Analysis of FMEA and FTA methods in identifying the causes of decreased quality of refined sugar products (case study: PT. Makassar Tene)

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Abstract. PT. Makassar Tene is one of the manufacturing industries that produce refined sugar from raw sugar as basic materials. Most of the refined sugar production process has been carried out automatically, but it still requires regular supervision and monitoring from the operator to ensure the smoothness and accuracy of the sugar processing steps in reducing the number of defect products significantly. Failure Mode and Effect Analysis (FMEA) is a method to identify product failures based on potential causes. FMEA is used to determine the value of Risk Priority Number (RPN), then further identified as the main focus in determining the root of the potential cause using the Fault Tree Analysis (FTA). The application of FTA can provide suggestions for improvements and controls in order to help companies reduce the risk of production failure. Based on the results of the research using FMEA method, it can be seen that the process stage with the greatest risk of failure lies in the stages of sugar evaporation/crystallization and the packaging stage in the packaging bin. The next step is to identify the type of problem at each stage of the process selected using Pareto diagram so that the results show that the evaporation/crystallization stage CV deviation often happened which can produce sugar dust, while at the packaging stage the problem that often occurs is metal detection, torn sack, and sweeping sugar. Then proceed with the use of the FTA method to identify the underlying causes of each failure that arises at the chosen process stage, and the results show that most of the failures that arise are caused by operator negligence, the operation process is still done manually, and the design of operating equipment is less optimal.

1. Introduction
The current rapid development of industry happened. The rapid development of the industry followed by competition increasement among industrial companies to attract the attention of customers, both in product pricing approach as well as by improving the quality/grade products [1,2].

Product pricing are not be the only factor that can influence customer interest in the products offered. Few customers are even willing to pay for the expensive price and become loyal to certain products simply because the quality of the products are better than the others [3]. Unfortunately, not all industry give an urge to this factor. They are stick to the principle of “price is everything” to attract buyers. Therefore, not a few of the industries that went bankrupt because of lags to the new industries that offer competitive quality products at affordable prices.

Based on data from the Ministry of Industry estimates that the national requirements for refined sugar reached up to 3.6 million tons for industrial purposes, which represents an increment of 6%
compared with the level of sugar consumption in 2017 reached 3.4 million tons. Projected growth is largely influenced by the growth of the food and beverage industry as much as 7% to 8% [1].

PT. Makassar Tene as the only refined sugar company industry in Eastern Indonesia. In carrying out the production activities of PT. Makassar Tene proved that it still has defects on the quality of produced sugar products such as the creation of sugar dust, metal detection, and unability of quality on the crystallization process. This phenomenon brings disadvantageous for both consumers and for the company. Besides, as the competition increase, sugar industries that offering sugar products with higher quality could be a threat if this condition continued over time and did not receive serious attention.

Based on this problem, consideration of methods selected in order to improve the quality/grade of refined sugar products with the adoption of FMEA (Failure Mode and Effect Analysis) and the method of FTA (Failure Tree Analysis). FMEA is a method that can be used to evaluate the probability of failures or accidents within the certain system [4]. While FTA is an analytical method that can analyze system failure, look for aspects of the system involved in the main failure, and find the cause of product defects in the production process [5]. The successful application of both the FTA and FMEA techniques has increased their adoption in several reliability and safety engineering analyses studies [6]. Therefore, this paper aim to identify the cause of decreasing refined sugar quality at. Makassar Tene assisted with analysis tools such as Pareto diagram.

2. Research methods

2.1. Identification of the type of failure that occurred
Researchers conducted a study on the possibility of failures in each stage of the production process with the aim of improving the quality of refined sugar products and minimized failures in the process of PT. Makassar Tene using Failure Mode and Effect Analyze (FMEA).

2.2. Identify the cause of the failure
At this stage, the causes of the failure will be identified and the percentage of failures projected using Pareto diagram.

2.3. Determine Rate of Severity, occurrence and Detection
Severity is the first step to analyze risks, which calculates how much impact or intensity of incident affect the final outcome of the process. Those impacts on the rating scale ranging from 1 to 10, where 1 is the most solve-able impact while 10 is the worst impacts and the determination of the rating. If the rating already specified on the severity factor, the next step is to determine the rating of the occurrence factor. Occurrence is a possibility of caused failure during the production of the product. After the value of occurrence obtained, the next step is to determine the value of the detection factor. Detection value estimates how well the control parameter can detect the cause of the failure when occurred but before the consumer knows it. Value detection judged on a scale of 1 to 10, where 1 means that the control are specifically made to detect occurring failures and the number of 10 means a special control for not detecting the problem of the failure (or no control at all).

2.4. Calculation and Sortment of RPN (Risk Priority Number) Value
Having obtained the rating value of severity, occurrence and detection, the next step is to multiply the value of the rating is to get the value of RPN then continued by the score sorted based on the highest to lowest RPN value. Once RPN value sorted, it determines the percentage of the cumulative value of the RPN and presented in the form of the Pareto diagram. The cumulative percentage of the value formed in the scale of priorities based on data clustering 80-20%.
2.5. **Analysis of Defect Cause with FTA Method**

The next step after the obtained priority grouping 80-20% on the Pareto diagram are analyze the cause of the defect using FTA method. The use of FTA method serves to identify the root of the occurring defect.

2.6. **Proposed Improvements and Control**

Proposed improvements and control in prevention phase to the product performed as a corrective measure that is able to do in the next production process.

2.7. **Conclusions and suggestions**

From the results of all calculations and analysis using FMEA and FTA method can be attached to conclusions and suggestions that are beneficial to the company.

3. **Collection and processing of data**

3.1. **Identification of the failure type that occurred**

Based on the process flow of sugar processing, ranging from raw sugar to the final product obtained some kind of failure with the percentage of reject for most of the sugar product caused by metal detection at the level of 8.78%, followed by rejection due to sacks torn of 6.81%, and reject caused by sugar sweep of 3.15%.

| No | Sugar Grade | Overall Number Evaporation Vacuum Pan | Number Evaporation Rated by CV (Not meet Standards) | Incompatibility Percentage CV Value (%) |
|----|-------------|---------------------------------------|----------------------------------------------------|----------------------------------------|
| 1  | Smooth      | 766                                   | 155                                               | 20.23                                  |
| 2  | Rough       |                                       | 26                                                | 3.39                                   |
|    | Total       |                                       | 181                                               | 23.63                                  |

In (table 1) above shows that the amount of sugar fondant and percentage of evaporation that the CV value is not in accordance with established standards. The standard of CV values assigned to each process in a vacuum pan is no more than 32 (<32), when the value of CV over 32 consequently has an impact on the creation of sugar dust (dust sugar).

In smooth sugar grade there are 155 dishes that do not meet the standard of CV value with a percentage of the overall number of dishes is 20.23% while in rough sugar grade there are 26 dishes that do not meet the standard of CV value with a percentage of the overall number of cook was 3.39%, a total of 23.63% of cook not meet the standards of CV value.

3.2. **Identify the cause of the failure**

Results of identification as a result of the failure can be seen in (table 2).

| Process Stages | Requirement | Potential Failure Mode | Potential Effect (s) of Failure |
|----------------|-------------|------------------------|--------------------------------|
| Raw Sugar      | Transportation and equitable distribution of raw sugar for tunnel | Raw sugar pile up at a certain point | Raw sugar in uneven distribution conveyor |
| Affinity       | The temperature of the hot water and steam that is appropriate | Improper hot water the temperature of 70°C | Raw sugar and melting process is not running optimally decolorizes |
| Carbonation    | The reaction was perfect on carbonator | Further reaction occurs at carbonator | The process of carbonation the reaction takes longer than it |
Curing | Liquar clear sugar | Liquar still there are deposits | should Liquar can not be crystallized
IER Operation | Impairment ICUMSA sugar | ICUMSA value is still above the standard | ICUMSA value is still relatively high and the crystallization process in the vacuum pan is not running normally
Evaporation / Crystallization | Sugar crystal sugar according to the standard specifications set by the quality control department | Sugar crystals do not meet the standards | Crystal formation conglomerate and the standard CV discrepancy resulting sugar dust
Screening | Filtering sugar MA size according to specifications set by the consumer demand | Filtering sugar MA size does not match the specifications of consumer demand | Crystal size mixed
Bin Packing | Sugar packed neatly and ready to be stored in warehouses of materials so | Sacks of sugar were torn and did not pass metal detection time has been packed | Sugar can not be saved and need to undergo a process of reprocessing
Packed Sugar | Sugar stored neatly on each Lot of storage per specifications sugar | Sugar pile collapse | Sugar can not be saved and need to undergo a process of reprocessing

3.3. Calculation and Sortment of RPN (Risk Priority Number) Value
Here are the results of the calculation of the RPN value (Severity x Occurrence x Detection), as shown in (table 3).

| Process Stages | Requirement | Potential Failure Mode | Potential Effect (s) of Failure | S | O | D | RPN |
|----------------|-------------|------------------------|--------------------------------|---|---|---|-----|
| Evaporation / Crystallization | Sugar crystal sugar according to the standard specifications set by the quality control department | Sugar crystals do not meet the standards | Crystal formation conglomerate and the standard CV discrepancy resulting sugar dust | 7 | 7 | 5 | 245 |
| Bin Packing | Sugar packed neatly and ready to be stored in warehouses of materials so | Sacks of sugar were torn and did not pass metal detection time has been packed | Sugar can not be saved and need to undergo a process of reprocessing | 7 | 8 | 2 | 112 |

Based on the calculation of the RPN value at every stage of the sugar processing, it can be arranged into the shape of Pareto diagram as follows:

Figure 1. Pareto diagram of earned RPN value
3.4. Analysis of defect cause with FTA method

The election of the two stages of the above process is then translated into the potential risks that occur in each stage of the process using FTA method, the following stages of the implementation of the FTA:

3.4.1. The evaporation/crystallization process. In the cooking process of the evaporation stage using a vacuum pan, it was found that the sources of the occurring problem often arises as follows:

![FTA process of evaporation/crystallization phase](image)

**Figure 2.** FTA process of evaporation/crystallization phase

3.4.2. Packaging Stages on Packaging Bin. At the stage of the packaging process, sugar-packed in polypropylene sacks by the operator found that the sources cause of the problem that often arises is as follows:

![FTA of Packaging Stage on Packaging Bin](image)

**Figure 3.** FTA of Packaging Stage on Packaging Bin
4. Discussion result

4.1. FMEA (Failure Mode and Effect Analysis)
Based on calculations using FMEA method by looking at the value of the RPN can be seen that the stages of the process to the value of the RPN largest to smallest in a row is a stage evaporation/crystallization with RPN 245 points, the stage of packing bin with RPN 112 points, the stage of packed sugar with RPN 70 points, RPN screening stage with 60 points, IER stage operation with RPN 54 points, carbonation stage with RPN 36 points, phase RPN raw sugar with 24 points, and phase RPN affinity with 18 points. So was taken two stages with the highest RPN value that stage evaporation/crystallization and bin packing stage.

4.2. Pareto diagram
Based on the stage of the process that has been selected using FMEA method before, when described again at each stage has a series of problems that often occur. At this stage Pareto diagram is used as a tool to determine the priority of the type of damage from the highest to the lowest, the following description:

4.2.1. Phase Evaporation / Crystallization. The stage evaporation/crystallization kind of damage is divided into 2 types of crystal formation conglomerate and CV values mismatch, but the case is very rare crystal conglomerate that deviation CV values on the type of refined sugar with 155 deviations (85.63% of total damage) into focus problem.

4.2.2. Phase Packaging Bin. At the packing stage bin, Pareto diagram shows that there are three types of problems that often occur that metal detection of 2934 units (46.85% of total damage), torn sacks of 2278 units (36.36% of total damage), and sugar sweep of 1051 units (16.79% of total damage).

4.3. FTA (Fault Tree Analysis).
After the percentage and type of damage have been known through the application of the Pareto diagram, then the implementation of the FTA method is intended to detect the root cause of the problem, the following description:

4.3.1. Stage evaporation / crystallization. As for the discrepancy evaporation stage CV value in cooking, sugar is generally caused by sugar beet quality is not good or those less scrupulous operators while monitoring the cooking process sugar. Poor seed quality sugar tends to rarely happen since PT Makassar Tene stop producing sugar beet seeds manually and import sugar from Germany while the lack of rigor operator is usually caused by the lack of concentration in particular operator on duty on the night shift, as well as the process of assessing the dishes still manually by checking the tube.

4.3.2. Phase Packaging Bin. At this stage of packaging bin, metal breakage detection usually occurs due to metal contamination in early stages, namely raw sugar, but is most often caused by not sterile packaging space of contamination due to less operator attention to the cleanliness of room packaging. Karung tear is usually caused by two things: operators who are less careful when handling sacks of sugar such as slamming or dragged repeated or failed sewing during sewing sacks entering the stage in an automatic sewing machine using a belt conveyor, while sugar strokes caused by sugar scattered during the process of filling bags of sugar due to the filling technique of sugar are still manually by the operator so charging intermittently between one sack to sack more and funnel filling sugar does not quite fit in terms of design that allows the sugar scattered upon sugar sack filling process takes place.
5. Conclusion

Based on the discussion of the results obtained from PT. Makassar Tene, as well as a discussion of the causes of the decline in the quality of the analysis of sugars by using FMEA and FTA, the authors conclude from the results of the discussion that:

1. In the FMEA method, the two-stage process has a high risk of failure is the stage evaporation/crystallization with the acquisition value of the RPN 245 points than with the packaging stage in the packaging bin with the acquisition value of the RPN 112 points.

2. In the implementation of the FTA method, the basic causes (basic causes) of the onset of problems/failures are:
   a. Stages evaporation / crystallization
      1) The checking process and sugar cook are not optimal (not fully automatic).
      2) Lack of rigor for the operator during the sugar cooking process, including cooking temperature, cooking time, as well as monitoring through a control panel.
   b. Phase Packaging Bin
      1) Lack of implementation of SOP procedure
      2) Lack of implementation of hygiene
      3) Handling sacks are not careful (slammed and dragged)
      4) Failure in sack sewing.
      5) Processes and techniques of refined sugar filling still done manually by the operator.
      6) Lack of strict material quality control to prevent contamination of raw sugar.

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