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RISK ANALYSIS OF DRINKING WATER PROCESS IN DRINKING WATER TREATMENT USING FUZZY FMEA APPROACH

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ABSTRACT

Drinking water treatment in the local water company in Indonesia faces a variety of complex and vulnerable problems. In order to know the potential risks to clean water treatment and selecting action based on priority is required a risk identification and evaluation model. The purpose of this paper is to identify and analyze the risk of drinking water processing. Risk identification will be done using the Fishbone method approach and risk analyze using the FMEA fuzzy model, with input data from several experts. The results showed that the main risk factors in water treatment such as machine, human, method and raw water material. The result of the calculation using MATLAB shows the highest FRPN value is incorrect dosing dosage (883) and lack of pumping machine maintenance periodically (809). In addition, other factors are still categorized medium and low. Overall this model can be used to identify risk factors and variables on clean water treatment processes and choose priority actions. Thus, it will be obtained a recommendation of the right action to anticipate it.

Keywords: risk identification and evaluation, processing, clean water, quality, FMEA fuzzy.

1. INTRODUCTION

One of the important biotic components in the environment to maintain life on earth is water. The study conducted by Muhammad *et al* (2013) notes that water is found in the ocean about 97% of the total water and the remaining 3% is fresh water. Furthermore, 2.97% are found on glaciers and ice cover and are present in small amounts of about 0.03% as surface water and groundwater used by humans. As an important element in life, the quantity and quality of water is an equally important factor. Water quality from water supply has a significant relationship to human health. Thus, the provision of safe water is one of the major health goals of society (Soticha *et al.*, 2014). United Nations, (2012) noted there are more than 700 million people having no access to safe and healthy water especially those living in the countryside. From the standpoint of human health protection, access to clean water is one of the basic goals that must be met. Thus, if pollutants enter the body of water then it is certain that the potential for decline in human health will occur (Bartram and Gordon, 2008). Gasana *et al.*, (2008) outlines some infectious diseases caused by low water quality such as diarrhea which is one of the causes of morbidity and mortality in humans. Thus, thus one of the important public health priorities is to provide sufficient quantity of clean water and meet WHO quality standards.

The problem of water supply is very complex. Pollution by micro-organisms both bacteria and viruses to water bodies as well as in the provision of drinking water is a frequent case. In addition, many countries are testing chemically on raw water quality since the discovery of arsenic in raw water in Bangladesh. However, WHO (2010) reported no arsenic and fluoride content in drinking water. In addition, the decline in the quality of raw water is also influenced by physical-chemical parameters, such as heavy metals such as lead, chromium, cadmium and mercury. The heavy metals are toxic and carcinogenic are very harmful to human health (Sorlini *et al.*, 2013). Several studies were conducted in developing countries in order to assess the concentration of heavy metals in drinking water. For example, increased concentrations of lead, selenium, molybdenum and chromium levels in Cambodia (Feldman, *et al.*, 2007), the heavy metals mercury in some surface waters in Ghana (Quagraine and Adokoh, 2010).

Indonesia as one of the developing countries also experienced problems related to access to clean water. Thus, improvements to the achievement of this objective become an important factor. In general, water use in Indonesia comes from well drilling around 29.2%, bore well approximately 24.1% and 19.7% water supply companies (ADB, 2010). Majority of the city's water supply is served by a local water utility company, which is a state-owned utility company. The Water Supply System Development Supporting Agency reports that the performance of water utility companies in 2011 is only able to serve around 37% of the population in the service area. In the production process, most of the regional water utility companies use river water as their raw material source.

Regional water utility companies owned by local governments providing clean water are required to improve their services, especially in the field of clean water supply and processing that meet quality standards. The quality of water that meets the standards is greatly determined by the processing done by the drinking water company. Furthermore, local water utilities still use river water as raw materials in the process. In general, river water in Indonesia has been polluted by heavy metals from industry and household activities. Thus, this will affect the quality of clean water produced. The water utility company seeks to improve the quality of water produced through processing using high technology and the use of chemicals in removing harmful biological and physical-chemical elements. In addition, monitoring and quality testing at each stage of processing is done strictly. However, the potential risk of failure at the processing stage may occur which leads to uncontrollable quality of clean water produced. Therefore, to prevent potential uncontrolled water quality and prevent the impact of costs due to these risks, it is necessary to identify and analyze the risks to eliminate the potential failures before system performance declines.

Local water utility companies are always required to produce the services and products with high quality in order to meet the customer desires. This desire encourages each company to a very complex problem in maintaining the quality and reliability of the product. Thus, the company faces challenges in designing the quality and reliability of the resulting product. In order to avoid all forms of failure in the process of clean water production and development, the method of Failure Mode Effect Analysis (FMEA) is used as a prevention effort. The method can also predict the form of failure and find the most economical way to stop the failure. FMEA techniques are implemented to identify potential forms of failure, determine their impact on production, and identify actions to reduce failures. Thus, this paper will analyze the risk factors of failure in clean water treatment by applying the Fuzzy FMEA method.

2. LITERATURE REVIEW

Risk management has been developed in a variety of applications primarily on cost and time risk assessment. Furthermore, there are several studies of technical or quality risks, related to the client's primary objectives. To respond to this objective, the Failure and Effects Analysis Method (FMEA) can be applied (Andery *et al.,* 1998). In addition, FMEA methods can also be applied to analyze the risk of hazard and waste management (Adeli 1988).

FMEA is a methodology used to evaluate failures occurring in a system, design, process, or service. Furthermore, identification of potential failures is performed by scoring or scoring each mode of failure based on occurrence, severity, and detection levels (Stamatis, 1995). The FMEA method is one of the more practical ways to identify hazards and risk assessment (Sharma *et al.*, 2005). Moreover, FMEA is a systematic method that has the ability to analyze system risks at each stage of the concept to various systems, detect failures in the design phase, and define corrective actions and actions for failure to control in minimizing impacts that will occur (Ben-Daya *et al.*, 2009).

FMEA will improve process reliability by preventing errors that can be detected in the system and reducing the consequences of losses (Chiozza and Ponzetti 2009). Some of the important factors in FMEA such as Occurence (O), Severity (S) and Detection (D) are components in this method that use numerical scales for judgment (Franceschini and Galetto, 2001). This method consists of two stages, which in the first stage consists of identification of the failure and the consequences associated with it. Furthermore, in the second stage of the analysis related to the determination of failure rate using Risk Priority Number (RPN) (Stamatis 2003).

$$RPN = SxOxD \tag{1}$$

However, this is a weakness of the traditional RPN. With no level of importance of these three elements, the calculation of RPN by multiplying these three elements is irrational (Gilchrist, 1993). Furthermore, Ben-Power criticizes Gilchrist's opinion, where Ben-Power states that the probabilities of all three elements are not always independent and that probability is difficult to estimate. The studies conducted by Xu *et al.* (2002); Yeh & Hsieh (2007) underlines some of the weaknesses of traditional FMEA are: 1) statements in FMEA are often subjective and qualitative described in natural language, 2) the third level of severity (S), occurrence (O), detectability (D) parameters that are assumed to have the same interest, it turns out that in practice the weight of importance of the three parameters is not the same, 3) The same Risk Priority Number (RPN) value generated from the multiplication of S, O, D levels may imply a risk representation.

In its development, the uncertainty in traditional RPN assessment can be solved with Fuzzy Logic. Fuzzy FMEA method is one of the most acceptable techniques. Furthermore, Keskin and Ozkan (2009) stated that research using fuzzy logic will obtain more accurate results than using traditional FMEA methods. In addition, the Fuzzy-based methodological assessment is more flexible in assessing the criticality of a failure as well as more consistent and logical (Sharma *et al.,* 2005). Furthermore, Tay and Lim (2006) underline Fuzzy RPN enabling the evaluation of the risk of failure, ranking, and prioritization based on expert opinions, expert knowledge and experience, and the evaluation of the risk of failure can be tailored to the existing process. Fuzzy Failure Mode and Effect Analysis can be used in a variety of RPN computing applications, such as reducing the number of rules or rules of the RPN, using consumer opinions as inputs (Sharma *et al*., 2005), designing FMEA with cost estimation approach (Dong, 2007) can solve the issues at the evaluation level (Marcello and Frosolini., 2002).

3. METHODOLOGY

The main requirement is to map out the characteristics and risk sources that trigger the performance of drinking water treatment in designing an effective and efficient risk identification model. Once the risks are identified, measurements are made to assess risk opportunities and analyze risk consequences by identifying all possible impacts on drinking water treatment. Further, evaluate the risks for controlling and managing solutions to the performance results of drinking water treatment (Wang *et al.*, 2009; Wu and Blackhurst, 2009).

The research stages were started by identifying the factors that influence the risk of drinking water treatment, then compiling the causal table, brainstorming, questionnaire making and data analysis. Consequence

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analysis is descriptive, while selecting priority in risk evaluation is done with Fuzzy FMEA, giving severity, occurrence, detectability (S, O, D), fuzzification (input membership function), fuzzy inference system, defuzzification (output membership) and obtained value of FRPN (fuzzy risk priority number).

The risk identification model of drinking water treatment aims to identify and determine the variables of each risk factor that greatly affects each level risk of drinking water treatment. In this research the identification of drinking water treatment risk is done by using Fishbone method (cause and effect analysis). This process is carried out by brainstorming from stakeholders in drinking water companies related to risk issues to find the causes of the resulting risks. The drinking water treatment risk evaluation model is used to measure the risk level of each variable of drinking water treatment risk. This risk assessment is required in order to select management actions based on priorities that are appropriate to the identified risk factors.

The Fuzzy FMEA method will be used as a model in this article. This model has been developed by Yeh and Hsieh (2007); Wang *et al.*, (2009). The level of risk variables in the FMEA fuzzy method is determined based on the expert opinion of drinking water treatment. These variables include severity (S) indicating the degree of failure of failure that will occur, occurrence (O) indicating the probability of failure, detection (D) indicating the detection rate of failure.

FMEA fuzzy inputs are values of Severity (S), Occurence (O) and Detection (D). The values of S, O and D are assessed by the input variables of the 1-10 scale, and are grouped into five categories of linguistic levels: Very Low (VL), Low (L), Moderate (M), High (H) and Very High (VH). The category of input variables in FMEA fuzzy is presented in Table-1. The three inputs are fitted using the membership function to determine the degree of membership of each input.

Output of value fuzzy fuzzy FMEA risk priority number (RPN fuzzy) applied to represent the priority of corrective action to the rating scale of 1-1000. The Fuzzy RPN is categorized in nine interval classes, such as Very Low (VL), Very Low-Low (VL-L), Low (L), Low-Moderate (LM), Moderate (M), Moderate- High (MH) High (H), High-Very High (H-VH) and Very High (VH). The categories of output variables are presented in the Table-2.

Table-1. Categoryof input variabel on Fuzzy FMEA.

No	Input parameter	The fuzzy set	Fuzzy domain
1	Severity	Very Low (VL)	1
		Low (L)	2, 3
		Moderate (M)	4, 5, 6
		High (H)	7, 8
		Very High (VH)	9, 10
2	Occurrence	Very Low (VL)	1
		Low (L)	2, 3
		Moderate (M)	4, 5, 6
		High (H)	7, 8
		Very High (VH)	9, 10
3	Detection	Very Low (VL)	1
		Low (L)	2, 3
		Moderate (M)	4, 5, 6
		High (H)	7, 8
		Very High (VH)	9, 10

Table-2. Category of output variables on FMEA fuzzy.

Output value	Category
1 - 50	Very Low (VL)
51 - 100	Very Low – Low (VL-L)
101 - 150	Low (L)
151 - 250	Low Moderate (LM)
251 - 350	Moderate
351 - 450	Moderate – High (MH)
451 - 600	High (H)
601 - 800	High – Very High (H-VH)
801 - 1000	Very High

The resulting fuzzy input is evaluated using the fuzzy rules (IF-THEN rule), ie the IF part as the fuzzy input variable and the THEN part as the fuzzy output variable. For example "IF Severity is Very High AND Occurence is Low and Detection is High, THEN FRPN is Very High". In this FMEA fuzzy, there are three input variables (Severity, Occurrence and Detection) with five levels of linguistic language ranging from Very Low (VL) to Very High (VH), thus that will obtain the amount of 125 (5x5x5) combination of fuzzy rule.

The fuzzy inference system is used to combine IF-THEN fuzzy rules in the rule base and fuzzy implications. The system is built with two methods such as Mamdani and Sugeno methods. The Mamdani method is the most commonly used method of discussing fuzzy

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methodology. The minimum inference system uses the min operator for "AND" on the IF side of the fuzzy rule and the max operator for "OR" of the rule. Combined operators are used to aggregate the combination of consequences into a single rule. The result of aggregation is then defuzzified to obtain the crisp value.

4. RESULTS AND DISCUSSIONS

The results of risk identification based on brainstorming on drinking water treatment stakeholders in the form of disturbance, cause and effect can be seen in Table-3. The results are analyzed based on risk factor group consisting of human, material, method and machine, then arranged into fishbone diagram form, in Figure-4. Risk assessment is carried out on the risk occurrence of the identified outcome. Assessment is given by the decision maker who knows about the risk issues on drinking water treatment through the questionnaire provided. The risk assessment includes how serious the impact of the risk (severity rating), the frequency of occurrence of the cause of the risk (occurrence rating) and whether the cause is detected (detection rate), using a scale of 1-10.

Table-3. Parameter of membership function of input variable.

Categories	Curve type	Parameter
Very Low (VL)	Trapezoidal	[0 0 1 2.5]
Low (L)	Triangle	[1 2.5 4.5]
Moderate (M)	Trapezoidal	[2.5 4.5 5.5 7.5]
High (H)	Triangle	[5.5 7.5 9]
Very High (VH)	Trapezoidal	[7.5 9 10 10]

Membership function for each category of input value S, O and D and its parameters can be determined based on the type of curve used.

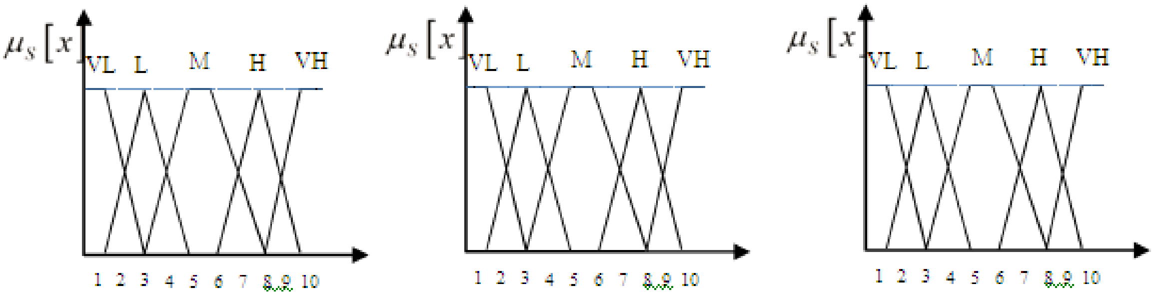

Figure-1. Fuzzy membership function for input severity level (a), occurence (b) and detection (c).

The method used is fuzzy FMEA, with input used in the form of assessment of severity rating (S), occurrence (O) and detection / detection (D), and output is fuzzy RPN (fuzzy risk priority number). Fuzzification process is done by changing the value of RPN (risk priority number) into fuzzy RPN using Mamdani method with MIN implication function. The results of the S, O and D scores are grouped into five linguistic level categories as in Table-3, then defuzzifikasi use the membership function to determine the degree of membership of each input.

Table-4. Parameter of membership function of output variable.

Categories	Curve Type	Parameter
Very Low (VL)	Trapezoid	[0 0 25 75]
Very Low – Low (VL-L)	Triangle	[25 75 125]
Low (L)	Triangle	[75 125 200]
Low Moderate (LM)	Triangle	[125 200 300]
Moderate	Triangle	[200 300 400]
Moderate – High (MH)	Triangle	[300 400 500]
High (H)	Triangle	[400 500 700]
High – Very High (H-VH)	Triangle	[500 700 900]
Very High	Trapezoid	[700 900 1000 1000]

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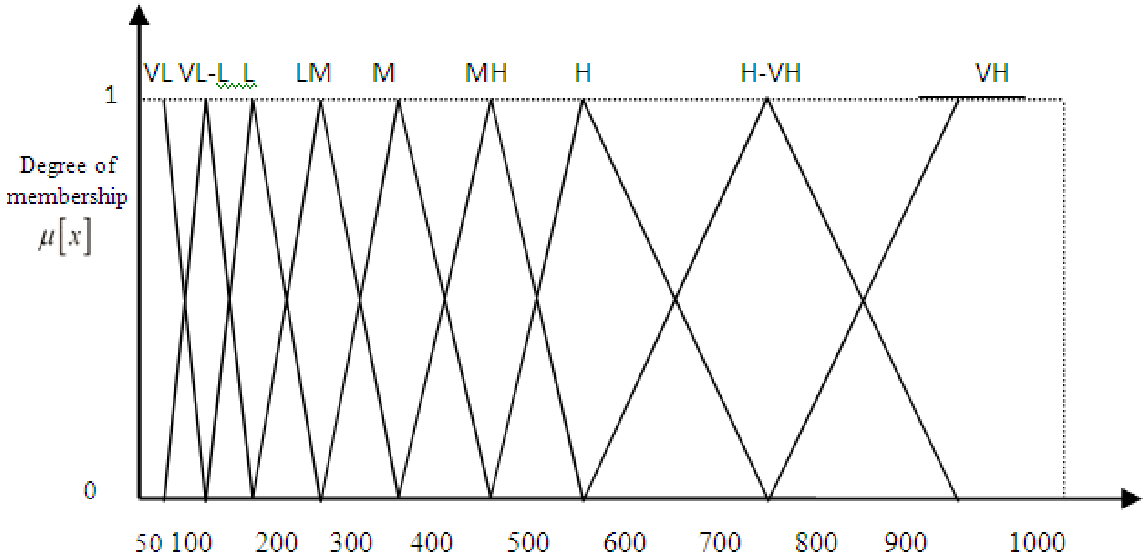

Figure-2. Membership function of output fuzzy RPN.

The resulting fuzzy input is evaluated using the fuzzy rules (IF-THEN rule). The input variables used are severity (S), occurrence (O) and detection (D), with five levels of linguistic category (Very Low, Low, Moderate, High, Very High) to obtain 125 fuzzy rule base combinations. The formulation of the fuzzy rule (IF-THEN rule) is done by considering that the severity value is the most decisive input for the fuzzy RPN value, so if the Severity (S) value is Very High (VH) then the RPN fuzzy value is also in the Very High (VH) category, regardless of the value of Occurrence (O) and Detection (O) obtained. The resulting fuzzy RPN value indicates the priority level of risk to be addressed. High fuzzy RPN values indicate that the risk is more priority to be addressed. The calculation of the RPN fuzzy value is performed using MATLAB.

The outputs of the RPN fuzzy values are categorized into nine interval classes: Very Low (VL), Very Low-Low (VL-L), Low (L), Low-Moderate (LM), Moderate (M), Moderate-High (MH), High (H), High-Very High (H-VH), and Very High (VH). The membership function of the output variable and its parameters can be determined based on the type of curve used (Table-4 and Figure-2).

The resulting fuzzy input is evaluated using the fuzzy rules (IF-THEN rule). The input variables used are severity (S), occurrence (O) and detection (D), with five levels of linguistic category (Very Low, Low, Moderate, High, Very High) to obtain 125 fuzzy rule base combinations. The combination of this FMEA fuzzy rule base is as the following example below:

Combination of the rule base in fuzzy FMEA

a. IF severity is VL AND occurrence is VL AND detection is VL THEN fuzzy RPN is VL
b. IF severity is VL AND occurrence is VL AND detection is L THEN fuzzy RPN is VL
c. IF severity is VL AND occurrence is VL AND detection is M THEN fuzzy RPN is VL
d. IF severity is VL AND occurrence is VL AND detection is H THEN fuzzy RPN is VL- L
e. IF severity is VL AND occurrence is VL AND detection is VH THEN fuzzy RPN is VL-L

The formulation of the fuzzy rule rule (IF-THEN rule) is done by considering that the severity value is the most decisive input for the fuzzy RPN value, so if the Severity (S) value is Very High (VH) then the fuzzy RPN value is also in the Very High (VH), regardless of the value of Occurence (O) and Detection (O) obtained. The resulting fuzzy RPN value indicates the priority level of risk to be addressed. High fuzzy RPN values indicate that the risk is more priority to be addressed. The calculation of the RPN fuzzy value is performed using MATLAB.

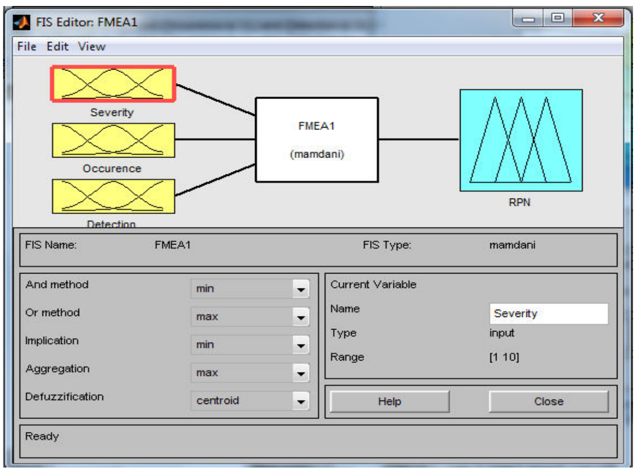

Figure-3. Input model FRPN.

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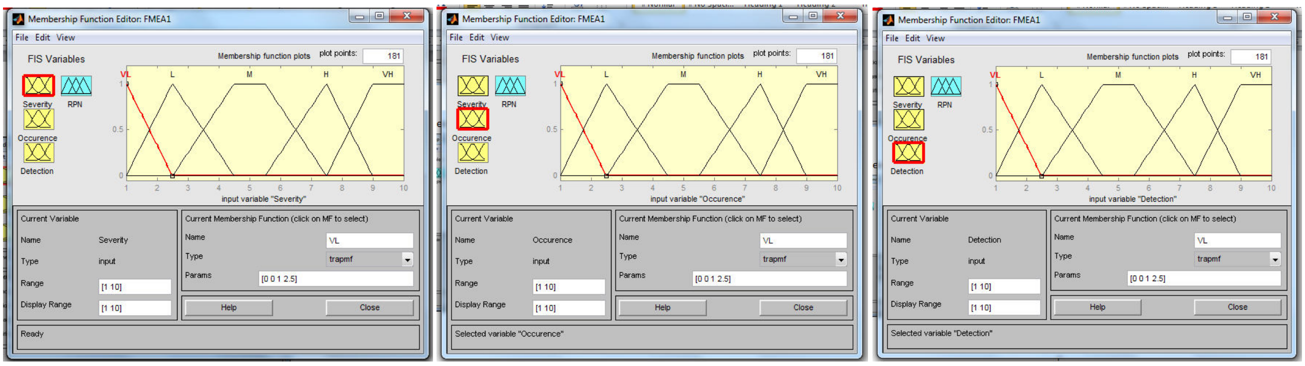

(4a) (4b) (4c)

Figure-4a, 6b dan 6c. Input model Severity, Occurrence and Detection.

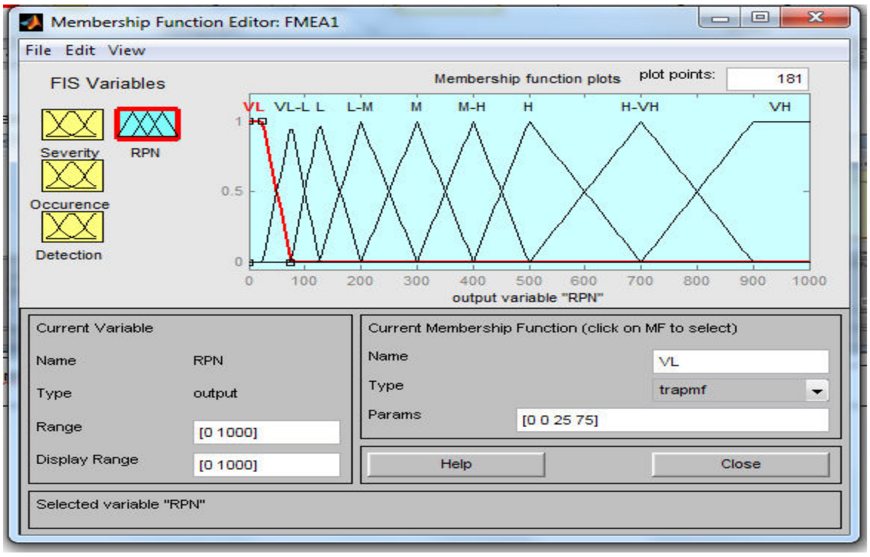

Figure-5. Output model FRPN.

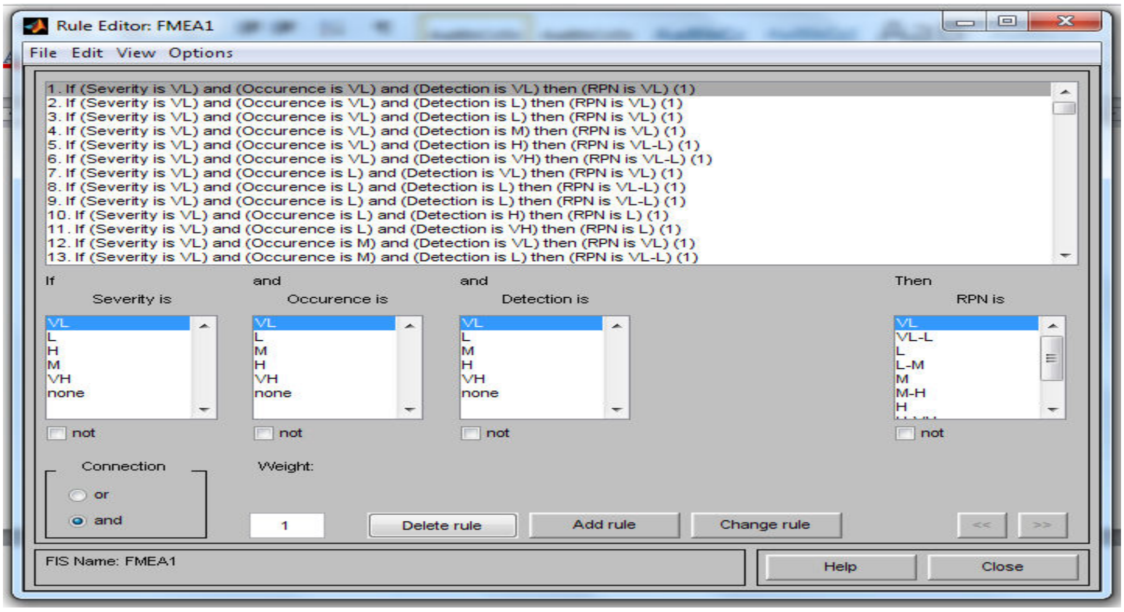

Figure-6. Rule Fuzzy FMEA.

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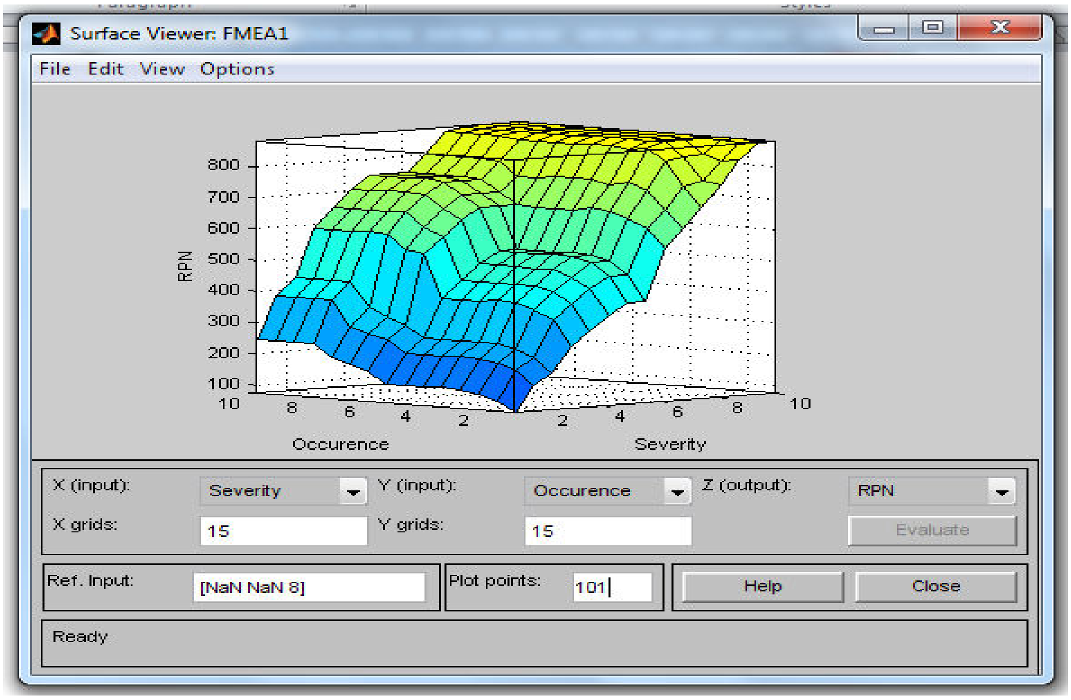

Figure-7. The Surface of FRPN.

Risk identification generates the source, driver (trigger) and risk events as presented in Figure-11. Based on the results of brainstorming conducted on several stakeholders responsible for the clean water production process obtained information that the source of the risk of water treatment process caused by several factors such as machine, human factors, methods and raw water materials. Furthermore, engine factors that have the potential to generate clean water treatment risks that does not meet the standards are caused by machine operational hours and lack of regular maintenance. In addition, factor failure of water treatment process caused by production operator non-fulfillment of standard operating procedure (SOP) water treatment. Furthermore, on the raw water factor obtained information that the potential cause of failure is the quality of raw water obtained from river water. Furthermore, on the method factors obtained information that there are two things that could potentially lead to failure of non-fulfillment of quality standards that dosage of incorporation chemicals is not appropriate and there is no measurement of chemical concentrations first.

Table-5 summarizes the results of the brainstorming causes and effects of non-fulfillment of clean water quality standards.

Table-5. Cause-effect of clean water treatment.

No	Risk	Cause	Effect
1	The production operators non-fulfillment of standard operating procedure (SOP)	Low level of concern and knowledge	The occurrence of irregularities in the work
2	The raw water quality parameters cannot be controlled	Water pollution by Industry on the river banks	Raw water quality that does not meet the standard
3	Lack of regularly maintenance of pumping machines	Lack of machine maintenance SOP	Easy breakdown machine
4	Working hours of the pumping machine exceed the limit	No machine replacement	Fast machine damaged
5	The dosage of chemicals is not appropriate	Not perform preliminary calculations	Parameter clean water that does not comply with quality standards
6	Chemical concentrations are not calculated	Lack of chemical dosage SOP	Parameter clean water that does not comply with quality standards

Based on Table-5 above then performed the fuzzy RPN assessment shown in Table-6 below.

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Table-6. Fuzzy RPN based on the calculation using Matlab.

Failure Modes Effect Analysis (FMEA) Worksheet		**Process name: Identification of Failure Mode Water Quality**
		Date Input : 1 Juni 2017
No *Worksheet* : WS.QS.01.2015	Rev : 00	Date analysis : 10 Juni 2017

No	Process step	ID Failure	Potential Failure Mode	Potential Failure Effect	Severity (S)	Potential Causes	Occurences (O)	Current Control	Detection	RPN	Action Recomended
1	Man	1	Not implementing SOP properly	Irregularities in the work	5	Low level of concern and knowledge	7	None	4	509	Skills training for operators
2	Material	2	The raw water quality parameters cannot be controlled	Raw water quality that does not meet the standard	6	Water pollution by Industry on the river banks	4	Coordinate with the administrator of the river	8	649	Regular monitoring and coordination with administrator of the river
3	Machine	3	Lack of regularly maintenance of pumping machines	Easy breakdown machine	8	Lack of machine maintenance SOP	2	None	8	809	Perform the priodic maintenance schedule
4		4	Working hours of the pumping machine exceed the limit	Fast machine damaged	4	No machine replacement	4	None	7	448	Replacement with a new engine to fit the budget funds
5	Method	5	The dosage of chemicals is not appropriate	Parameter clean water that does not comply with quality standards	8	Not perform preliminary calculations	9	None	8	883	Preparation of SOPs on formula of dosage of addition of chemicals that adjusted to river water quality standard
6		6	Chemical concentrations are not calculated	Parameter clean water that does not comply with quality standards	5	Lack of chemical dosage SOP	2	None	3	364	

Based on the results of FRPN calculation from Table-6 above it can be seen that the method factor, especially the element of incorrect dosage of chemicals has the highest potential risk of failure because it has a value of FRPN 883. Thus, this factor becomes the 1st rank to get attention improvement in order to meet the quality of clean water which is in accordance with the quality standards determined by the Ministry of Health. Furthermore, the lack of maintenance of pumping machines periodically also has a high potential risk of failure with the value of FRPN around 809. Low maintenance of the pump machine due to the absence of a regular maintenance schedule. For example, for minor maintenance should be done regularly every day as provide oil to reduce the occurrence of damage. In addition, other activities can be checked condition of the machine on a regular basis daily, weekly or monthly. Thus, the company mayprovide the inspection and maintenance schedule such as intake pumps, distribution pumps and other pumps in clean water treatment plants. Furthermore, based on the results then created table of risk categories as the table below:

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Table-7. Risk categories based on FRPN value.

No	Potential risk	Severity	Occurrence	Detection	FRPN	Category
1	The dosage of chemicals is not appropriate	8	9	8	883	High
2	Lack of regularly maintenance of pumping machines	8	2	8	809	High
3	The raw water quality parameters cannot be controlled	6	4	8	649	Medium
4	Not implementing SOP properly	5	7	4	509	Medium
5	Working hours of the pumping machine exceed the limit	4	4	7	448	Low
6	Chemical concentrations are not calculated	5	2	3	364	Low

Based on Table-7 above, it can be seen that there are two highest potential risk in clean water processing such as incompatible dose and less maintenance of pumping machine periodically. Furthermore, in the medium risk category obtained source water parameters difficult to control and does not implement SOP properly. Additionally, in the low risk category there is the working hour of the pumping engine exceed the limit and Chemical concentrations are not calculated. Thus, to be able to produce quality clean water and meet the quality standards of the Ministry of Health, the company can emphasize improvement on the potential risks that have the highest category. With the improvement is expected to be able to improve the quality of clean water produced.

5. CONCLUSIONS

As an important factor in life, the quantity and quality of water is an equally important element. Water quality from supply has a significant relationship to human health. Therefore, the evaluation and risk analysis is required to improve or eliminate failures before system performance declines. The method used in this risk assessment is fuzzy FMEA (fuzzy failure mode and effect analysis), with input severity rating (S), occurrence (O) and detection (D), and output value of fuzzy risk priority number. Based on the brainstorming process and FMEA fuzzy analysis results can be concluded that, the main risks in clean water processing are machine, human, methods and raw water materials. The result of the calculation using MATLAB shows the highest FRPN value is incorrect dosing dosage (883) and lack of pumping machine maintenance periodically (809). While other factors are still medium and low categories. Thus, risk evaluation (priority risk to be controlled) on clean water treatment is focused on the two highest risk categories.

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