Risk Analysis and Mitigation Strategy for Sugar Cane Production Processes (Case Study: X Sugar Cane Factory – West Java)

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Abstract. As an agricultural industry, sugar mills face additional risks affecting the performance of production processes derived from raw materials due to their seasonal, perishable, bulky, and diverse quality. Therefore, risk management becomes very important.. The purpose of this study was to identify, analyze, and define risk mitigation strategies. The methods used are: (1) Risk breakdown structure for exploring Sugar Cane Production Processes; (2) Failure Mode and Effects Analysis Fuzzy (Fuzzy FMEA) for assessing risk components and risk priority number (RPN), and (3) Modified Fuzzy House of Risk 2 (HOR2) for determining rank of priority to each mitigation action. The research was conducted at X sugar factory in West Java as a case study. The whole energy consumption of the factory is supplied from biomass energy. The study identifies 42 risk incidents and 9 risk events with very high priority categorical value. The dominant incidence of risk occurs in the activity of cane sugar supply, sugar cane milling, evaporation, and cogeneration. While one of the recommended risk mitigation strategies that can address the cross-activity risk is by improving the management process of sugarcane supply. This is done by maintaining the stability and the quality of the established cane supply..

Key word: risk management, FMEA, fuzzy, house of risk, cogeneration, mitigation

1. Introduction

Sugar is one of the strategic food products in Indonesia that must be available at any time. Currently, the national demand for sugar cane is supplied both from domestic and import product where the national sugar cane production is 40% [1] and the rest is imported.

Sugar cane industry have high uncertainty due to the nature of its raw materials are perishable, seasonal, bulky, and diverse in quality. Risks caused by raw materials can disrupt the entire value chain from sugarcane cultivation, harvesting, production to marketing [2]. Risks in a production process can occur in any activity (operational risk). Such risk is not only cause performance loss but also financial, psychological, social, and time losses [3]. Therefore risks must be addressed so the chances of occurrence or the resulting impact can be mitigated through a risk management that is a process ranging from identification, analysis, evaluation and risk handling. Such process is known as risk management [4, 5]. Risk identification and analysis enabling more appropriate business and risk management decisions [6].

Each organization face different risks depending on supply sources, type of process, technology and its age, human resources (HR) condition, environmental conditions and others. Research on one sugar factory in Java, namely PG. X was conducted to study the risk on the operational activities of the organization.

PG X is a sugar cane factory whose raw materials are mostly comes from their own farm (83%) and the rest 17% comes from farmers [7]. However, PG faced quite large risks especially that impact on the cessation of the production process or milling stops. According to PG X report, in the periods of 2012-2016, the average of milling stops reached 22% of total milling time. Milling stops incidents above average was occurred in 2013 and 2016, namely 30% and 33%, respectivelly, due to factories outside factors, that is 23% and 25% respectivelly. In 2014, contribution of milling stops due to inside factory factor (14%) is much larger than the outside (4%), although it is still below the average. Outside factory factor is associated with disruption of flow or raw material supply while inside factor is due to disruption of sap processing into crystals sugar.

Risk sources, both outside and inside factory factor, may come from raw materials, intermediary materials, machinery/equipment, human resources, utilities etc. Therefore, this study aims to: a). Identify risk of sugarcane production process in a series of sugarcane production process activity. The identification process will be done by FMEA (*failure mode and effects analysis*) method as a systematic method to find failure modes, causes and impacts on a design, process, and system [8]. b) Perform risk analysis with Fuzzy FMEA approach to determine risk priority to be handled by calculating *fuzzy risk priority number/*FRPN [9, 10], and 3). choose effective mitigation actions that are easy to implement with the proposed method, modified Fuzzy HOR2. The proposed method is a development of the HOR2 method introduced by Geraldin Pujawan and Geraldin [11] with a fuzzy approach to reduce the bias of expert opinion, and modify it by replacing aggregate risk priority (ARP) with FRPN on total effectiveness function.

2. Research Methodology

2.1. Collecting Data Method

Data collection in this research is performed through:

1. Literature study, scientific journals and related textbooks such as risk management and analysis methods, as well as sugarcane production processes
2. Discussion and direct observation on sugarcane production process from harvest dan transportation activity, inside factory production process to white sugar crystal storage.
3. Semi-structured questionnaire as a guide for interviews with individual who responsible on each activities to identify risks, assess risk components, and suggestions for handling.
4. In-depth interviews to actors/persons who responsible for each of these activities, particularly related to the causes of risks and mitigation measures.

2.2. Research Stages

The study was conducted in three main stages: 1). Risk identification stage of sugar cane production process activity. This stage divides sugarcane production process into activity/sub activity and followed by identification of potential risks, risk impacts, risk causes, availability of control systems, and risk sources. 2). Risk analysis stage, that is risk assessment of three risk components, namely: severity, occurrence, detection and calculating *fuzzy risk priority number* (FRPN) using Fuzzy FMEA method 3). choose effective mitigation actions that are easy to implement with the proposed method, modified FuzzyHOR2. Such research stages are illustrated in the flow diagram as shown in Figure 1.

2.2.1 Risk Identification, Risk identification stage is performed by: 1). Sugarcane supply activity, sugarcane production process, and boiler station utility unit into sub-activity based on sugarcane production process flow; 2). identify the potential failure mode that occurs in each activity; identify the impact caused (failure effect), failure causes, existing detection system, failure source, and treatment risk advice. The results are presented in the FMEA table and encoded.

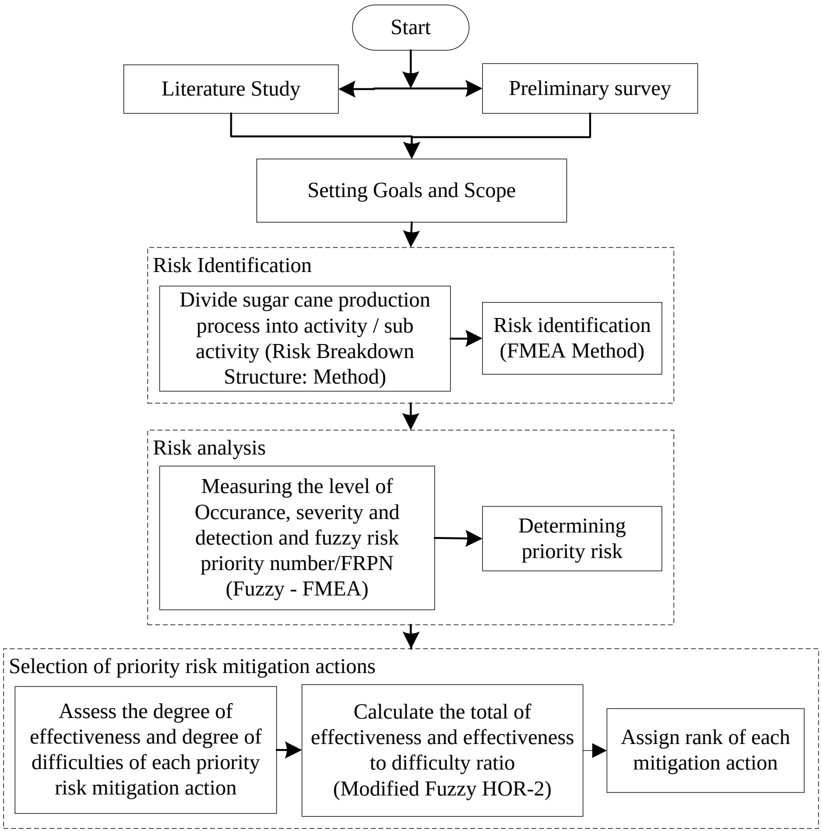

Figure 1. Research's Stage

2.2.2 Risk Analysis. The purpose of risk analysis is to find risk number. In the conventional FMEA method, risk are function of severity (S), occurrence (O), and system capability to detect failure (detection/D). This risk number is referred as risk priority number/RPN [8]. Risk component value is expert perception and fuzzy logic approach used to reduce the bias [12-14]. The stages of risk analysis with Fuzzy FMEA method is follow Tay [10].

FRPN value is the output of *fuzzy inference system* (FIS) that has been through defuzzyfication with the input value of the membership function of each risk component S, O, and D, shown in Figure 2a. The output membership function is shown in Figure 2b. In this research, FIS method was follow Mamdani method (Max Min method) and evaluation of risk component scale was refers to Sharma, Kumar and Kumar [12]. While in defuzzyfication method, output value is using central average method, because has several advantages such as reasonable, simple and continuous computation [13].

2.2.3 Selection of risk mitigation strategies. Risk mitigation strategies aim to reduce the chances of occurring, sharing, and/or reducing the impact of risks [15, 16]. Determination of mitigation is on risk nature basis [16],, in which the nature is related to the source (internal, external, and external in the supply chain or outside the supply chain). The effectiveness of risk mitigation is highly dependent on variation understanding and interrelationships among risks [17].

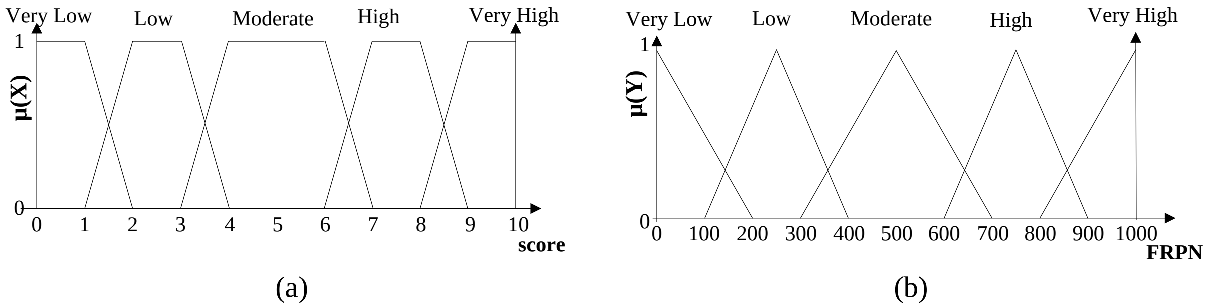

Figure 2. Graph of membership function of risk component input b). Graph of output membership function

According to [11], selection of the most feasible implemented mitigation strategies is based on two considerations namely correlation level between mitigation and risk agents and the degree of difficulty in their implementation. Correlation level can be interpreted as the effectiveness level. Such method is known as HOR-2 (House of Risk Stage 2). This HOR-2 method is utilizes Agregrate risk number (ARN) value from HOR-1 to calculate total effectiveness (TE). In this research, HOR-2 uses fuzzy approach and ARN value is replaced by Fuzzy RPN. Such method is referred as Modified Fuzzy HOR-2.

Assessment of correlation level ($\tilde{E}$) and difficulty level ($\tilde{D}$) of mitigation implementation with fuzzy approach is presented in Figure 4. Expert opinion aggregation is using Non-Numeric Multi Criteria technique [18].. Total fuzzy effectiveness ($\widetilde{TE}$) and fuzzy mitigation difficulties ($\widetilde{ETD}$) ratios are calculated using equation (1) and (2), respectively. The mathematical operations of fuzzy numbers are referring to Marimin, Djatna, Suharjito, Hidayat, Utama, Astuti and Martini [19].

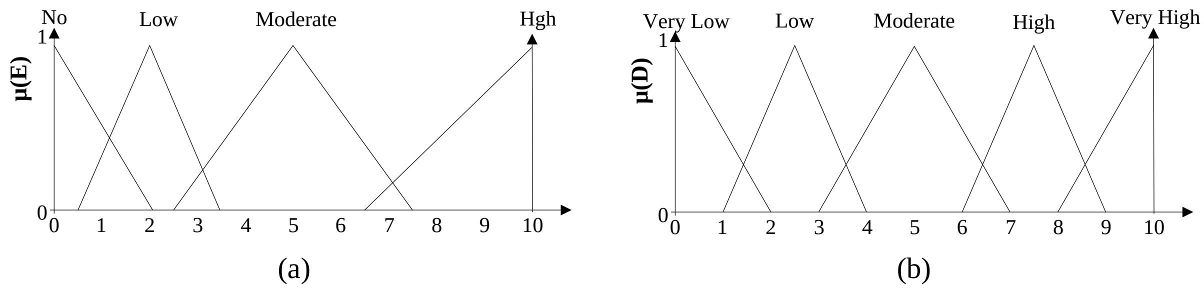

Figure 3. a). Graph of effectiveness level membership function b). Graph of difficulty level membership function

$$TE_k = \sum_{j=1}^{m} FRPN_j E_{jk} \;, \; \text{k=1, 2, … n} \;. \tag{1}$$

$$ETD_k = \frac{TE_k}{D_k}, \text{ k=1, 2, … n} \tag{2}$$

Then, $\widetilde{ETD}$ value is sorted, where the largest mitigation $\widetilde{ETD}$ value is the most efficient and easiest mitigation to be implemented.

3. Results And Discussion

3.1 Risk Identification of Sugarcane Industry Process

PG X began operation on 5 September 1980 with mixed system production process, carbonation and sulfitation. The milling system uses 4 serial mills, sugar products drying using rotary sugar dryer, and cooking using ACD patterns. The cogeneration system is completely use raw materials from bagas (non-supply) to produce steam to drive production machinery and electric generators.

Off farm activity of sugarcane production process in PG X is begins with manual and semi manual loading sugar cane activity. During the period 2013-2016, the source of sugarcane raw materials is 81% (on average) comes from own farm; 17% of farmers and the rest (2%) from other sources. Control of such activities is under PG management. The aims is to control the raw materials both quality and quantity. Plant location is inside farm with an area of 8,200 ha. The farm is a dry land, located 30-45 m above sea level and tropical rainy climate.

Risk identification includes cutting, loading, hauling (TMA) activity, milling, refining, evaporation, cooking, crystallization, drying, packaging, and storage and cogeneration activities. The results of risk identification for each activity are presented in Table 1.

Table 1. Risk identification of sugarcane production process by activity

Activity	Risk			
1. cutting, loading, hauling (TA)	TA.01	Harvest volume is less than milling capacity	TA.05	Harvesting residue (stump and stem) is above the target
	TA.02	Trash on sugarcane > 5%	TA.06	Transport delay
	TA.03	Sugarcane is not sweet	TA.07	Sugarcane stay in the emplacement > 24 hours
	TA.04	Sugarcane is unfresh		
2. Milling (SG)	SG.01	Sugarcane supply to sugarcane table is not kontinu / stopped	SG.04	Milling hydraulic pressure is unstable.
			SG.05	Damage on milling roll
	SG.02	The rate of milling process is disrupted	SG.06	POL Bagasse (> 2,5%)
			SG.07	Bagasse water content (> 52 %)
	SG.03	Damage on the cane carrier unit or its components		
3. Purification (SP)	SP.01	Disruption of sugarcane juice pump	SP.06	Purification heating temperature (< 90
	SP.02	Heating temperature > standard	SP.07	Juice turbidity of flash tank is high (> 150 NTU)
	SP.03	Heating temperature < standard		
	SP.04	Ph fluctuate in defecation process	SP.08	Filtercake (Blotong) pol is high (>2%)
	SP.05	Ph fluctuate in sultitasion 1 process		
4. Evaporation (SE)	SE.01	CaO on clear juice is high	SE.03	Vacum pressure is low (< 65 cm hg)
	SE.02	Steam pressure is low (< 0,5 kg/cm^2)	SE.04	Damage on condensate water pump
			SE.05	Damage on Viscous Nira pump
5. Crystalization/ sentrifugation (SM)	SM.01	Brick of syrup is low (<65%)	SM.04	Bulk density of crystal is small (< 0,9 mm)
	SM.02	Steam pressure is (< 0,5 Kg/Cm^2)		
	SM.03	Vacuum pump is less powerfull	SM.05	Degree of purity's molasse < 32 %
6. Finishing (SF)	SF.01	Level of canesugar dryness is under standard [20]	SF.02	Packaging is not perfect
7. Storing (SI)	SI.01	Canesugar damage		
8. Cogeneration (SB)	SB.01	Low steam pressure	SB.05	Leakage of steam distribution pipes
	SB.02	Diruption fuel supply	SB.06	Leakage of condensate water pipe
	SB.03	Power overload	SB.07	Electrometer burns
	SB.04	Pipe boiler leaking		

Source: Survey Result, 2016

These risks if not handled properly will lead underperformance such as sugar quality, milling stop, processing time, yield, milling efficiency, etc.

3.2 Risk Assessment of Sugar Cane Industry Process

The purpose of the risk analysis is to assess 3 components of risk (SOD) and determine the risk priority value. Risk assessment is using fuzzy approach model, that is modified FMEA method which referred as fuzzy FMEA and its risk scale is called Fuzzy RPN (FRPN). By using Fuzzy Logic Toolbox from Matlab software, such assessment model utilizes FIS in fuzzy logic toolbox. The basic input of FIS rules for FPRN measurement is shown in Figure 4 while the fuzzy critical system is in Figure 5.

According to expert assessment on the risk, FRPN calculation and by considering *pruden*[1]*t* nature of risk, there are 9 very high risk categories to be mitigated. Very high risk category of FPRN is presented in Table 2.

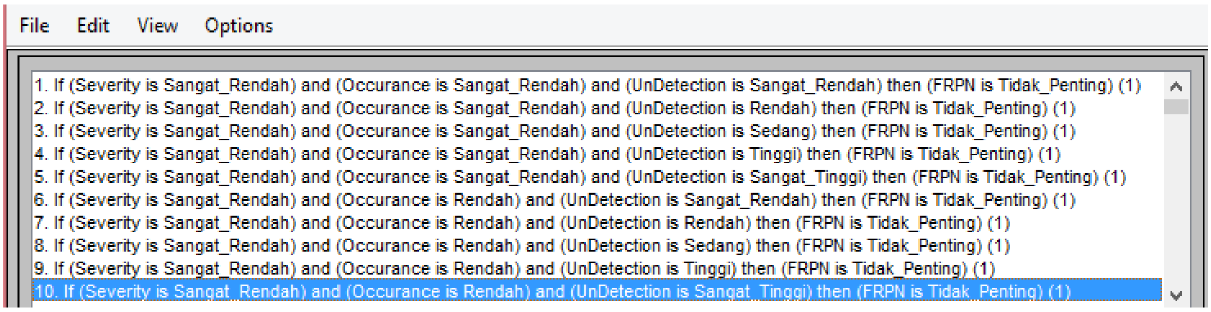

Figure 4. Input rule base display of sugarcane factory risk assessment

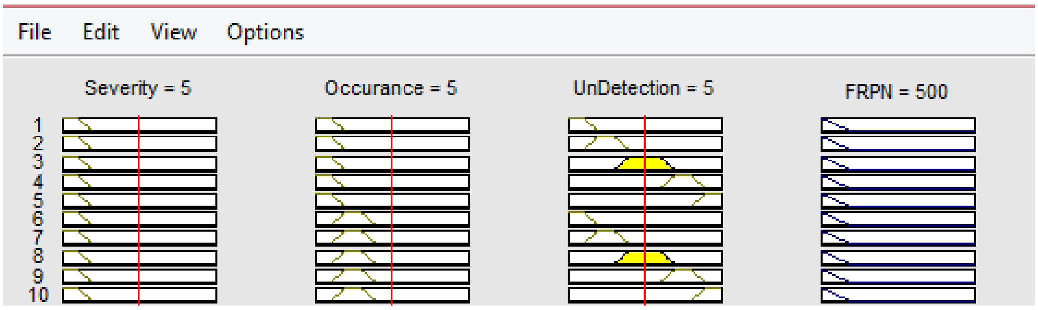

Figure 5. Fuzzy critical System Display of sugar cane production process risk assessment

The results of the risk analysis in very high category is different from Kristyanto, Sugiono and Yuniarti [21] on PG. Kebon Agung who found the priority risk was mostly caused by equipment damage. This is due to different condition of sugar factories. In some cases where raw materials come from farmers, sugar cane factory often face raw material supply risk due to insufficient quantity of raw materials. In this research, the lack of raw material supply is more due to the issue of cutting, loading and hauling as well as natural/weather factor. The risk due to the weather has been proposed by Everingham, Muchow, Stone, Inman-Bamber, Singels and Bezuidenhout [2] that the weather will affect the whole supply chain of sugar agro industry from cultivation to marketing.

3.3 Planning for Risk Mitigation Measures

The nature of the risk associated with the source of risk, if sourced from the internal then it can be controlled so that it can be reduced opportunities chances, while if sourced from external / climate then only able to be reduced impact. However, if sourced from external but

[1]Prudent is a cautious attitude again risks. In this study, if the RPN fuzzy value falls in two or more output category ranges, the highest risk category is selected

still able to cooperation, then the risk can be shared (risk sharing). The risk mitigation strategy is determined by its nature and set forth in the mitigation action plan. Not all mitigation action plans can be implemented, it is necessary to rank by calculating the difficulty mitigation ratio using Formula (2) above. However, if sourced from external but still able to cooperation, then the risk can be shared (risk sharing). The risk mitigation strategy is determined by its nature and set forth in the mitigation action plan. Not all mitigation action plans can be implemented, it is necessary to rank by calculating the difficulty mitigation ratio using Formula (2) above.

Table 2. Cause and source of very high risk category in PG. X

No.	Risk		Risk Agent		Risk Source/ Category	FRPN		
						LL	ML	UL
1.	TA.01	Harvesting volume is less than milling capacity	TA.01.1	High rainfall/wetlands or floods	Nature Environment/ E	500	750	937
			TA.01.3	Shortage of labor harvest	Social Environment/ E_{rp}	500	750	937
2.	TA.02	Trash on sugarcane > 5%	TA.02.1	Operating Systems and Procedures is not followed	SDM/ E_{rp}	500	750	937
3.	TA.07	Sugar cane stay in the amplasemen > 24 hours	TA.07.1	Milling stop due to factor in the factory are not reported by harvesting unit	Management/ I	250	500	937
4.	SG.01	The rate of milling process is disrupted	SG.01.1	Sugarcane supply is less than milled capacity	Raw Materials / I	500	750	937
5.	SG.04	Milling hydraulic pressure is unstable	SG.04.2	Low new steam pressure	Utility /I	500	750	937
6.	SG.05	Damage on milling roll	SG.05.1	Milling roll coat is damage/crack	Tools/I	250	500	937
7.	SE.01	CaO on juice is high	SE.01.1	Refining reaction is not perfect at Purification Station	HR/I	250	500	937
8.	SE.02	Steam pressure is low (< 0,5 kg/cm^2)	SE.02.1	Boiler pressure is low	Utility/I	500	750	937
9.	SB.01	Steam pressure and/or temperature are not reached	SB.01.1	Combustion disorders: grate closed with soil / sand	Fuels/I	500	750	937

Note: E: Extern; I: Intern; E_{rp} : Extern in supply chain; LL: Lower Limit, ML: Midle Limit, UL: Upper Limit

By using risk handling strategy criteria as mentioned above, it can be formulated strategy recommendation and priority risk handling plan as showed in Table 3.

Mitigation measures in Table 3 show that measures to address a risk can also address other causes of risk. Improvement of TMA management (M.01, M.05) such as supply quantity, sugarcane inventory management (M.04), sugarcane quality control (M.03, M.10) can overcome risk not only at cutting loading, and hauling risk but also risks in milling and cogeneration. This shows that the success of TMA activity will determine the success of the next activity. Other mitigation measure which affect other activities are mitigation measures to address nonstandard steam pressure, this is because all activities require steam. Basically, mitigation measures to overcome low boiler steam pressure (M.10) due to low quality of sugarcane is the same as M.06 and M.09 while other mitigation measure is more partial.

Calculation of effectiveness level shows that M.10 is the highest level of effectiveness, followed by M.03 and M.01. By considering the difficulty level of mitigation implementation, it is known that the difficulty ratio of M.06 is the easiest level to be implemented, followed by M.10.

Table 3. The nature and risk mitigation strategy of FRPN with very high category

No.	Risk Agent	Risk Nature	Mitigation Strategy	Mitigation Actions	TE	ETD
1.	TA.01.1	The opportunity cannot be reduced, severity can be reduced and cannot be shared	RR	M.01 Improved TMA management planning with rainy day forecasts	21.974	3.711
2.	TA.01.3	severity can be reduced and cannot be shared	RR	M.02 Controlled planning on milling stop coupled with machine repair schedule	17.992	2.963
3.	TA.02.1	The occurrence can be reduced and shared	RP and/or RS	M.03 TMA SOP implementation and *Reward & Punishment*	23.505	3.953
4.	TA.07.1	The occurrence can be reduced	RP	M.04 Improved communication system between production unit with TMA	17.132	2.721
5.	SG.02.2	The occurrence can be reduced	RP	M.05 If it is raining, sugar cane should be covered both in transport and storage	21.193	3.540
6.	SG.04.2	The occurrence can be reduced	RP	M.06 Quality control of *bagas* through milling control	19.538	6.713
7.	SG.05.1	The occurrence can be reduced	RP	M.07 Replacement of mill roll with the appropriate standard quality and regular improvement	13.931	2.145
8.	SE.01.1	The occurrence can be reduced	RP	M.08 The use of lime and lime milking process according to the standard	13.931	4.092
9.	SE.02.1	The occurrence can be reduced	RP	M.09 Quality control of *bagas* through milling control.	21.912	3.690
10.	SB.01.1	The occurrence can be reduced	RP	M.10 Tightly control the cane clean from soil/sand and/or the installation of impurities prevention system into the process	27.034	4.684

Note: RR: Risk reducing, RP: Risk Preventing, RS: Risk Sharing; TE: Total effectiveness, ETD: Effectiveness to difficulty ratio

4. Conclusions and Recommendations

4.1 Conclusions

According to the analysis results and discussion above, it can be drawn some conclusions as follows:

- There are 42 risks or failures for PG X case studies with Fuzzy FMEA method that contraint the performance.
- Based on risk analysis, there are 9 priority risks (very high category) to get priority for mitigation. Priority risks occur in cutting, loading, hauling activities, milling stations and boiler stations.

- There are interconnected risks, where harvesting, loading, transporting risks will cause subsequent process risks, in particular the risks associated with the raw material, ie unfulfilled quality and quantity. Therefore, risk handling is aimed at the main cause
- Mitigation measures with high effectiveness and degree of difficulty in implementation are M10 ie, tightly milling control and quality of the sugarcane from soil and/or sand as well as instalation of impurities prevention system into the process

4.2 Recommendations

From the modified HOR-2 analysis, it is known that one mitigation can be used for more than one risk agent, therefore further research is needed to determine the contextual relationship between risk mitigation

5. References

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