Error
B : Machine Error
1 : Insufficient Cooking Duration for Sugar Crystals
2 : Machine Rotation Not Set to Normal
3 : Operators Lacking Skill in Operating the Machine

3.1.1. Probability Calculation

Probability calculation for sugar color defect:

P_1 : 0,000393
P_2 : 0,000563
P_3 : 0,000377
$P_A = P_1$
$= 0{,}000393$
$P_B = P_2 + P_3$
$= 0{,}000563 + 0{,}000377$
$= 0{,}00094$
$P_{Sugar\ Color} = (P_A + P_B) – (P_A \times P_B)$
$= (0{,}000393 + 0{,}00094) – (0{,}000393 \times 0{,}00094)$
$= (0{,}001333 – 0{,}000000369)$
$= 0{,}001332$
$= 0{,}1332\ \%$

Probability calculation for grain size defect:

P_1 : 0,000300
P_2 : 0,000369
P_3 : 0,000263
$P_A = P_1 + P_2$
$= 0{,}000300 + 0{,}000369$
$= 0{,}000669$
$P_B = P_3$
$= 0{,}000263$
$P_{Grain\ Size} = (P_A + P_B) – (P_A \times P_B)$
$= (0{,}000669 + 0{,}000263) – (0{,}000669 \times 0{,}000263)$
$= (0{,}000932 – 0{,}00000018)$
$= 0{,}0009318$
$= 0{,}09318\ \%$

3.2. Failure Mode And Effect Analysis

After identifying the type of component failure using Fault Tree Analysis, the next step is to prioritize repairs to enhance the quality of white crystal sugar production using Failure Mode and Effect Analysis (FMEA). The identification of potential failures is conducted by assigning a value or score to each failure mode based on its severity level (S), occurrence level (O), and detection level (D). Subsequently, the Risk Priority Number (RPN) value is determined, which helps prioritize improvements that need to be addressed first. The failure mode and effect analysis (FMEA) shown on Table 2.

Table 2. Failure Mode And Effect Analysis (FMEA)

Potential Failure Mode	Potential Effect of Failure	S	Potential Casue	O	Current Control	D	RPN
Sugar Color	Sugar color defects cause the sugar to be darker in color than the sugar on the market, making the majority of consumers less interested in the sugar.	5	– Poor Quality of Raw Materials – Excessive Levels of Additional Raw Material berlebih – Residual Sap on the Machine	7	– Control the raw materials before they enter the process. – Make appropriate measurements for additional auxiliary raw materials. – Perform pre-milling at every shift change.	4	140
Butiran Gula	Sugar grain size defects where the sugar is large in size and has a rough texture means that the sugar cannot be marketed and must be reprocessed	8	– The cooking duration of sugar crystals is too short. – The operator lacks skill in operating the machine. – The rotating machine is not set to normal conditions.	5	– Conduct routine inspections on the machine. – Provide training to operators. – Perform routine machine maintenance	3	120

3.3. Failure Mode And Effect Analysis

From the results of the analysis using FMEA, a sugar color defect was identified with the highest RPN value of 140. Sugar color defects cause the sugar to be darker than the sugar available on the market, making it less appealing to the majority of consumers. This defect is caused by poor raw materials, excessive levels of additional raw materials, and residual sap on the machine. Recommendations for improvements include sorting raw materials before entering the production process, making precise measurements for additional raw materials supporting the production process, and pre-milling at each shift change.

Next, with an RPN value of 120, are grain size defects. Grain size defects occur when the sugar is too large and has a coarse texture, making it unmarketable and necessitating reprocessing. This defect is caused by the cooking duration of the sugar crystals being too long, the operator being less skilled at operating the machine, and the machine not being set to normal conditions. Recommendations for improvements include regularly checking cooking machines during the production process, providing training on machine use to operators, and conducting routine machine maintenance.

4. Conclusion

Based on the research conducted, there are two types of defects in the production of white crystal sugar at the XYZ Sugar Factory: sugar color defects, with a defect occurrence probability of 0.1332%, and sugar grain size defects, with a defect occurrence probability of 0.0932%. Sugar color defects are caused by poor quality raw materials, excessive levels of additional raw materials, and residual sap in the machine. On the other hand, sugar grain size defects are caused by insufficient cooking duration of the sugar crystals, operators being less skilled at operating the machine, and the machine rotation not being set to normal conditions.

From the results of the analysis and calculations using the FMEA method, the defect with the largest RPN value was identified as sugar color, with an RPN value of 140, followed by grain size defects with an RPN value of 120. Recommendations for improvement for sugar color defects include sorting the raw materials before entering the production process, making appropriate measurements for additional raw materials to support the production process, and conducting pre-milling at every shift change. Meanwhile, recommendations for improvement for sugar grain size defects include regularly checking the cooking machine during the production process, providing training on machine use to operators, and performing routine machine maintenance..

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