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Sugar manufacturingprocess :risk analysis and mitigation using fuzzy fmea and fuzzy ahp method

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All attempts to produce high quality sugar do not always run smoothly due to many factors. Error in manufacturing is one of the factors causing poor sugar quality. Product quality is closely related to the efficiency of manufacturing activities. There are several risks that may result in failure during the manufacturing process of white crystal sugar. Thus, a risk analysis is needed to determine the possibility of failure that can affect the manufacturing process and product quality. This study was aimed to determine the risk priority which occurred in the manufacturing process of white crystal sugar, and risk mitigation strategies for avoiding the most influential risk. This study employed a case study at XYZ Sugar Factory. The method employed for risk assessment of sugar manufacturing process was Fuzzy FMEA (Failure Mode and Effect Analysis) method. Fuzzy FMEA was used to measure the risk, so the risk level of each factor could be obtained. After knowing the potential of the most influential risk, it was necessary to determine risk management strategy by using Fuzzy AHP (Analytical Hierarchy Process). FAHP method was used as a tool in making decision to determine the priority of the criteria to be selected. The result of FAHP method was an alternative solution that was expected to help the factory minimizing the risk. The results indicated 18 identified risks occurrences. Based on the calculation, there were 5 priority risks which had the highest FRPN value above the aggregate.

Keywords: Fuzzy AHP, Fuzzy FMEA, Risk Assessment, Sugar

INTRODUCTION

The main sources of sugar are variety of plants such as sugarcane, beet, coconut, sugar palm. In tropical area, sugarcane is the main sugar producer. Sugarcane contains hydrocarbons found in plants as the result of photosynthesis. These carbohydrates consist of glucose, fructose, sakharose and cellulose (Santoso, 2016).

Factors that affect the sugar manufacturing process in Kebon Agung Sugar Factory include the quality of raw materials from sugarcane farmers. Disorganized schedule of raw materials can affect the number of queues in the milling process. The factory's management has not yet applied the regulation to sugarcane farmers, thus the yield of sugarcane has not met the standard as sugar raw material. Damage to the machine which stops the manufacturing process will reduce the amount of sugar production. Damage to mill extraction and boiling house recovery causes inefficient so that the capacity is not maximal. Machine maintenance before milling period affects the engine performance during manufacturing process (Shinta and Pratiwi, 2011).

Risk identification model is defined as mapping the characteristics and risk sources that trigger the effectiveness and efficiency of process performance. Once the risks are identified, measurements are made to assess risk opportunities and risk consequences. Furthermore, risk evaluation is conducted to control and manage solutions to process performance results (Wu and Black hurst, 2009).

Risk management is a systematic process of planning, identification, analysis, response and oversight of project risks. Risk management involves certain processes, technologies, tools, and techniques that will help managers make the right decisions in order to maximize positive possibilities and consequences, as well as minimize the negative possibilities and negative consequences of an occurrence. Risk management underlines at least 3 things: (i) risk identification, (ii) risk assessment and (iii) risk minimization and control that may occur during business as long as it runs systematically (Sandhyavitri and Niko, 2013).

Risk measurement is done by estimating the level of loss (damage) and the probability of occurrence; it is more subjective based on reason and experience. Some risks are easy to measure, but it is difficult to ascertain the probability of a very rare occurrence. Thus, at this stage it is important to make the best estimation in order to determine the priorities in the implementation of risk management planning (Kouvelis et al., 2012).

FMEA identifies the risk of failure and effect as three factors: severity, occurrence, and detection. Severity (S) conveys the consequences of failure in an occurrence. Occurrence (O) reflects the probability or frequency of failure occurs. While detection (D) is the probability of failure detected before the effect is realized. Each potential failure mode and its effects are ranked in each of these three factors on a scale ranging from 1 to 10, low to high. Generally, an analyst or expert is required to set the score, risk level of component, process, or product which are obtained by multiplying the S, O, D score; it is called the Risk Priority Number (RPN) (McDermott et al., 2009).

Fuzzy logic has many practical applications but involves complicated operations. The concept of fuzzy numbers is based on the fact that many qualitative phenomena in the real world cannot be expressed with precise and exact numbers. In the application, it is often easy to work with triangular and trapezoidal fuzzy numbers due to their computational simplicity and usefulness in promoting representation and information processing in fuzzy environment. This method has more advantages over other fuzzy-AHP approaches. The most important thing of these advantages is the consistency index measurement for pair-wise fuzzy comparison matrix (Zegordi et al., 2012).

MATERIALS AND METHODS

This research was conducted by employing a case study of manufacturing process in XYZ Sugar Company. The data were analyzed by using Fuzzy FMEA (Failure Mode and Effect Analysis) approach and Fuzzy AHP (Analytical Hierarchy Process). The assessment stage of FMEA method consisted of severity, occurrence, detection and risk priority number (RPN). There were 3 expert respondents from the manufacturing department.

The initial phase of the research was identifying the manufacturing process and risk of each stage of the process. The second stage was determining the level of risk assessment of the manufacturing process in each component. This risk level assessment was conducted with an assessment of severity, occurrence, and detection (Wang et al., 2009). Furthermore, the highest potential risk assessment was determined. The third stage was determining the mitigation strategies to reduce the impact of risks posed. The results of this research recommended some alternative strategies to reduce the impact of potential risks realistically. Risk mitigation strategy was using AHP fuzzy (Adnyana, 2016).

RESULTS AND DISCUSSION

Risk Identificationand Analysis

Risk identification was performed by filling out questionnaires by expert respondents. Furthermore, validation was done by conducting in-depth interviews with respondents. Based on the interviews, the risks identified and often encountered by the manufacturing department are shown in Table 1.

The method used in measuring the effect of performance risk of sugar manufacturing process was fuzzy FMEA. Fuzzy FMEA calculation was used as a basis for determining handling priority and risk level for each stakeholder. Fuzzy theory was used in FMEA calculation to obtain an unbiased RPN value and to take into account the factor weights. Fuzzy logic can be used to manage and overcome the limitations of traditional FMEA (Wessiani and Satria, 2015).

On aggregation calculation of severity, occurrence and detection value, each failure mode was assessed by the experts at XYZ Sugar Factory. The respondents assessed the value of S, O, and D. The average aggregation value can be seen in Table 2.

Table1 : Identified Risks of Sugar Manufacturing Process

No.	Identified Risk
1	Delay in sugarcane supply
2	Non-standard sugarcane quality
3	*Hammer* HDS machinery damage
4	Risk of foreign matter contamination
5	*Carrier*machinery damage
6	Mill corrosion
7	Less maximum amount of extraction
8	Cane cutter damage
9	Unstable temperature during evaporation
10	Large amount of mixed up juice and residual bagasse
11	Sucrose damage due to high temperature and long period of time
12	Non-standard crystal size
13	Different crystal size
14	Inappropriate viscosity of juice
15	Lack of tools sanitation
16	Metal-containing sugar
17	Packing machine damage
18	Accident due to machine operation

Table2 : Average Aggregation Value of S,O, and

No.	Identified Risk	S	O	D
1	Delay in sugarcane supply	6	3.5	6.3
2	Non-standard sugarcane quality	6.3	3.5	6.7
3	*Hammer* HDS machinery damage	6.7	7.5	5
4	Risk of foreign matter contamination	8.3	7.25	6.3
5	*Carrier*machinery damage	8	2,.5	6.3
6	Mill corrosion	7.3	2.5	5.7
7	Less maximum amount of extraction	7.6	3.25	5.4
8	Cane cutter damage	7	4.25	4.4
9	Unstable temperature during evaporation	7	4.25	5.1
10	Large amount of mixed up juice and residual bagasse	8.3	3.25	3.9
11	Sucrose damage due to high temperature and long period of time	7.6	3.15	3.8
12	Non-standard crystal size	7.7	3.5	4.8
13	Different crystal size	7.4	3,.5	4.8
14	Inappropriate viscosity of juice	9	7	3.7
15	Lack of tools sanitation	7.1	2.65	4.5
16	Metal-containing sugar	7	2.5	4.9
17	Packing machine damage	8.3	7.5	4.5
18	Accident due to machine operation	8.6	7	4.9

Based on Table 2, it could be seen that the risk with the highest average severity value wasinappropriate viscosity of juice with the value of 9.By having the highest severity value,it indicated that the impact of the viscosity which was not appropriate to the risk of manufacturing process was in serious condition. Sugar juice which is too thick inhibits the evaporation process;the crust from juice blocked the pipe. If the sugar juice is too dilute, it will slow down the evaporation process. The risk with the highest average occurrence value was damage to HDS hammer machine with a value of 7.5. It was shown by the frequency of damage to the machine every two days even once a day. The risk with the highest detection ratewas non-standard sugarcane quality witha value of 6.7. By having the highest detection value,it proves that it is not easy to detect the risk due to the large amount of sugarcane for the milling process;the decision whether the sugarcane meets the standard or not is only based on the representative sample. Risk assessment was done by assigning value to the severity, occurrence, and detection factors performed by 3 experts. Informant 1 was a manufacturing supervisor with a weight of 40%, informant 2 was a crystallization station coordinator with a weight of 30%, and informant 3 was a foreman with a weight of 30%.

The value of Fuzzy Risk Priority Number (FRPN) was calculated based on the equation. Then FRPN value of each risk was sorted from the largest to the smallest value, in which the largest FRPN value got the highest ranking. The largest or first rank of FRPN indicated that this risk needed full attention. The FRPN value of manufacturing process risk is shown in Table 3.

The geometric mean of FRPN value of white crystal sugar manufacturing process was 5.368. The five risks with the highest FRPN ratings having value above the geometric mean were:

1. Risk of foreign matter contamination
2. Accident due to machine operation
3. Packing machine damage
4. Hammer HDS machinery damage
5. Inappropriate viscosity of juice

Risk Mitigation Strategies

Risk mitigation strategy of white crystal sugar manufacturing process employed AHP fuzzy method. Analytical Hierarchy Process (AHP) is a quantitative technique developed for cases that have different levels of analytic hierarchy. This method is a practical way of dealing with various functional relationships on a complex network. This method uses pair wise comparisons by calculating the weighting factors and analyzing the result in order to produce relative priority among the alternatives. In the early stage of risk mitigation strategy using AHP method, the hierarchy was made to achieve the goal. The hierarchy was determined by conducting an inventory and identifying elements that affected the risk mitigation strategy of white crystal sugar manufacturing process. It was done through interviews with the parties involved or previous identified risks and priorities. Risk identification and risk mitigation strategis of manufacturing process is shown in Table 4.

Based on Table 4, there were some alternative risk mitigation strategies at 5 priority risks. The first risk was the risk of foreign matter contamination with the severity of soil, roots and leaves found in the milling process. The occurrence of foreign material risk in sugar cane milling process was quite frequent but still within the maximum limit that was below 2% of the total raw material which was milled. Detecting the foreign material could be seen during milling process, thus the foreign materials such as leaves and roots could be removed first because it did not produce juice as the ingredient of white crystal sugar.

The second risk was HDS machine damage specifically in its spare part causing the engine stopped temporarily, thus the next process had to wait until the machine was back to normal. There was once minor and major HDS machine damage in one or three days. Detecting any HDS engine damage could be done by hearing the sound of the engine or when the engine stopped while it was operated. HDS machine downtime data were obtained from daily report from engineering department. The downtime data showed the failure duration and components failure rate. The data can be seen in Table 5.

Accidents due to the operation of production machinery happened because the workers did not wear Personal Protective Equipment (PPE), and the operation of machines and tools were not in the right procedures. Thus the accidents caused some injures and even loss of life. The frequency of minor accident such as exposure to heat engines was quite rare, as well as major accident that led to death. In order to avoid accidents, the workers should keep a safe distance from the dangerous zones.

The damage to the packing machine resulted in torn and imperfect packaging. The frequency of packing machine damage was quite rare,once in three days at most. The failures of the packaging process were including wrinkled and torn packaging. Detecting the damage of the packing machine could be done by checking the product packaging or when the machine stopped working when it was operated.

The next step of evaporation process was rather difficult to be continued due to the juice thickness; normal thickness was 60% brix but the current result indicated 70% brix. If the viscosity is below the normal standard which is less than 60% brix, it will increase the workload of the evaporator.

The machine becomes heavier and the evaporation process becomes longer. The occurrence of inappropriate viscosity of the juice was quite rare, it was influenced by raw materials and imbibition added during evaporation process. Detecting the appropriate thickness of juice could be done by checking every 30 minutes.

Table3:Value FRPN

No.	Identified Risk	FRPN	Ranking
1	Delay in sugarcane supply	4.957	11
2	Non-standard sugarcane quality	5.126	8
3	*Hammer* HDS machinery damage	6.498	4
4	Risk of foreign matter contamination	7.458	1
5	*Carrier*machinery damage	4.867	12
6	Mill corrosion	4.587	15
7	Less maximum amount of extraction	5.071	9
8	Cane cutter damage	5.169	7
9	Unstable temperature during evaporation	5.362	6
10	Large amount of mixed up juice and residual bagasse	4.835	13
11	Sucrose damage due to high temperature and long period of time	4.594	14
12	Non-standard crystal size	5.089	10
13	Different crystal size	4.418	16
14	Inappropriate viscosity of juice	6.738	5
15	Lack of tools sanitation	4.376	17
16	Metal-containing sugar	4.349	18
17	Packing machine damage	6.861	3
18	Accident due to machine operation	7.102	2

Table4:Risk Mitigation of Manufacturing Process

Aim	AlternativeStrategy
Mitigation Strategy of White Crystal Sugar Manufacturing Process Risk	Raw materials control Standardization of sweet, clean, and fresh sugarcane Milling process check
	Wearing personal protective equipment Scheduling working hour Regular training for workers
	Regular maintenance Adjusting the amount of raw material to the machine capacity Operational supervision
	Engine maintenance Operational supervision Adding spare machine
	Milling capacity control Machine operational supervision Keeping shaping machine (evaporator) clean

Table5:Downtime of HDS Machine Components

No.	Components	*Downtime* (Jam)	Damage Frequency
1	Hammer Handle	6.5	7
2	Hammer Tip	9.2	7
3	Rotor	0.67	2
4	As Shredder	0.59	2

Based on Figure 1, it could be seen that the first level was the goal in which the hierarchy goal was the risk mitigation strategy of white crystal sugar manufacturing process. The second level was the factor in which during the making of risk strategy factors of white crystal sugar manufacturing process was divided into 3 factors. Factor hierarchy of risk mitigation strategy of white crystal manufacturing process consisted of human, machine and material.

Based on the result of data processing from expert respondents using AHP fuzzy method, the weight value of each variable with the first priority was the material variable indicating the highest weight of 0.353. Therefore, material variable had an important effect compared to other variables. The material used in XYZ Sugar Factory was sweet, clean, and fresh sugarcane. Material had the highest risk of sugarcane containing foreign matter and other chemical contamination. According to Nurhayati (2013), material or raw material is significantly important factor for the manufacturing process.

Based on the Figure 1, machine variable had the second priority weight with a value of 0.327. The main problem experienced by XYZ Sugar Factory was a machine which was continuously operated for 3 shifts during the milling season, so the manufacturing process relied heavily on the machine. According to Sodikin (2008), continuity of a production process is affected by the reliability of machine and equipment used. Therefore,regular maintenance needed to be scheduled in order to anticipate the downtime due to machinery and equipment damage.

Figure 1 shows the weight value of alternative strategies for humans to minimize the risk of employee procedural error in the process of manufacturing white crystal sugar could be found; the highest alternative was to conduct workers training with a weight of 0.423. It was the chosen alternative compared to other alternatives such as scheduling shift and operational supervision of the process. Workers training is significantly important to improve their performances both quantity and quality of work. The training will improve the skills of workers to operate the machine and anticipate engine and equipment breakdown. In XYZ Sugar Factory, training that has been conducted was intended for new employees.

Training is expected to improve the mastery of various skills and specific techniques in detail which is conducted regularly. The benefits of training are improving the quantity and quality of productivity, meeting the needs of HR planning needs, and reducing the amount of costs and accidents (Turere, 2013).

Based on Figure 1, the weight value of alternative strategies on machine to minimize the risk of machine damage in the process of manufacturing white crystal sugar could be found; the highest alternative was to plan the machine maintenance with a weight of 0.479. It was the chosen alternative compared to other alternatives such as adding machine and equipment, and planning production schedule.

Machine maintenance was done regularly based on its condition. Then, machine repair was needed when there was an unexpected damage. Maintenance was performed by doing inspection of machine condition, giving lubricant, and replacing spare parts.

Appropriate maintenance system will affect the continuity of manufacturing process. Smooth running of a manufacturing process requires a great performance of machine and equipment (Sodikin, 2008).

Based on Figure 1, the weight value of alternative strategies for material to minimize the risk of inappropriate raw material in the process of manufacturing white crystal sugar could be found; the highest alternative was to control the quality of raw material with a weight of 0.375. It was the chosen alternative compared to other alternatives such as handling materials and equipment, and improving raw material availability.

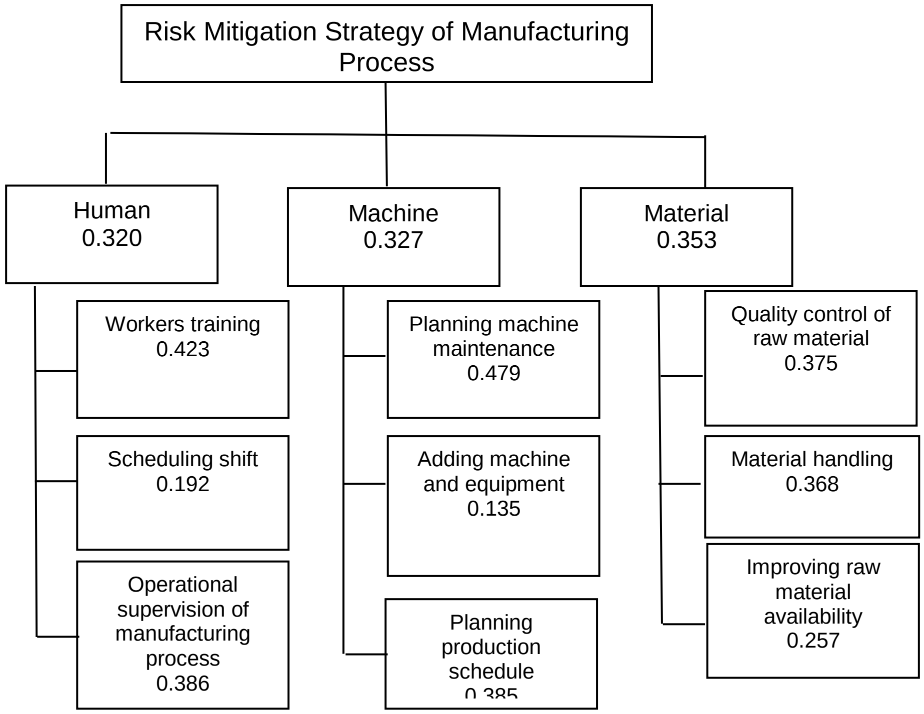

Figure1: AHP Hierarchy Structure

Quality control of raw material was a very important thing. In order to achieve high quality raw material, the minimum standards of sugarcane was set before manufacturing process stage.

The standards included yield, harvesting time, sugarcane cleanliness to name but a few.

Controlling the raw materials purchaseis significantly important since raw material is always required for the manufacturing activities. Without proper control of raw material, it is possible to purchase at an exorbitant price that ultimately harms the company (Kwang and Suryandi, 2011).

CONCLUSION

Based on the results that have been explained above, it could be concluded that there were 18 identified risks in white crystal sugar manufacturing process. The mitigation strategies were intended for the critical risks which were in the top five risks based on FRPN value from geometric mean calculation.

The result of risk assessment of the production process found that the highest risks were the risk of foreign matter contamination, HDS hammer machine damage, accidents due to the machine operation, damage to the packing machine, and inappropriate juice viscosity. Development of clear strategies to minimize the risks that occurred in XYZ Sugar Factory was using AHP fuzzy method. The material factor became the main factor since it had the highest weight with value of 0.353. The strategy used to avoid risk related to material was conducting a quality control of raw material with a value of 0.375. The strategy used for human was conducting regular workers training with a weight of 0.423. The strategy used related to the machine was scheduling machine maintenance with a weight of 0.479.

CONFLICT OF INTEREST

This research was carried out without any conflict of interest with any party.

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AUTHOR CONTRIBUTIONS

DTCY was responsible for conception, methodology, data analysis and interpretation, drafting and correcting of the manuscript. IMS and DMI were responsible for supervise conception, design, data analysis and interpretation. IMS was correspondence author as responsible in correcting and finalise the concept and final manuscript.

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