RISK MANAGEMENT IN SAND MINING ENTERPRISE USING FUZZY FAILURE MODE AND EFFECT ANALYSIS (FUZZY FMEA)

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Abstract

It's known that business has several risk that might be happened. An enterprise should manage their risk to minimize the problem that will be faced. Bunga Mawar is a company which runs sand mining. There are some conditions might be potential to be a problem such as wrong maintenance planning, mismatch the amount of sand, broken sucking tool on mining activity, and difficulties destination to be achieved. This research aims to list the risk in sand mining enterprise, identify, control, and solve the biggest risk that might be happened using fuzzy FMEA (Failure Mode and Effect Analysis). Supply Chain Operation Reference (SCOR) used for classify the risk and fishbone diagram will shows cause and effect of highest rank risk in enterprise. It's founded that Bunga Mawar has 14 risks which consist in 4 plan activities, 3 procurement activities, 3 mining activities, and 4 shipping activities. There are 4 risk that included very high, 1 high-very high, 1 high, 4 moderate, 2 low-moderate, 1 low, and 1 very low-low. In conclusion, all very high risk will be analyzed and managed. The risk control strategies in this research analyze 3 accepted risks, 7 mitigated risks, and 4 avoided risks.

Keywords:
Fuzzy, Risk, FMEA, Sand Mining

1. Introduction

Risk exist in every business activities and caused by many conditions. It is a threat to life, property, or financial profit due to its perils (Kusumadewi *et al.*, 2017) . Hopefully, risk management will help companies to manage all of their risks and minimize their problems. Risk management is a method to identify, to analyze, and to control the risk in every company activities to run effectively and efficiency (Hanafi, 2014). Risk can be defined as a combination of probability or frequency of occurrence of a defined hazard and magnitude of the occurrence (Wang *et al.*, 2009).

Failure mode and effect analysis (FMEA) is one of the risk analysis techniques recommended by international standards such as MIL-STD-1629A in U.S. Department of Defense 1980 (Abdelgawad and Fayek, 2010). Failure mode and effects analysis (FMEA) widely used in engineering technique for defining, identifying and eliminating known and/or potential failures, problems, errors and so on from system, design, process, and/or service before they reach the customer (Stamatis, 1995). FMEA proves to be one of the most important early preventative actions in system, design, process or service which will prevent failures and errors from occurring and reaching the customer. The main objective of FMEA is to identify potential failure modes, evaluate the causes and effects of different component failure modes, and determine what could eliminate or reduce the chance of failure. (Liu, Liu and Liu,

2013). The results of the analysis can help analysts to identify and correct the failure modes that have a damage effect on the system and improve its performance during the stages of design and production.
A system, design, process, or service may usually have multiple failure modes or causes and effects. In this situation, each failure mode or cause needs to be assessed and prioritized in terms of their risks so that high risky (or most dangerous) failure modes can be corrected with top priority. FMEA determines the risk priorities of failure modes through the risk priority number (RPN), which is the product of the severity (S), occurrence (O), and detection (D) of a failure. The three risk factors are evaluated using the 10-point scale described in Tables 1–3. The failure modes with higher RPNs are assumed to be more important and will be given higher priorities for correction (Wang, 2009).

Table 1. Crisp ratings for severity of a failure

Rating	Effect	Severity Effect
10	Hazardous without warning (HWOW)	Very high severity ranking when a potential failure mode affects safe system operation without warning
9	Hazardous with warning (HWW)	Very high severity ranking when a potential failure mode affects safe system operation with warning
8	Very High (VH)	System inoperable with destructive failure without compromising safety.
7	High (H)	System inoperable with equipment damage
6	Moderate (M)	System inoperable with minor damage
5	Low (L)	System inoperable without damage
4	Very Low (L)	System operable with significant degradation of performance
3	Minor (MR)	System operable with some degradation of performance
2	Very Minor (VMR)	System operable with a minimal interference
1	None (N)	No effect

The severity (S) rating is used to represent the potential effects associated with the occurrence of a failure mode. Thus, it reflects the seriousness of the effects of the failure. The occurrence rating (O) is the frequency of the occurrence of the failure ((Abdelgawad and Fayek, 2010)

Table 2. Crisp ratings for occurrence of a failure

Rating	Probability of Occurrence	Failure Probability
10 9	Very high (VH) : failure is almost inevitable	>1 in 2 1 in 3
8 7	High (H): Repeated failures	1 in 8 1 in 20
6 5 4	Moderate (M): Occasional failure	1 in 80 1 in 400 1 in 2000
3 2	Low (L): relatively few failures	1 in 15,000 1 in 150,000
1	Remote (R) : Failure is unlikely	<1 in 1,500,000

The detection rating (D) is a measure of the capability of the current controls. It is an assessment of the ability of current design control to detect a potential cause or mechanism. As the RPN is a measure of the risk of failures, it can be used to rank failures and to prioritize actions. Actions will be taken with priority given to the failure that accorded the highest RPN. (Tay and Lim, 2006). RPNs should be recalculated after the corrections to see whether the risks have gone down, and to check the efficiency of the corrective action for each failure mode. (Liu, Liu and Liu, 2013)

Table 3. Crisp ratings for detection of a failure

Rating	Detection	Possible detection by controller tool
10	Absolute Uncertainty (AU)	Design control cannot detect potential cause/mechanism and subsequent failure mode
9	Very Remote (VR)	Very remote chance the design control will detect potential cause/mechanism and subsequent failure mode
8	Remote (R)	Remote chance the design control will detect potential cause/mechanism and subsequent failure mode
7	Very Low (VL)	Very low chance the design control will detect potential cause/mechanism and subsequent failure mode
6	Low (L)	Low chance the design control will detect potential cause/mechanism and subsequent failure mode
5	Moderate (M)	Moderate chance the design control will detect potential cause/mechanism and subsequent failure mode
4	Moderately High (MH)	Moderately high chance the design control will detect potential cause/mechanism and subsequent failure mode
3	High (H)	High chance the design control will detect potential cause/mechanism and subsequent failure mode
2	Very High (VH)	Very high chance the design control will detect potential cause/mechanism and subsequent failure mode
1	Almost Certain (AC)	Design control will detect potential cause/ mechanism and subsequent failure mode

In fact, the crisp RPNs have been criticized for various reasons (Tay and Lim, 2006). From a management perspective, the traditional RPN calculation is easy to understand and straightforward. However, from a technical perspective, several opinions have noted related to using the traditional FMEA approach to calculate the RPN. Majority of fuzzy FMEA approaches employs fuzzy if–then rules for prioritization of failure modes. The fuzzy RPN approach typically requires a large number of rules, and it is a monotonous task to obtain a full set of rules. The larger the number of rules provided by the users, the better the prediction accuracy of the fuzzy RPN model. As the number of rules required increases, ease of use of the model decreases since the users have to provide a lot of information/rules for the process (Abdelgawad and Fayek, 2010).

Fuzzy logic, as opposed to probabilistic techniques, is suitable for handling situations in which data are not available or are difficult to obtain, or in which assessments are made in linguistic and subjective terms (Abdelgawad and Fayek, 2010). Using fuzzy logic, an assessment of the problem can be derived from experts in the form of linguistic terms such as “very low,” “medium,” “high,” etc. Since fuzzy logic is based on a natural way of human communication, the subjective assessment of the problem can be used to derive an acceptable prediction. Fuzzy logic is combined with FMEA to overcome the deficiencies associated with the traditional approach of computing the RPN number. Instead of depending on the multiplication of S, O, and D, to calculate the RPN, the proposed approach uses a fuzzy expert system, based on information elicited from experts, to analyze and prioritize different risk events. Fuzzy expert system is composed of three processes consist of fuzzification, fuzzy inference, and defuzzification. In fuzzy FMEA, the fuzzification process is the process in which severity (S), occurrence (O), and detection (D) are converted into their fuzzy representations (Wang *et al.*, 2009). User provides assessments of severity (S), occurrence (O), and detection (D) during the process.

This research consider to develop risk management using Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA) method. Fuzzy FMEA method illustrate an obscurity on the risks. This research aims to know risk that occur in sand mining activities, know the biggest failure risk and find out the causes, and also to control and suggest improvement to manage the biggest risk in sand mining company. In this research, Supply Chain Operation Reference (SCOR) which is developed by Supply Chain Council (1999) being a guidance to categorize the risk due to the framework contain standard description of management and its distinct processes for SCOR model: source, make, deliver, and plan.(Huan, Sheoran and Wang, 2004).

In order to represents a model of suggestive presentation for the correlations between the risk (effect) and its multiple causes, Fishbone (Ishikawa) diagram is used. The structure provided by the diagram helps to think in a systematic way (Mahto and Kumar, 2008). Some of the benefits of constructing a Fishbone diagram are that it helps determine the root causes of a problem or quality characteristic using a structured approach. Causes in Cause and Effect Diagram (CED) are frequently arranged in three major categories which are manufacturing industry, marketing industry, and service industry (Kiran, 2017). Ishikawa advocated the CED as a tool for breaking down potential causes into more detailed categories so that they can be organized and related into factors which help in identifying the root cause (Dobrusskin, 2016). This diagram analyzes potential causes of a defect, error or problem of a process under identification.

2. Research methods

Generally, there are three main steps of the risk management process: identification, analysis and treatment (Hanafi, 2014). In this research, identification were categorized based on SCOR model. There are 5 (five) process management core SCOR model which is plan, source, make, deliver and return in company's supply chain and how their performance measured (Delipinar and Kocaoglu, 2016). Firstly, plan which is including all *plan* activities in company. Secondly, *source* which is a process of procurement goods nor service for fulfill demand. Thirdly, *make* which is process of transform from raw material to product that customer desires. Fourthly, *deliver* process for fulfill demand toward goods and services. *Return* as the last category in SCOR is exclude in this research because there is no product return process from customer to company.

In the analysis step, there seems to be a dominant distinction between the following two main activities: risk estimation, which refers to an assessment of the likelihood of severity, occurrence and possible consequences of the risk events identified in the previous step, concerned with the determination of the likelihood of each risk factor (Tummala and Schoenherr, 2011); and risk assessment, which refers to evaluation of the assessed risk by comparison with the criteria and thresholds of the decision maker(s) in order to determine the priority for treatment (Raz and Hillson, 2005). As mention in previous section, RPNs number is difficult to adopt in real system. Fuzzy FMEA help to present the uncertainty of crisps ranking to be more realistic (Tay and Lim, 2006). Fuzzy Mamdani method were chosen to analyze.

The Mamdani method is often also known as the *Max-Min* Method. This method was introduced by Ebrahim Mamdani in 1975. To get the *output* , it takes 4 stages (Kosasih, 2016):

a. The formation of *fuzzy* sets. In the *fuzzification* process the first step is to specify the *fuzzy* variable and its *fuzzy* set. Then specify *degree of membership* between the *fuzzy* input data with the defined *fuzzy* set for each variable system input of each rule *fuzzy* in interval 0-10. The categories of membership functions shoulder (Formulation 1), triangular (Formulation 2), and trapezoidal (Formulation 3) are used to this research as follows.

$$\mu(x)=\begin{cases} 0 & ;\text{ if where } x \leq a \\ (c-x)/(c-b) & ;\text{ if where } a \leq x \leq b \\ 0 & ;\text{ if where } x \geq c \end{cases} \quad \text{.................................. (1)}$$

$$\mu\,(x)=\begin{cases} 0 & ;\text{ if where } x \leq a \text{ or } x \geq c \\ (x-a)/(b-a) & ;\text{ if where } a \leq x \leq b \\ (c-x)/(c-b) & ;\text{ otherwise} \end{cases} \quad \text{..............................(2)}$$

$$(x)=\begin{cases} 0 & ;\text{ if where } x \leq a \text{ or } x \geq d \\ (x-a)/(b-a) & ;\text{ if where } a \leq x \leq b \\ 1 & ;\text{ if where } b \leq x \leq c \\ (d-x)/(d-c) & ;\text{ otherwise} \end{cases} \quad \text{..............................(3)}$$

Input members function for severity, occurrence, and detection criteria and the Input parameter members function for each linguistic variable shown in Table 4 and Table 5 respectively (Supriyadi, Ramayanti and Afriansyah, 2017).

Table 4. Input Members Function

Ranking			Category
Severity (S)	Occurrence (O)	Detection (D)	
1	1	1	Very Low (VL)
2, 3	2, 3	2, 3	Low (L)
4, 5, 6	4, 5, 6	4, 5, 6	Medium (M)
7, 8	7, 8	7, 8	High (H)
9, 10	9, 10	9, 10	Very High (VH)

Table 5. Parameter Input Members Function

Category	**Curve type**	**Parameter**
Very Low	Shoulder/Trapezoidal	[0;0;1;2,5]
Low	Triangular	[1;2,5;4,5]
Moderate	Shoulder/Trapezoidal	[2,5;4,5;5,5;7,5]
High	Triangular	[5,5;7,5;9]
Very High	Shoulder/Trapezoidal	[7,5;9;10;10]

Fuzzy RPN (FRPN) is resulted from multiplication of members function for severity, occurrence, and detection criteria and categorized as shown in table 6 with output parameter members function shown in table 7 (Supriyadi, Ramayanti and Afriansyah, 2017).

Table 6 Category Risk Output

Risk Priority Number	Category
1 – 49	Very Low (VL)
50 – 99	Very Low – Low (VL – L)
100 – 149	Low (L)
150 – 249	Low – Moderate (L – M)
250 – 349	Moderate (M)
350 – 449	Moderate – High (M – H)
450 – 599	High (H)
600 – 799	High – Very High (H - VH)
800 – 1000	Very High (VH)

Table 7. Output Parameter Members Function

Category	**Curve type**	**Parameter**
VL	Shoulder/Trapezoidal	[0, 0, 25, 75]
VL-L	Triangle	[25, 75, 125]
L	Triangle	[75, 125, 200]
L-M	Triangle	[125, 200, 300]
M	Triangle	[200, 300, 400]
M-H	Triangle	[300, 400, 500]
H	Triangle	[400, 500, 700]
H-VH	Triangle	[500, 700, 900]
VH	Shoulder/Trapezoidal	[700, 900, 1000, 1000]

b. Fuzzy Rules Bases. On this stages, *fuzzy* IF-THEN rules was used. IF as input variable (S, O and D) and THEN as output variable.
c. Fuzzy inference process. In Mamdani method, the implication function used is *min*. Perform *fuzzy* implications based on strong ignition and undefined *fuzzy* sets for each variable outputs within the consequences section of each rule.
d. Defuzzification. The input of the defuzzification process is a *fuzzy* set obtained from the composition *fuzzy* rules, while *output* the result is a number in the *fuzzy* set domain. Defuzzification on Mamdani method composition

using centroid method (Dhimish *et al.*, 2018). Where in this research, the *crisp* solution is obtained by taking the *fuzzy* area center point.

The last step was risk treatment step, the set of possible courses of action mentioned by most of the standards was quite limited, and includes the following: avoidance; probability reduction (preventive counter-measures); consequence limitation, including recovery and contingency planning; and risk transfer, including subcontracting. (Raz and Hillson, 2005). In some cases, company is choosing to accept the risk because the risk can't be avoid or reduce due to an integral part of the organizational scope of work. Then, fishbone diagram is used to breakdown the root cause of the higher risk in company. The design of the diagram looks like the skeleton of a fish. Mostly, the representation is simple, through bevel line segments which lean on an horizontal axis, suggesting the distribution of the multiple causes and sub-causes which produce them, but it can also be completed with qualitative and quantitative appreciations, with names and coding of the risks which characterizes the causes and sub-causes, with elements which show their succession, but also with other different ways for risk treatment. The diagram can also be used to determine the risks of the causes and sub-causes of the effect, but also of its global risk (Ciocoiu, Ilie and Ciocoiu, 2010).

3. Result and Discussion

Sand mining company presented by Bunga Mawar Company is participated to this research. Established since 2008 and located at Tanjung Redeb, Berau, the company provides data related to the risks by fills the questionnaire and do some interviews. Data collection with questionnaires is conduce to obtain a list risks that exist in the company and to get the value of severity, occurrence, and detection on each risk list. Meanwhile, interviews are done to find out the causes, handling and suggestion against risks that occur in the company.
The risk map in CV Bunga Mawar use SCOR method with S, O, and D values for each risk shown in Table 8. All risk categorized on plan, source, make, and deliver activity.

Table 8. Risk Identification

Activity	Code	Risk	Severity	Occurrence	Detection
Plan	P1	Maintenance schedule is unattended	8	3	10
	P2	Delivery plan to consumer is not ascertain	2	3	10
	P3	Uncertain time return ship	1	1	10
	P4	Lack of capabilities for human resources	3	1	10
Source	S1	Type of sand needed is not suitable	2	3	4
	S2	The amount of sand needed is not appropriate	2	3	1
	S3	Limited source of fund	4	4	2
Make	M1	Sand sucker broken at the time of mining	10	5	6
	M2	Ship broken at the time of mining	7	5	6
	M3	Flood in the river	9	5	6
Deliver	D1	Broken transportation tools	10	4	1
	D2	Instability of fuel price	3	2	5
	D3	Lack of fuel	4	7	5
	D4	Delivery destination difficult to reach	2	4	1

The stage in FMEA Fuzzy method shown in Figure 1 to Figure 3. As an example, the broken suction machine risk as the first risk on the list make activity will explain briefly on this article.

a. *Fuzzy membership function* is the stage for definite the members function. The input are severity, occurrence, and detection, with the same parameter number.

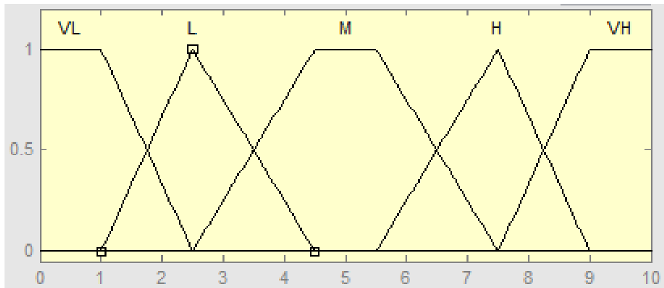

Figure 1 Input parameter of member function

In membership function stage also include the output parameter of the member function that is FRPN value which seen in Figure 2.

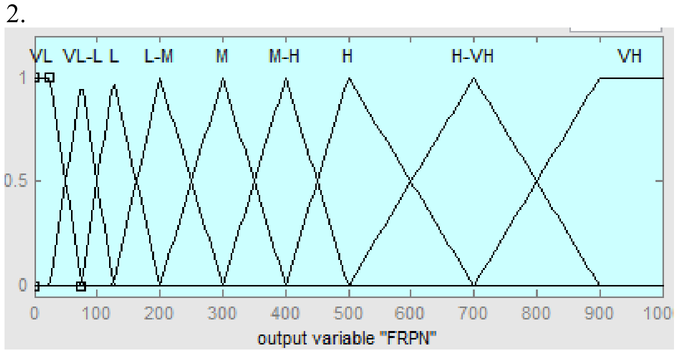

Figure 2. Output parameter of member function

b. Fuzzy rule bases and Fuzzy inference process with the severity number 10, occurrence 5, and detection 6 as seen on Figure 3 use 125 rules based on 5 (five) categories which shown on table 4 and table 5 previously. Then, obtained two rules that have the result area number 113 and 114 and result FRPN 886 for risk M1.

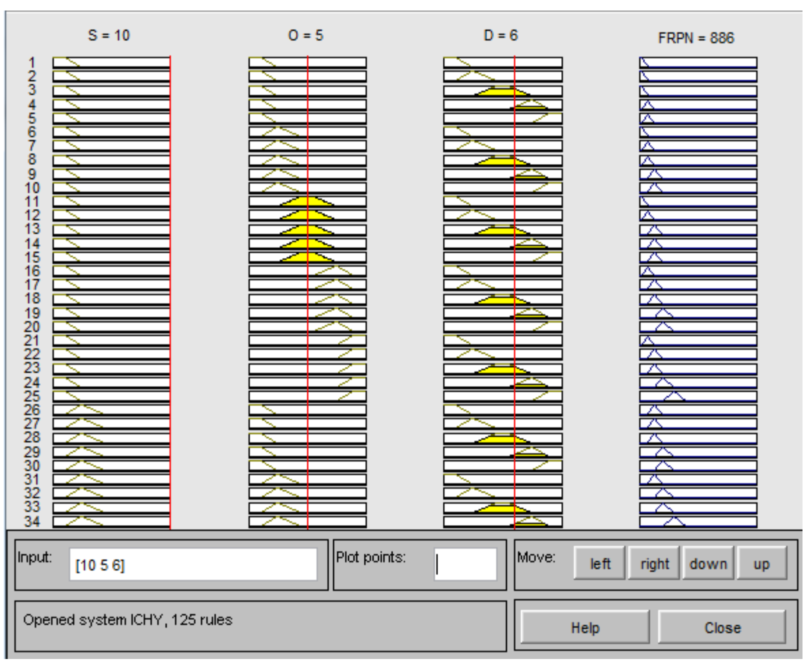

Figure 3. Fuzzy Rule Bases

Fuzzy inference process on Figure 4 shown the rules which have minimum function area. The result on Figure 4 with 125 rules shown there are 2 result areas which are rule number 113 and rule number 114. It is seen on FRPN column with shade area. It means, the shade area have values while the others have zero values.

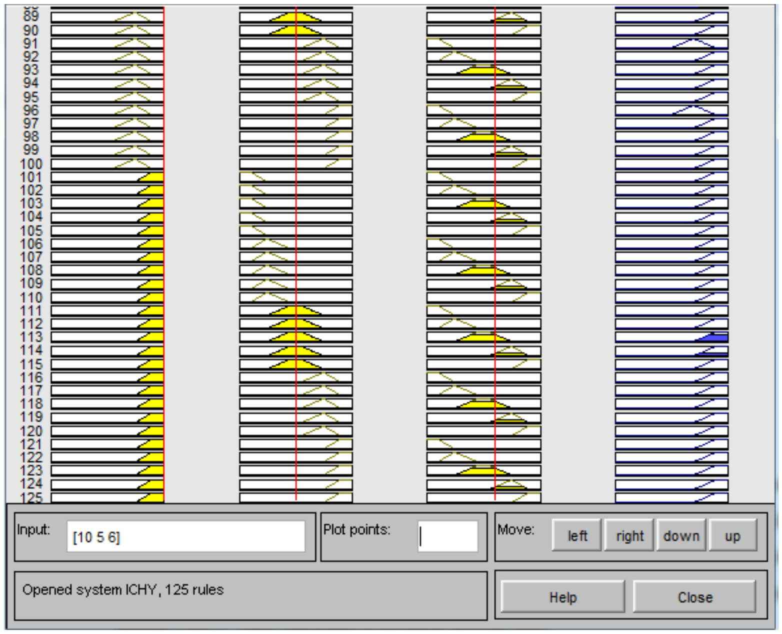

Figure 4. Fuzzy Inferences Process

Each rule in the fuzzy knowledge base would be dealing with a fuzzy relation. Compound statement which is used in developing the rules on fuzzy logic is the implication function (if-then rule). In fuzzy IF-THEN rule, the IF-part is antecedent as the fuzzy input variables, and the THEN-part is consequent as the fuzzy output variable. Thus, minimum inference engine is used to combine the fuzzy IF-THEN rules in fuzzy rule base and implicate the fuzzy conclusion.
In this research, defuzzification process used centroid method, which crisp solution is obtained by taking the center of a fuzzy area.
Risks can be sort based on FRPN value that have been processed before, the risk sequence at Bunga Mawar company shown in Table 9.

Table 9. Sequence and risk control based on FRPN value

Code	FRPN	Category	Control
M3	894	Very High	Accept
M1	886	Very High	Mitigation
D1	885	Very High	Mitigation
P1	883	Very High	Mitigation
M2	792	High – Very High	Mitigation
D3	479	High	Accept
S3	317	Moderate	Mitigation
P4	275	Moderate	Mitigation
D2	258	Moderate	Accept
P2	254	Moderate	Mitigation
S1	203	Low – Moderate	Avoid
S2	201	Low – Moderate	Avoid
D4	103	Low	Avoid
P3	75	Very Low – Low	Avoid

Based on the table 9, the risks are classified as very high to moderate which must be mitigation. Flood in the river risk (code M3) has the highest FRPN value. It means that the risk is a crucial condition and has to be manage to minimize company's loss. In fact, flood is a circumstance caused by natural condition. It is something that company can't control. Accept the condition is the only react to manage the risk. To minimize the loss, company needs to add an inventory sand when this risk happen. Further process with fishbone diagram to find out the cause and improvement suggestion. Risk priority to control based on the highest rank of FRPN value. As limitation, firstly, risk which is accepted by company doesn't analyzed with fishbone diagram. Secondly, only the highest FRPN is analyzed for the root cause which shown on Figure 5.

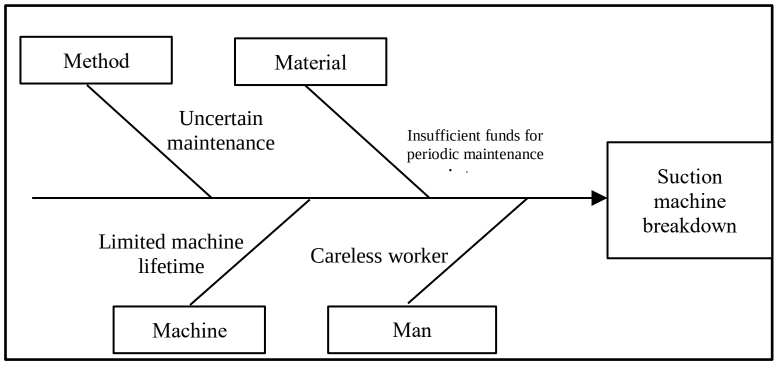

Figure 5 Fishbone diagram suction machine breakdown

The suction machine breakdown risk caused by method, material, machine, and manpower. From the interview, mitigation is the best way to control the risk. In method, uncertain maintenance is the main cause that might shorter time between failures. To mitigate this problem, the company need to strict the action plan of maintenance, follow the schedule, and fulfil the need of material component in maintenance. It is related to material cause which is dealing with insufficient funds. This is the common matter of preventive maintenance which is including periodic maintenance. The company needs to change its mindset about funds for maintenance. Money that company spent for maintenance is not wasting, but something that makes lifetime machine longer. In the other side, based on interview, lack of funds caused by payment regulation in company trade. Some cases, buyer paid the transaction months later. It makes unbalance financial company. In machine cause, limited machine lifetime restrict the use of the machine. Additionally, the maintenance are not scheduled. After almost ten years of using, it is proper that the machine has low reliability and low durability. To mitigate this problem, predictive maintenance in needed. Finally, the man power has become the crucial causes of the breakdown condition. Careless worker while operate the machine could cause significant damage. Moreover, maintenance activities is not being the habit for the workers. Company need to train their worker about the importance of maintenance and safety in operation.

4. Conclusion

In conclusion, identification the type of risks in companies using the Supply Chain Operation Reference (SCOR) method gives 4 risks in plan, 3 risks in source, 3 risks in make, and 4 risks in deliver. So, there are 14 risks in the company. There are 4 risks that very high. There is 1 risks that classified as high-very high. 1 risk is high. 4 risks are moderate enough. 2 risks that classified as low-moderate. 1 risk included low and 1 risk included very low-low. The risk control strategies in this research analyze 3 accepted risks, 7 mitigated risks, and 4 avoided risks. Improvement suggestion that can be done is to perform routine checks, allocate fund in accordance with the needs, worker and payment regulation, and add a sand reservoir to add existing sand stock.

For further research, analyze risk map based on the mining process and be focus on mining section will sharpen the risk management and control. To expand the research, researcher could analyze the reliability of suction machine to solve the risk.

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Biographies

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Ichy Dini Editiya was an undergraduate student in Industrial Engineering Department, Faculty of Engineering, Mulawarman University, Samarinda, Indonesia. Nowadays she is working in oil palm plantation company responsible for procurement and company contract. She has good capability in data analyze and computer programming.