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Application of the Failure Modes Method, Effects and Analysis and Fault Tree Analysis in Analyzing the Failure of the Glass Product Making Process (Case Study of PT. X)

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Abstract

Industrial development nowadays is relatively fast; almost all companies want to get optimal benefits and can minimize costs incurred. PT. X has exported its products in the form of glassware. The production failure experienced by the company is still high at 3.1% of the total production while the defect target that the company wants is 2%. This study used Failure Mode and Effect Analysis (FMEA) and the Fault Tree Analysis (FTA) methods to identify failures that occur and provide preventive solutions. The purpose of this study was to identify the types of defects that occur in glass products PT. X based on the results of a literature study search and deep interview with employees of PT. X. It was known that PT X got the biggest risk of failure of the production process in the RPN (Risk Priority Number) value of the FMEA method which was then re-analyzed using the FTA method. The proposed improvements were determined to get the results. The type of defect that occurs most often is rupture before the annealing process, and the proposed improvement needs are to wait for about 10 minutes because the uneven molecules can be flattened and much labour is needed in that section and cause defects. The second sequence is the driving motor that is in the mixer, and the proposed improvement is regular checking and periodic maintenance.

Keywords - *Quality Control, Causes of Defect Product, FMEA, FTA, RPN*

I. INTRODUCTION

Industrial development nowadays is relatively fast; almost all companies want to get optimal benefits and minimize costs incurred. However, the journey to reach the industrial target is not easy; various obstacles must be faced and passed by utilizing the resources owned by the industry. In terms of production management, constraints that may be faced by the industry include the availability of resources, product delivery time, management policies. The diversity of these products forces producers to continue to improve the quality of products following the consumers' demand. However, there are still many industries who pay less attention to product quality. Defective products are a major source of waste. These companies face serious problems because of defective products claimed from consumers. In addition, there are also problems related to technical fields, one of them is the availability of resources such as human beings who are ready to work by relying on their expertise and capacity, machinery and other supporting facilities which is ready to use for running the production operations. If a defective product passes to the consumer and causes a loss, then the company must compensate for the loss suffered by the consumer. One of the negative impacts caused is the collapse of the company's reputation in the consumers' perspective. If such a situation is not addressed immediately, the company loses potential customers.

This paper has some literature to support the research, for example, paper with title Analysis of Failure Modes Effect and Criticality Analysis (FMECA): A Stand-Alone Photovoltaic System (Omar Ngala Sarr, 2017). Failure Mode, Effects and Criticality Analysis (FMECA) for medical devices: Does foster standardization improvements in the practice? (Rossella Onofrioa, 2015). Reliability Analysis of Metro Door System Based on FMECA (Xiaoqing Cheng, 2013). Healthcare Safety Management: The Model of Fmea/Fmeca in Anatomic Pathology Service (Ianni A, 2018). Assessment of the Reliability of Fractionator Column of the Kaduna Refinery using Failure Modes Effects and Criticality Analysis (FMECA) (A, 2016). Analysis of The Propulsion System Toward The Speed Reduction of Vessels Type PC-43 (Arica Dwi Susanto, 2017). Maintenance Optimization for Critical Equipment in process industries based on FMECA Method (T. Sahoo, 2014). Quality Risk Management –Understanding and Control the Risk in Pharmaceutical Manufacturing Industry (Bhattacharya, 2015). Methods for Risk Management of Mining Excavator through FMEA and FMECA (Prakash Kumar, 2016). Implementation of Failure Mode and Effect Analysis: A Literature Review (Prajapati, 2012). Multicriteria FMECA Based Decision-Making for Aluminium Wire Process Rolling Mill through COPRAS-G (Bhatt, 2016). MAFMA: multi-attribute failure mode analysis (Braglia, 2000). Comparative Analysis Result of Towing Tank and Numerical Calculations With Harvard Guldammer Method (I Nengah Putra A. D., 2017). Risk Analysis Method: FMEA/FMECA in the Organizations (Haq, 2011). Modified Prioritization Methodology for Risk Priority Number in Failure Mode and Effects Analysis

(Palanikumar, 2013). Implementation of FMECA and Fishbone Techniques in Reliability Centred Maintenance Planning (Tamer M. El-Dogdog, 2016). FMECA Analysis (A Heuristic Approach) For Frequency of Maintenance and Type of Maintenance (Malay Niraj, 2012). Using causal reasoning for automated failure modes and effects analysis (FMEA) (D. Bell, 1992). Type of Ship Trim Analysis on Fuel Consumption with a Certain Load and Draft (I Nengah Putra A. D., 2017). A revised failure mode and effects analysis model (Raouf, 1996).

FMEA is a methodology used to evaluate failures occurring in a system, design, process, or service. Potential failure identification was performed by giving a score of each failure mode based on the occurrence level, severity, and detection level.

This paper is organized as follows. Section 2 review the basic ship theory. Section 3 contains the result, and 4 contains a discussion of the research. Finally, in section 5, the conclusion this paper would be presented.

II. MATERIALS METHODS

A. Failure Modes and Effects Analysis (FMEA)

FMEA is a structured procedure to identify and prevent as many failure modes as possible. A failure mode is anything that is included in the defect or failure in the design, conditions that are outside the limits of the specified specifications or changes in the product that causes the disruption of the function of the product. Through the disappearance of the failure mode, FMEA will increase the reliability of products and services to increase consumer satisfaction for the product or service. FMEA is used to identify potential failures, effects caused by the operation of the product and identify actions to overcome the problem.

The procedure in FMEA steps can be divided into the following stages(Wang, 2003):

1. Describing the process flow and review the process, if the system works well in each process line.
2. Identifying potential failure mode in the process
3. Creating a list of potential effects in each failure mode on each line and its influence.
4. Determining severity (S) ratings for each failure mode that occurs with a level scale of 10.
5. Determining the rank of occurrence (O) for each failure mode with a level scale of 10.
6. Determining the detection rating (D) for each failure and / or effect mode that occurs with a level scale of 10.
7. Calculating the value of the Risk Priority Number (RPN) for each defect.
8. Making priority failure mode based on the RPN value to take corrective action.
9. Making recommendations for improvements.

Table 1, Number of Defective Production

Production /Week	Number of Production (pcs)	Number of Defects (pcs)	Percentage of Defect (%)
1	5708	177	3.10
2	4440	110	2.48
3	7894	115	1.46
4	8550	202	2.36
5	9995	212	2.12
6	13004	309	2.38
7	12785	344	2.69
8	10104	306	3.03
9	13004	309	2.38
10	10124	226	2.23

Table 1 shows the percentage of the defective products experienced by this company; there was still a number that was relatively high above the percentage rate set by the company, which was 2%. Actions that could be taken to minimize product damage are quality control using statistical aids, one of them by using the method or Failure Mode and Effect Analysis (FMEA) approach. The results of the FMEA method will be reprocessed to find out the root cause of the problem by using Fault Tree Analysis (FTA). There are 3 main FMEA processes, including severity, occurrence, and detection.

1. Severity : Severity is a rating or level that refers to the severe impact of a potential failure mode.
2. Occurrence : Occurrence is a rating that refers to some frequency of defects in a product.
3. Detection : Detection is a process control that will detect the root causes of failure specifically.

Table 2, Severity Rating

Rank		Criteria
1	Minor	Unreasonable to expect that the minor nature of this failure would cause any real effect on the product and/or service. Customer will probably not even notice the failure.
2 - 3	Low	Low severity ranking due to the nature of failure causes a slight costumer annoyance. The customer probably will notice a slight deterioration of the product and/or service—a slight inconvenience in the next process, or minor rework action.
4 - 6	Moderate	Moderate ranking because failure causes some dissatisfaction. Customer is made uncomfortable or is annoyed by the failure. May cause the use of unscheduled repairs and/or damage to equipment.
7 - 8	High	High degree of customer dissatisfaction due to the nature of the failure such an inoperable product or inoperative convenience. May cause disruptions to subsequent processes and/or does not involve safety issues or government regulation.
9 - 10	Very High	Very high severity is when the failure affects the safety and involves non-compliance with government regulations.

Table 3, Occurance Rating

Rank		Criteria
1	Unlikely	Failure is unlikely (less than 1 in 1.000.000)
2	Very Low	The process is in statistical control. Isolated failure exist. (1 in 20.000)
3	Low	The process is in statistical control. Isolated failure sometimes occurs (1 in 4.000)
4 - 6	Moderate	The process is in statistical control with occasional failure but not in the significant proportion. (1 in 1.000 to 1 in 800)
7 - 8	High	Process no in statistical control. Have failure often. (1 in 40 to 1 in 20)
9 - 10	Very High	Failure is inevitable.

Table 4, Detection Rating

Rank		Criteria
1	Very High	The remote likelihood that the product or service will be delivered. The defect is functionally apparent and readily detected—detection reliability at least 99,99%.
2 - 5	High	The low likelihood that the product would be delivered with the defect. The defect is apparent—detection reliability at least 99,80%.
6 - 8	Moderate	The moderate likelihood that the product will be delivered with a defect. The defect is easily identified—detection reliability at least 98,00%.
9	Low	High likelihood that the product would be delivered with the defect. The defect is subtle—detection reliability at greater than 90%.
10	Very Low	The very likely that the product and/or service will be delivered with the defect. Item is usually not checked or not checkable. Quite often, the defect is latent and would not appear during the process or service—detection reliability 90% or less.

B. Fault Tree Analysis

Fault Free Analysis is a technique used to identify risks that contribute to failure. This method is carried out with a top-down approach, which begins with the assumption of failure or loss from the top event and follows by detailing the causes of a Top Event to obtained the root cause. Foster stated in 2004 that Fault Tree Analysis is an analytical tool that graphically translates the combinations of errors that cause a system failure. This technique is useful for describing and assessing events in the system. FTA uses two main symbols called events and gates. There are three types of events, namely:

1. The primary event is a stage in the process of using a product when it might be failing. For example, when entering a key into a lock, the key may fail to fit the lock. Primary events are further divided into three categories: Basic events, Undeveloped events and External events.
2. Intermediate events are the result of a combination of errors, some of which may be primary events. This intermediate event is placed in the middle of a fault tree.
3. The expanded event requires a separate fault tree analysis due to its complexity. For this new fault tree analysis, the expanded event is an undesired event and placed at the top of the fault tree.

C. Risk Priority Number (RPN).

RPN confirms the priority level of failure (Stamatis, 1995). The RPN value depends on the value of severity rating, occurrence rating and detection rating. The formula used to calculate the RPN is:

RPN = Severity rating x Occurance rating x Detection -rating
= S x O x D

D. Method of Research

The data collection and processing stage is carried out to obtain various information and data from the object to be studied.

1. Identification of the type of defect that occurs
2. Stage of failure mode and effect analysis (FMEA)
   a. SOD questionnaire preparation and distribution (severity, occurrence, detection).
   b. Recapping the results of the SOD rating assessment (severity, occurrence, detection).
   c. Calculating the RPN (risk priority number), the value that has been obtained from the results of the questionnaire
3. Make a Pareto diagram to show priority issues that must be corrected
4. Stage of fault tree analysis (FTA)
   a. Making the fault tree.
   b. Determining the minimal cut set.
   c. Quantitative analysis
5. Make a proposed improvement based on the results of the fault tree analysis (FTA) that has been made

III. RESULT

Direct interviews and observations were conducted to find out the type of defect that occurs in each glass production process and the causes of the defect in a particular manner.

Table 5, Stages of Production Process for Making Glassware in PT. X

No	Production Process
1	The main components for making glass: 1. Sand: the most known is the quartz type 2. Soda: Na_2O which is supplied in various soda ash (Na2CO3). 3. Feldspar: the chemical formula is: R_2O, Al_2O, $6SiO_2$ where R_2O can be the oxidation mixture of Na_2O ash K2O ash 4. Borax: reduce the coefficient of expansion and increase resistance to chemicals. 5. Cullet: a piece of glass from a product that did not pass quality control. Cullet serves to reduce the melting temperature of the raw material. Cullets are fed as much as 25% of the total raw material.
2	Raw material preparation (batching): At this stage, there are milling and sieving of raw materials and separation of impurities. The raw material powder was weighed according to the composition, including other necessary additives such as colouring agents or substances based on the desired glass product. Mixing the raw material mixture in a mixer was performed so that the mixture becomes homogeneous before be liquefied.
3	Melting/Fusing: Raw homogeneous materials, sieved before being put into a furnace at a temperature around 1500^{o}C. So that the mixture will melt. During the liquefaction process, each raw material would interact with each other to form chemical reactions.
4	Pot furnace: Usually used to produce special glass such as art glass or optical glass with a small production scale of about 2 tons or lower. Pot is made of special silica-alumina (clay) brick or platinum.
5	Tank furnaces: Used in large-scale glass industries and made of refractory bricks (heat-resistant bricks). This furnace can accommodate around 1350 tons of glass liquid that forms a pool in the centre of the furnace.
6	Forming/Shaping: Liquid glass material has then flowed into tools that function to form solid glass as desired.
7	Fourcault Process: Liquid material is streamed vertically upwards through a section called "debiteuse". This part floats on the surface of the liquid glass with a gap under the desired glass thickness. Above the debiteuse, there is a circulation section of cooling water that will cool the glass to 650 - 670^{o}C.
8	Colburn (Libbey-Owens) Process: If the Fourcault process is about the glass movement that takes place vertically, then in the Colburn process the glass will move vertically and then followed by horizontal movement after passing through the clamping wheels that form fused glass into sheets.
9	Pilkington Process (float process): Liquid material is channelled into a pool of hot tin (Sn) liquid. The speed of the flow of this liquid material is a thick-thin regulator of flat glass that will be processed. The glass will float above the lead liquid because of the difference in density between the two.
10	Blowing Process: This process is used to make glass bottles, packaging glasses, or various other forms of glass art.
11	Annealing: The function of this stage is to prevent the emergence of stresses between molecules on the glass that is not evenly distributed so that it can cause breakage.
12	Finishing and Quality Control: Some of the complete processes in the glass industry are cleaning and polishing, cutting, enamelling, and grading

IV. DISCUSSION

The data collection and processing phase then determines the potential failure modes in terms of the material used, the production process, labour and machinery. After that, the determination of the RPN calculation for each failure mode based on the most massive RPN value was performed.

Calculation and Ordering of Risk Priority Number (RPN): RPN value was obtained from the multiplication of SOD values (severity, occurrence, and detection). The stage after getting the RPN value is to sort the RPN value from the largest value to the smallest RPN value.

Table 6, Product Potential Failure Modes of PT. X

Tool Name/Process	Potential Failure Modes
Glass Forming Material	The difficulty of getting dolomite in the market
Raw Material Preparation	Mixer tools for stirring raw materials are often damaged
Melting/Fusing	The melting in the furnace temperature is less than 1500^{o}C
Pot Furnace	Small production of fewer than 2 tons
Tank Furnace	The tank can hold 1350 tons of liquid
Forming	Tools often experience formation as expected
Fourcault Process	Coldwater circuits are less than 650-670^{o}C
Colburn Process (Libbey-Owens)	Clamping wheels to pass are jammed
Pilkington Process	The material is put into a hot liquid pool
Blowing process	Blowing tools to form the material as desired
Annealing	It breaks before the annealing stage
Finishing and Quality Control	Need a fast process in the finishing stage

Table 7, RPN rank for each of Failure Modes

Rank	Failure Mode	RPN
1	The difficulty of getting dolomite in the market	54
2	The mixer motor drive is broken	128
3	The melting in the furnace temperature is less than 1500ºC	100
4	Small production of fewer than 2 tons	96
5	The tank can hold 1350 tons of liquid	96
6	Tools often experience formation as expected	84
7	Coldwater circuits are less than 650-670ºC	84
8	Clamping wheels to pass are jammed	75
9	The material is put into a hot liquid pool	72
10	Blowing tools to form the material as desired	63
11	It breaks before the annealing stage	280
12	Need a fast process in the finishing stage	36

Tabel 8, Proposed Improvement based on RPN

RPN Rank	Failure Mode	RPN	Proposed Improvement
1	It breaks before the annealing stage	280	Wait 10 minutes before annealing
2	The mixer motor drive is broken	128	Frequent checking and maintenance
3	The melting in the furnace temperature is less than 1500ºC	100	A temperature rise of 1500 ºC
4	Small production of fewer than 2 tons	96	Small production is increased
5	The tank can hold 1350 tons of liquid	96	The tank is enlarged
6	The tool is unstable	84	Repaired until it becomes stable
7	Coldwater circuits are less than 650-670ºC	84	Expand the pump
8	Clamping wheels to pass are jammed	75	Lubrication of clamping wheel oil every 3 days
9	The material is put into a hot liquid pool of tin	72	Always checked and monitored
10	Blowing tools to form the material as desired	63	Store in the available place
11	The difficulty of getting dolomite in the market	54	Stock is increased
12	Need a fast process in the finishing stage	36	Increase labour

There are 2 types of defect that are included in the 20% total percentage of risk priority number (RPN) which will be identified more using the fault tree analysis (FTA) method.

1. Breaking before annealing stage

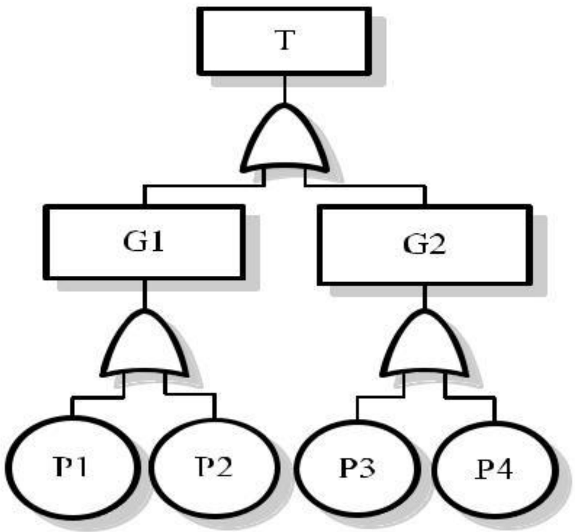

Fig. 1, Fault Tree Chart for breaking before the annealing stage

2. The mixer motor drive is broken

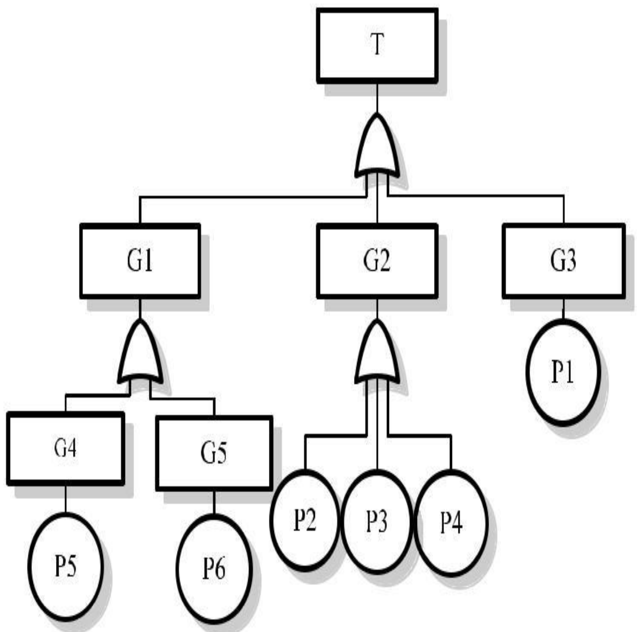

Fig. 2, Fault Tree Chart for when the mixer motor drive is broken

V. CONCLUSION

Based on the results of the research and analysis that had been done, it can be concluded as follows: The type of defect that occurs most often is breaking before the annealing process where there was uneven tension between molecules on the glass that can cause breakage. Therefore, the need to wait was about 10 minutes because uneven molecules can be levelled, and much labour is needed in that section. Other than that, the second-order defect was the driving motor in the mixer for mixing additives from the production of glass. This mixture needed to mix into homogeneous before liquefied; this is needed to reach the desired glass product. The mixer has an important role as the second cause of defect after the process before annealing, one of the way to prevent it is conducting routine checks and periodic maintenance.

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