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RISK ANALYSIS BY COMBINING FAULT TREE ANALYSIS (FTA) AND ANALYTIC HIERARCHY PROCESS (AHP) METHOD APPLICABLE TO CANE CUTTER MACHINE

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Abstract *2000 times of downtime had been occurred during year 2013 to 2014 in Tjoekir sugar factory. The most serious downtime occurred in mill. Fault Tree Analysis (FTA) was employed to analyze the probability score and implement Analytic Hierarchy Process (AHP) to find out impact score of risk event. The results of FTA indicate that risk event in cane cutter blade had the highest probability score, while results of AHP shows that the decrease of steam pressure in turbine drive had the highest impact score. The scores classified in risk class and mapped in risk matrix show that there were three risk events. Tjoekir has to set a conveyor gate to filter canes before being received by the machine, use blades with the thickness not exceed 22 cm to avoid fatigue, and check harvested cane thoroughly that is loaded onto carriers to ensure no machete is accidently loaded with the cane.*

Keywords*: Cane cutter, risk, Fault Tree Analysis, Analytic Hierarchy Process*

1. Introduction

Sugar manufacturing in Indonesia is normally carried out in six months for its production. The process starts after cane is harvested and sent it to the factory. During the production period, the machine production failure should be avoided to ensure the production works smoothly. However, the preparation for production is carried out between two consecutive production periods. In this period, maintenance department should do the planned maintenance.

The downtime is the condition that should be avoided during production period. Internal or external factors may cause unexpected downtime that can hamper production [1]. The internal factor i.e. production machinery should be monitored to reduce the failures coming up during production, resulting in the damage of the machine during operation [1].

This research took place in Tjoekir, one of sugar factories in Indonesia, located in East Java. In six-month production period, Tjoekir working hours is 24 hours a day divided into three shifts per day. It can process approximately 4,000 tons of sugar cane per production period. After cane arrives in the actory, the juice extraction is started.

The cane is crushed to obtain juice before purifying process takes place to produce clear juice. After purifying, crystallization and centrifuging process to separate sugar crystal from molasses are performed. The manufacturing process ends up with drying, followed with packaging process.

During production period from 2013 to the end of 2014, a number of downtime occurred, in which 441.63 hours of downtime with the frequency of 746 times of failure were reported in 2013. The number of failure increased nearly one and a half higher (1254 times) in 2014. However, the amount of downtime decreased significantly to 23.13 hours in the same period. Mill station, at which the first step of production takes place, was reported to have the highest frequency of downtime. Seventy-four point ten and 14.25 hours of downtime were reported in 2013 and 2014, respectively.

Cane cutter, which is the main machine in this station, was reported to be the main reason why sugar production in Tjoekir was delayed. Once this machine experiences a breakdown, the production is stopped and other stations cannot perform the rest of the process.

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Although Tjoekir has already planned maintenance schedule, the condition above shows that Tjoekir needs to reduce the downtime to increase production time.

Possible risks that may come up from undesired events during production period of Tjoekir were compiled and analyzed. A combined method of Fault Tree Analysis (FTA) and Analytic.Hierarchy Process (AHP) was reported to be a suitable method to solve problems in manufacturing process. Both methods also known as a schematic process can help to create a better plan in maintenance to reduce frequency of failures.

FTA is an analytic technique that can be used to find optimal approach in reducing repetitive failures by analyzing failures happening in a system [2]. AHP, however, is a systematic process that can help make a policy to make the manufacturing company increase its production rate [3,4]. The policy can come from intuition, past experience and heuristic method along with mathematical principal.

2. Research Methods

Descriptive research consisting of explanation and interpretation [5] of failure risks of Tjoekir's cane cutter was employed in this paper. Primary data comprises failure cause and the effect level of cane cutter failure, which were collected from 2013 to 2014. Besides, evaluation report of production year 2013, year 2014 and daily production report during those consecutives years were added to support the analysis.

2.1. Data Processing

The data collected was processed and analyzed. The first step was identifying types of cane cutter failure followed with determining risk management context and identifying risks. The next step was constructing FTA. This step was performed to assess the impacts of risk events in cane cutter failure made in the following order: Identifying the objectives of the construction of FTA; determining top event; determining the scope of FTA; determining the resolution of FTA; determining the ground rules of FTA; constructing FTA; evaluating the fault tree and finally analyzing and providing results.

The next step was constructing the AHP. This step was performed to assess the impacts of risk events of cane cutter failure. It began with elaborating problems, which serves as the objectives of hierarchy, risk category, and level of risk events. Determining risk impact rating of risk events and comparing risk impact rating obtained in the second step. Normalizing matrix comparison followed with calculating matrix consistency and determining risk impact score was the steps to do the constructing risk class and risk matrix.

3. Results and Discussion

3.1. Determining Failure Risk Context in Cane Cutter

Risk analysis performed in this research aimed to find out failure risk in cane cutter. This analysis would not comprise the area of company's finance. According to the analysis, it is important that risk control be arranged to reduce the amount of downtime occurring in cane cutter.

3.2. Identifying Risk of Cane Cutter Failure

According to the report from mill station of Installation Services Department, cane cutter experienced unexpected downtime as many as 46 times in 2013 and 4 times in 2014. From 2013 to 2014, some failures such as broken blade of cane cutter, overloaded cane, turbine failure, jammed cane cutter and loosed bolt from the blade had occurred from 2013 to 2014. Table 1 shows data of evaluation of cane cutter failures that caused some downtime in cane cutter according to the report from mill station of Installation Services Department.

Table 1 Cane Cutter Evaluation Data

Year	Failure	Frequency (time)
2013	Broken cane cutter	30
	Turbine failure	2
	Jammed cane cutter	14
2014	Broken cane cutter	3
	Jammed cane cutter	1
TOTAL		50

(Source : PTPN X Pabrik Gula Tjoekir, 2015)

According to Table 1, risk event failure, which led to downtime in cane cutter from 2013

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– 2014 can be arranged. The failure of cane cutter could be categorized into two elements: the failure caused by turbine, which drives cane cutter and the cane cutter failure itself. From those two categories, there were 8 risk events, which serve as cane cutter failure. Table 2 represents the 8 risk events of failure in cane cutter.

Table 2 Identification of Cane Cutter Failure Risk

Risk Category	***Risk Event***
Turbine failure	Inclomplete bagasse burning process
Machine failure	Fatigue cane cutter
	Machete accidentally trapped in the machine
	Wood accidentally trapped in the machine
	Rock trapped in the machine
	Overloaded cane
	Steel cable tangled around machine rotor
	Loosed bolt

In Table 2, the turbine failure was caused by decreasing steam pressure, while the eight risk events such as overloaded cane, fatigue cane cutter, steel cable tangled around the rotor of cane cutter, machete and rock accidentally trapped in the machine, and loosed bolt were all caused by machine failure.

3.3. Analyzing Risk Probability with Fault Tree Analysis (FTA)

The top event in fault tree, which was constructed in probability analysis of cane cutter failure risk was cane cutter downtime. The list of downtime triggered by cane cutter failure is presented in Table 3 with codes written in letters

Table 3 Letter Code for *Risk Event*

Level	**Kode**	***Event***
Top event	A1	Cane cutter downtime
Intermediate event	B1	Turbine failure
	B2	Machine failure
	C1	Turbine downtime
	C2	Broken blade of cane cutter
	C3	Jammed cane cutter
	D1	Decreasing steam pressure of turbine
	D2	Cane cutter fatigue
Intermediate event	D3	Machete trapped in the machine
	D4	Wood trapped in the machine
	D5	Rock trapped in the machine
	D6	Overloaded cane
	D7	Steel cable tangled around the rotor
Intermediate event	D8	Loosed bolt
Undeveloped event	E1	Inclomplete bagasse burning process
Basic Event	E2	The thickness of raw materials exceeding the capacity
	E3	Negligence of cane cutting men when tying cane in the field
	E4	Negligence of cane cutting men when tying cane in the field
Basic Event	E5	Negligence of cane cutting men when tying cane in the field
	E6	Negligence of the person in charge of operating the machine
	E7	Negligence of the person in charge of operating the machine
Undeveloped event	E8	The corroded blade bolt

Event level is presented in fault tree as seen in Figure 1.

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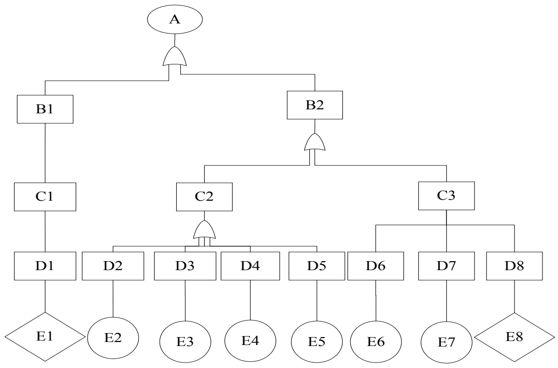

Figure 1. Cane Cutter Downtime Fault Tree

According to what can be seen in Figure 1, probability analysis from each risk event of cane cutter failure could be performed. Probability analysis could be calculated based on the frequency of each risk event with the overall fifty-time downtime frequency occurring from 2013 – 2014. The probability analysis of each risk event could be arranged with the following equations:

$$P\,(\textit{Risk event A}) = \frac{\text{Number of frequencies A}}{\text{Number of frequencies of cane cutter downtime}}$$

(equation 1)

a) Risk event probability of turbine failure

$$\mathrm{P(E1) = P(B1) = P(C1) = P(D1)}$$

$$\mathrm{P(E1)} = \frac{\text{Number of frequencies of event in turbine failure}}{\text{Number of frequencies of cane cutter downtime}} = \frac{2}{50} = 0.040$$

$$\mathrm{P(E1) = P(B1) = P(C1) = P(D1)} = 0.040$$

The score of failure probability caused by turbine failure was 0.040.

The Result of probability analysis was performed according to the classification of probability score used in previous research as presented in Table 4.

Table 4 Probability Score Risk Matrix

Probability Score	Probability Level	Probability
5	*Very likely*	>80%
4	*Likely*	51-80%
3	*Possible*	21-50%
2	*Unlikely*	11-30%
1	*Very Unlikely*	<10%

(Source: Hyun, Min, Choi, Park dan Lee, 2015)

Probability analysis and classification of the eight risk events are presented in Table 5.

Table 5. Risk Event Probability Score Classification

Risk Event	Code	Proba-bility	Proba bility Score
Decreasing turbine steam pressure	D1	0.040	1
Cane cutter fatigue	D2	0.420	3
Machete trapped in the machine	D3	0.160	2
Wood trapped in the machine	D4	0.040	1
Rock trapped in the machine	D5	0.040	1
Overloaded cane	D6	0.260	2
Steel cable tangled around the rotor	D7	0.020	1
Loosed bolt from the cutting blade	D8	0.020	1

Based on the result of classification of probability score, it was found out that all risk events ranged from 1 – 4. Cane cutter fatigue had the highest probability score (3). Thus, it is concluded that cane cutter fatigue was at the level of ‘possible’.

3.4. Analyzing Impacts of Risk Event with Analytical Hierarchy Process (AHP)

The probability score of cane cutter failure is obtained from the last part, the analysis on impacts was performed by using Analytical Hierarchy Process (AHP). Figure 2 shows the

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construction of hierarchy of impact analysis of cane cutter failure.

In Figure 2, it is clearly seen that the hierarchy was constructed of two categories such as turbine and machine failure. Each risk category consisted of 8 risk events. This hierarchy will then be proposed for discussion with representatives of the company in order to determine the level of importance of impact analysis. In Table 6, the results of discussion are presented to find out the level of impacts of risk events on the sustainability of production process. Every risk event is assessed to obtain comparison of level of importance with the scale ranging from 1 to 9.

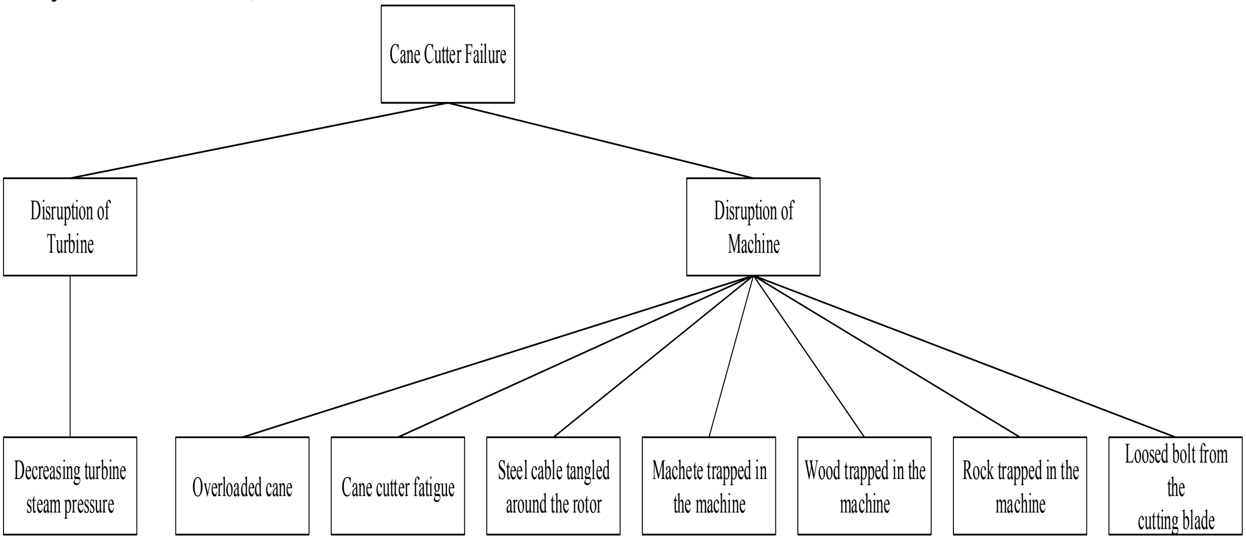

Figure 2. Hierarchy of Risk Event in Cane Cutter Failure

Table 6. Results of Discussion on the Level of Importance of Risk Event

Risk Event	Score	*Risk Event*
Decreasing steam pressure	7	Steel cable tangled around the rotor
Decreasing steam pressure	5	Machete trapped in the machine
Decreasing steam pressure	5	Wood trapped in the machine
Decreasing steam pressure	7	Rock trapped in the machine
Decreasing steam pressure	7	Loosed bolt from the blade
Machete trapped in the machine	3	Overloaded cane
Machete trapped in the machine	2	Cane cutter blade fatigue
Machete trapped in the machine	3	Steel cable tangled around the rotor
Machete trapped in the machine	5	Wood trapped in the machine

Risk Event	Score	*Risk Event*
Machete trapped in the machine	3	Rocked trapped in the machine
Cutting blade trapped in the machine	3	Loosed bolt from the blade
Cane cutter blade fatigue	7	Overloaded cane
Cane cutter blade fatigue	3	Steel cable tangled around the rotor
Cane cutter blade fatigue	5	Wood trapped in the machine
Cane cutter blade fatigue	5	Rock trapped in the machine
Cane cutter blade fatigue	5	Loosed bolt from the blade
Steel cable tangled around the rotor	3	Overload
Steel cable tangled around the rotor	2	Wood trapped in the machine

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Comparison results presented in Table 6 were made in paired comparison of matrix among risk events. In pair comparison, the calculation involved the calculation among risk events of row and column vectors. Each of the risk events was then summed for normalization. The normalization was done for each risk event, and the equation of matrix normalization was arranged as what is presented in equation 2.

$A_{ij} = \frac{a_{ij}}{z_j}$ (equation 2)

One of examples of paired matrix normalization of row of risk event of decreasing steam pressure and column of risk event:

$A_{decreasing\ steam\ pressure,overload} = \frac{5}{26} =$ 0.192

To find out the consistency of paired comparison between risk events, consistency test with the following equations was required:

$CI = (\lambda\ maks - n)/n$ (Equation 3)

$CR = CI/RC$ (Equation 4)

The score of RI for the table with matrix 8 was 1.4. Consistency test was performed as follows:

$$\lambda\ maks = (2.17\times0.399) +(26\times0.034) +(9.08\times0.182) +(16.33\times0.070) +(8.03\times0.159) +(21.33\times0.047) +(21.50\times0.045) +(18.50\times0.064\ )$$

$\lambda\ maks = 8.978$

$CI = \frac{8.978-8}{7} = 0.139$

$CR = \frac{0.139}{1.41} = 0{,}09$

With the score of CR ≤ 10% , the repaired comparison of matrix of risk event was consistent. The results of the weight able to be used to determine impacts of risk events according to risk scoring matrix. Table 7 represents classification of impact score by considering the calculation of weight of score in previous research.

Table 7 Risk Matrix Impact Score

Impact Score	Impact Level	Impact
5	*Very High*	>0.16
4	*High*	0.12-0.16
3	*Moderate*	0.08-0.12
2	*Low*	0.04-0.08
1	*Very Low*	<0.04

(Source: Hyun, Min, Choi, Park dan Lee ,2015)

The result of impact score calculation is presented in Table 8.

Table 8. Classification of Impact Score

Risk event	Code	Weight of score (Impact)	Impact Score
Decreasing steam pressure of drive turbine	D1	0.461	5
Cane cutter fatigue	D2	0.092	3
Machete trapped in the machine	D3	0.092	3
Wood trapped in the machine	D4	0.066	2
Rock trapped in the machine	D5	0.066	2
Overloaded cane	D6	0.092	3
Steel cable tangled around the rotor	D7	0.066	2
Loosed bolt from the cutter blade	D8	0.066	2

3.5 Analyzing Risk Level

Risk level analysis can be performed later by determining the probability and impact of an event in risk scoring matrix. Risk level can be obtained by multiplying probability score by impact score. The equation of the calculation of risk level refers to equation 4 presented as follows:

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$$Risk \text{ level} = Probability \times Impact \quad \text{(Equation 4)}$$

$$Risk \text{ level}_{\text{dicreasing steam pressure of turbine}} = 1 \times 5 = 5$$

Table 9 represents the analysis of risk level according to risk matrix in risk event of cane cutter failure.

Table 9. Risk Class Analysis

Risk event	Probability score	Impact Score	Risk Level
Decreasing steam pressure of turbine	1	5	5
Cane cutter fatigue	3	3	9
Machete trapped in the machine	2	3	6
Wood trapped in the machine	1	2	2
Rock trapped in the machine	1	2	2
Overloaded cane	2	3	6
Steel cable tangled in the rotor	1	2	2
Loosed bolt from the cane cutter blade	1	2	2

Risk matrix obtained from the result of level classification in Table 10 is presented in Figure 3.

			Impact				
			Very Low	Low	Moderate	High	Very High
			1	2	3	4	5
Probability	Very Unlikely	1		D4, D5, D7,D8			D1
	Unlikely	2			D3,D6		
	Possible	3			D2		
	Likely	4					
	Very Likely	5					

Figure 3. Risk matrix of Cane Cutter Failure

Color code showing risk level of each risk event in Figure 3 is explained in Table 10.

Table 10. Risk Class Category

Color	Risk class
	Negligible
	Tolerable
	Undesirable
	Intolerable

Source: Hyun, Min, Choi, Park dan Lee ,2015)

In Table 7 and Figure 3, it is obvious that cane cutter fatigue had the highest level (9) with the risk class tolerable. Similarly, other risk events such as overloading and trapped machete in the machine were categorized as tolerable, while the other four risk events were categorized as negligible. Risk event mapping is elaborated as follows:

1. Decreasing steam pressure of turbine
   Risk event of decreasing steam pressure of turbine was at risk level negligible marked in green. With this category of negligible, the probability score reaching 1, and impact score of 5, the risk event was in the category of negligible.
2. Overloaded cane
   According to the mapping result of risk matrix, risk event of overloaded cane was marked in yellow, meaning the risk class was categorized tolerable with the probability score of 3 and impact of 3. Both of the probability and impact caused by the event of overloaded cane should be taken into account by the company for more control at tolerable level.
3. Cane cutter fatigue
   Risk event of cane cutter fatigue was marked in yellow, meaning tolerable. The company should take into account control of this risk event because the probability obtained was higher than the overall risk event failure of cane cutter.
4. Steel cable tangled around the rotor
   With the probability score categorized as very unlikely and the impact score as low, risk event of steel cable tangled around the rotor was marked in green in risk matrix, meaning the risk class was at negligible.
5. Machete trapped in the cane cutter

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machine
Risk event of trapped machete in cane cutter machine was categorized as tolerable in the risk class. The company is required to control this risk event because, in addition to downtime, it can trigger hazard, which may harm the worker who operates the machine.

6. Wood or rock trapped in cane cutter machine, and loosed bolt from the cutter blade
   All the three risk events mentioned above had low probability and impact.

3.6 Controlling Risk Event

Risk control would need to be done for the three events with highest risk that were categorized as tolerable: cane cutter fatigue, overloaded cane, and trapped machete in the machine. Risk control aims to reduce risk level of each risk event. In this research, risk control was aimed at any probability and impact possibly occurring. The following are some recommendations for risk event control:

1. Overloaded cane
   To control the risk caused by the overloaded cane, the company should consider conveyor gate which would only accept 250-300 kg/m^3 canes, so that the cane whose has weight exceeds what could be accepted by the conveyor gate will automatically be discarded to both side of conveyor table before it is picked and loaded back to the truck. The conveyor gate is illustrated as follows:

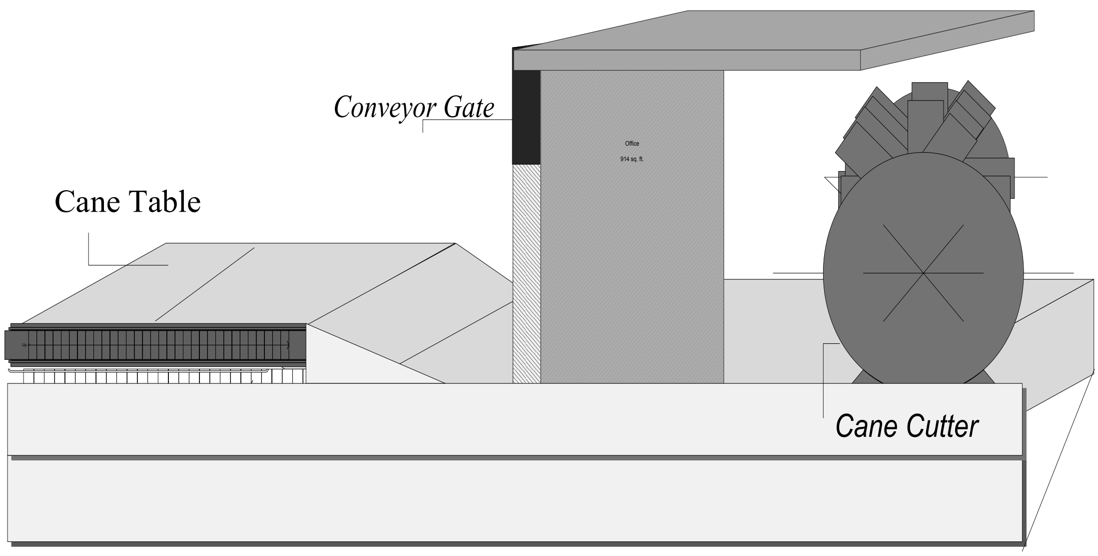

Figure 4. Conveyor Gate

2. Cane cutter fatigue
   PTPN X Tjoekir Sugar Factory only uses a set of blades with the thickness reaching 22 mm to mill cane. It is important for the company to use thicker blades when the existing 22 mm blades are no longer capable of performing cutting process.
3. Trapped machete in the machine
   The trapped blade in the machine was simply caused by negligence. To reduce the risk, inspection needs to be carried out before cane is loaded onto a cane carrier, so that any trapped objects will be easily identified before cane is sent into the machine.

4. Conclusion

After the data was analyzed, the researcher drew some conclusion as follows:

1. The types of failures of cane cutter in PTPN X Tjoekir Sugar Factory occurring from 2013 – 2014 are identified:
   a. The decreasing steam pressure of drive turbine failure was caused

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by the inclomplete bagasse burning process.
   b. The broken blades were caused by cane cutter fatigue, trapped machete, rock, and wood in the machine.
   c. Jammed cane cutter was caused by overloaded cane, steel cable tangled around the rotor, and corroded bolt which led to the loose bolt and fell out of the blade, hampering the spin of the cutter.
2. Based on the probability analysis using FTA of risk event of cane cutter, it was found out that overall risk events were in the range of 1 – 4. Risk event of cane cutter fatigue had the highest probability score (4). While the result of impact analysis using AHP shows that failure risk event of cane cutter had the highest impact score on the decreasing steam pressure of drive turbine. The results of impact and probability analysis were arranged in risk matrix mapping and they indicated that cane cutter fatigue had the highest risk level (9), with the risk class tolerable. The risk event of overloaded cane and trapped machete in the machine was also in the category tolerable.
3. All the four risks were in the category negligible. According to the result of discussion with the manager of mill station, risk control will be focused on the three risk events of the highest score with category tolerable: cane cutter fatigue, overloaded cane, and machete stuck in the machine.
4. Some recommendations are given to control the chance and impact of risk event of cane cutter failure. It is essential that the company
   a. Consider setting conveyor gate
   b. Consider using blade thicker than 22 mm in a way that only one set of blades is used according to the standard set in the production process when cane cutter still occurs and leads to broken blades.
   c. Inspect cane before it is loaded onto a cane carrier to avoid the risk of stuck machete in the cane cutter.

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