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ANFIS method to enhance FMEA water operation model of Indonesia drinking water distribution system

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Abstract
Many problems are found in water treatment and distribution in water operations. Those problems range from low to critical risk. All critical risks must be addressed immediately. The Failure Mode and Effects Analysis (FMEA) prioritizes problems based on Occurrence, Severity, and Detection values to identify critical risks. However, this method is also having problems. With the same risk priority number (RPN) calculation, FMEA would be a ranking problem with the same RPN value; hence, we have a priority problem that is not critical but based on the highest value. To solve this problem, we propose additional methods, such as the ANFIS, to give weight based on risk level classification. From the results of data processing carried out by the ANFIS method, it is proven that it can perform re-ranking, for example, in the L2, R5, S8, and U3 code, which has an FMEA RPN value of 12. However, in FMEA-ANFIS, the RPN value becomes L2 2.05, R5 1.52, S8 1.32, and U3 2.52. Furthermore, with these results, it can be concluded that the ANFIS method can enhance the FMEA model in water operations.

Keywords:
ANFIS;
Drinking Water;
FMEA;
Risk Priority Number;
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INTRODUCTION

Clean water is the most important basic human life needs [1]. Excessive groundwater exploitation can cause a decline in environmental quality, such as salinization [2], aquifer depletion [3], and many others [4]. In the long term, this will cause a high economic cost for the community. To solve this problem, the Tangerang Regency Government has collaborated with a private drinking water company (concession) to provide clean water for the community in the Tangerang district area. In raw water treatment, many problems are often found in the water treatment process and distribution. The issues in the water distribution system include supply fulfilment, supply monitoring, network leaks, disruption of water supply, and pressure management. The quality improvement is needed, which the Tangerang Regency Government mandates in the Concession Agreement. Using Risk management can solve and enhance water distribution problems.

Various strategies are available for measuring risk levels and modeling risk techniques. Most approaches may be classified as either qualitative or quantitative. Qualitative techniques describe risk in words or through categories, whereas quantitative methods convey risk numerically. Semi-quantitative describes largely qualitative procedures, such as assigning a numerical value to probability and consequence classes. There are several methods in the risk assessment in water supply (quantitative, probabilistic, qualitative, semi-qualitative or deterministic, etc.), with the following tools (FMEA/FMECA, ETA, QMRA, FTA, HRA, Markov, etc.) [5].

FMEA has been widely utilized to identify significant failure modes impacting the system and subsystems [6][7]. FMEA is a quantitative method that a water company risk rating can represent. It exceeds various methods, given that it relies on a quantitative-proactive analysis of risk re-detection [8]. Historically, FMEA was established by the US military forces in the late 1940s [9]. The aerospace industry deployed it as a design process in the 1960s, with its inherent reliability and safety requirements [10]. Ford Motor Company introduced FMEA to the automobile industry in the late 1970s for safety and regulatory concerns [11]. The FMEA technique is widely utilized and recognized as a practical risk analysis and assessment tool for water operation [12, 13, 14], medicine [15][16], food [17], and others. The FMEA approach also has benefits like improving the assessed products' and processes' quality and dependability, estimating the product's redesign time and cost, bringing risks and their effects down to a manageable level, creating risk control plans, and offering data to remove major risks increase client contentment [18].

Unfortunately, all FMEA methods have weaknesses. Even though the FMEA method was exemplary for finding failure in the system, it still has a problem, such as the risk that is different in severity has the same value because of the multiplication with occurrence and detection parameters [19]. According to Sharma et al., traditional FMEA approaches have limitations. When a failure mode has numerous impacts in different severity categories, the criticality number of the item may be overestimated in the CN calculation since only the most severe effect is used in the computation. In RPN analysis, various occurrence, severity, and detection sets may produce an identical value. However, the risk implication may differ, and the RPN ranking method has neglected the relative importance of occurrence, severity, and detection [20]. To solve this problem, Geramian [21] and Łapczyńska [22] propose to add a fuzzy method into FMEA. In this paper, ANFIS was proposed to solve the FMEA prioritize problem. The neural network approach enhanced the ANFIS method so its value can automatically be readjusted in the input and output system [23]. With this method, we can enhance FMEA according to the input and output of real-world value.

METHOD

To successfully enhance FMEA with ANFIS, we need to do the steps below, as seen in Figure 1.

1. Determining the process for production and quality assurance.
2. Determining every possible mode of failure for the production and quality control process, how it affects both and what caused the mode of failure.
3. Evaluating the modes of failure of the system for severity (S), occurrence (O), and detection (D).
4. The FMEA is then used to identify potential failure modes in the drinking water distribution process, determine their effect on product operation, occurrence and detect current control when failures occur during the drinking water distribution process,
5. Calculate the Risk Priority Number (RPN) to see the level of risk [24].
6. Enhancing FMEA RPN using ANFIS Methods.

Failure Modes and Effect Analysis (FMEA)

The aircraft industry was the first to use FMEA as a formal design technique in the 1960s, and it has since become a decisive and vital factor for deterring potential issues and preventing their growth [25]. One well-known quality management method for ongoing enhancements to processes or product designs is FMEA. The likelihood of failures can be decreased or eliminated by prioritizing remedial action based on the impact of those failures [26]. By definition, the FMEA transforms into a methodical process that makes use of organizational development, reliability, and engineering expertise or the method for optimizing the system, design, process, product, and service [27]. For each of the three parameters, a score of 1 to 5 (with one being the best and five being the worst scenario) and a risk-priority-number (RPN) are assigned. As a result, the RPN value aids the FMEA team in identifying the components that require immediate attention [28].

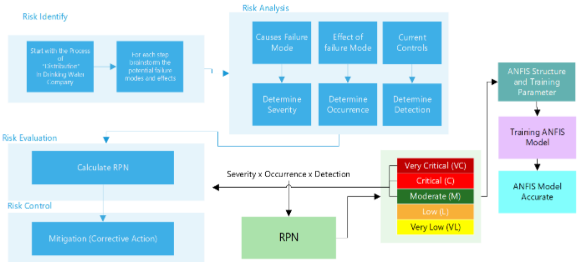


Figure 1. The research step in this study

The mathematical model for FMEA would be:

$$RPN = O \times S \times D \tag{1}$$

Where:
O = the Occurrence value
S = the Severity value
D = the Detection value

FMEA RPN in Indonesia Water Operation

Data was gathered through risk identification based on interviews and observations of the drinking water distribution process. In this section, we interview three people with the most experience in water distribution, such as the manager and supervisor of the distribution department. Then, we examine direct statements using Standard Operating Procedure (SOP). Actual field conditions in the form of disturbances in the monitoring, supply, and water loss processes are used to determine risk effects. A risk assessment is performed based on the aspects identified during data collection. Table 1 presents the results of the Risk Priority Number (RPN) levels such as low, moderate, and critical.

Table 1. Calculation the RPN Value

Failure Mode	Effect of Risk/Failure	Code	Cause of Risk/Failure	S	O	D	RPN	Risk Level
Intermittent Water Pressure	Small water flow	L1	Fluctuating Pressure	4	4	3	48	Critical
		L2	Production interruption	4	1	3	12	Low
		L3	Network quality is not worth it	3	2	3	18	Moderate
		L4	There is a leak in the pipe	4	3	4	48	Critical
		L5	External network disturbances, such as pipe leaks due to SDPU work	3	2	3	18	Moderate
	Pressure/supply does not meet the demand	M1	The valve cannot be operated	4	3	3	36	Moderate
		M2	Network quality is not proper	4	3	4	48	Critical
		M3	Inaccurate GIS data	4	3	4	48	Critical
Supply Fulfillment	Not achieving the target Pressure.	N1	Lack of supply/pressure	4	3	4	48	Critical
		N2	The valve cannot be operated	4	3	3	36	Moderate
		N3	Network quality is not proper	4	3	4	48	Critical
		N4	There is a leak in the pipe	4	3	4	48	Critical
Supply Monitoring	The results of pressure monitoring do not match the conditions in the field	O1	Measuring tools are not accurate	3	2	3	18	Moderate
Reduce water loss.	No water leak was found.	P1	The network image does not match the pipe network in the field	3	4	4	48	Critical
		P2	Broken manometer	3	3	2	18	Moderate
		P3	Material Quality	3	1	2	6	Low
		P4	Changes in Water Pressure Increase	3	2	3	18	Moderate
		P5	Existence of external work (repair of waterways by SDPU, Telkom, PLN)	3	4	3	36	Moderate
	Physical leaks do not rise to the ground	Q1	Low Water Pressure	4	4	3	48	Critical
		Q2	Concrete Surface Type	4	4	4	64	Critical
Network leak repair	High Water Loss	R1	Low quality of installed material	3	3	3	27	Moderate
		R2	House Connection Material Quality is low	4	2	3	24	Moderate
		R3	House Connection repair work quality is low	4	2	3	24	Moderate
		R4	The pipeline network is old	5	2	4	40	Moderate
		R5	Material availability	3	2	2	12	Low
		R6	Damaged supporting equipment (pump, generator, breaker)	3	3	3	27	Moderate
		R7	Lack of HR competence (3rd party)	3	2	2	12	Low
	Water loss cannot be identified.	S1	Customers do not get water at the time of isolation	2	3	2	12	Low
		S2	Change of pressure (zero	2	3	3	18	Moderate

Failure Mode	Effect of Risk/Failure	Code	Cause of Risk/Failure	S	O	D	RPN	Risk Level
			pressure)					
		S3	Layered valve due to road elevation	2	4	3	24	Moderate
		S4	GIS data inaccuracies	3	4	4	48	Critical
		S5	The location of the Chamber, which is in the body or the middle of the road	2	4	3	24	Moderate
		S6	Disturbance of mass organization and Persons	2	4	2	16	Moderate
		S7	Lack of HR competence	2	2	2	8	Low
		S8	Lack of available human resources	2	3	2	12	Low
	Not knowing physical or commercial water loss.	T1	Rejection from customer	2	3	2	12	Low
		T2	Broken measuring instrument	2	2	2	8	Low
		T3	Battery run out	2	2	2	8	Low
		T4	Low measuring accuracy	2	3	3	18	Moderate
		T5	Disturbance of ORMAS and Persons	2	4	2	16	Moderate
		T6	Customer meter locations that are difficult to access	4	4	2	32	Moderate
District Meter/ Chamber Accessories Maintenance	Disruption of water supply	U1	There is a blockage in the accessories	2	4	2	16	Moderate
		U2	Accessories age	2	3	3	18	Moderate
		U3	Valve Life	2	2	3	12	Low
		U4	Disturbance of ORMAS and Persons	2	4	2	16	Moderate
Pressure Management	Supply does not match demand.	V1	Low-pressure inlet	2	3	3	18	Moderate
		V2	Tool durability	2	3	3	18	Moderate
		V3	Lack of HR competence	2	3	2	12	Low
		V4	Material availability	3	2	2	12	Low
	Disrupted Pressure Management	W1	Covid-19 Pandemic Conditions	3	4	4	48	Critical

Table 1 shows the results from field observations. We present the consequence of the failure mode and its cause. The failure mode in water operation, especially in water supply, consists of several parts: Intermittent Water Pressure, Supply Fulfillment, Supply Monitoring, Reduced water loss, Network leak repair, District Meter/ Chamber Accessories Maintenance, and Pressure Management. Many things can cause each risk/failure effect, so the risks can be calculated using those things. This calculation can determine the severity, occurrence, and detection rate based on Table 2. Using Table 2, the RPN can be calculated for each cause of risk/failure.

Table 2. Rating of Severity, Occurrence, and Detection [29]

Rating	Severity	Occurrences	Detection
1	Very Low (VL)	Rare (R)	Almost Certain (AC)
2	Low (L)	Unlikely	Moderate (M)
3	Moderate (M)	Possible	Low (L)
4	High (H)	Likely	Very Low (VL)
5	Very High (VH)	Almost Certain	Absolute Uncertainty (AU)

In Table 2, the rating consists of 5 levels with each level containing a separate linguistic variable. The risk assessment considers the impact of the risk's severity (severity level), the frequency of occurrence of the risk's cause (occurrence level), and whether the cause can be detected (detection level). The calculated RPN from Table 1 and Table 2 can be seen in Table 3.

The risk level scale is then determined using Table 3 after obtaining the Risk Priority Number (RPN) value. The risk level scale is divided into five categories: very low, low, medium, critical, and very critical. However, the results in Table 1 indicate that only three levels exist: low, moderate, and critical. To determine a scale of 1-5 for severity, occurrence, and detection. In Table 2, to simplify the rating, we modify from a 10 to a 5 rating in S, O, and D.

Adaptive Neuro-Fuzzy Inference System (ANFIS)

In 1975, Zadeh created fuzzy logic by utilizing Linguistic Variables and their Application to Approximate Reasoning [30]. The fuzzy rule was then developed to address the problem by modeling the qualitative components of human knowledge (experience-based reasoning) and utilizing those as its cornerstones [31].

Table 3. Category for Risk Level from RPN Value (Risk type modify from [29]

Color	Score	Risk Type	Criteria
🟨	1-5	Very Low (VL)	The risk that can cause a negligible amount of loss is called very low.
🟧	6-15	Low (L)	A risk that has a small potential for negative effects is called Low.
🟩	16-40	Moderate (M)	Risks that do not pose a major threat but significant losses can be classified as moderate.
🟥	41-75	Critical (C)	Risks that have a substantial negative effect and will seriously impact the success of a job are called critical.
🟫	>76	Very Critical (VC)	Risk stemming from human or environmental error. Other causes can be procedural deficiencies or missing critical systems. This will require closure on the so-called catastrophic/very critical.

Fuzzy is usually used for localization [32], robot control [33], protection control [34], and many others. In 1985, Takagi and Sugeno created Fuzzy Sugeno [35]. A fuzzy Sugeno algorithm can be presented here:

The goal of step one is to increase the degree of membership, and each output is denoted by O_i^1:

$$O_i^1 = \mu A_i(x) and O_i^1 = \mu B_i(x), i = 1,2 \quad (2)$$

Where:
i = each node of ANFIS architecture.
A, B= is the linguistic label.
x = is the input to node i. (such as small, large, etc.). At this point, we can use all membership function types. However, generalized bell types were used because they can achieve a maximum equal to 1 and a minimum equal to 0. Hence:

$$\mu Ai(x) = \frac{1}{1+\left(\frac{x-c_i}{a_i}\right)^{2b_i}} \quad (3)$$

Where:
a,b,c= is the parameter set.
The firing strength is determined by the second stage of fuzzy inference, which is by multiplying the two input signals. Each node represents this.

$$O_i^2 = \mu A_i(x).\mu B_i(x), i = 1,2 \quad (4)$$

The following phase involved applying normalization for each fuzzy inference firing.

$$O_i^3 = \overline{W_i} = \frac{W_i}{W1+W2}, i = 1,2 \quad (5)$$

Where:
W= is the firing strength of the node.
$\overline{W}$ = is the normalized firing strength of the node.

In the next step, a calculation was made using the inference/rule that would be used in the next step:

$$O_i^4 = \overline{W_i}.F_i = \overline{W_i}.(P_i x + Q_i x + R_i x), i = 1,2 \quad (6)$$

Where:
P, Q, R = is the parameter set.
The final phase computes the overall output by adding up all of the input signals:

$$Output = O_i^5 = \sum_{k=0}^{n} \overline{W_i}.F_i = \frac{\sum_{k=1}^{n} W_i .F_i}{\sum_{k=1}^{n} W_i} \quad (7)$$

Jang Jyh Shing Roger created the Adaptive Neuro-Fuzzy Inference System (ANFIS) in 1993 [23] based on fuzzy Takagi Sugeno's if-then rules. The fuzzy inference system can naturally evolve based on its training data by using the ANFIS technique. ANFIS's artificial neural network approach is predicated on the Takagi-Sugeno fuzzy inference system. This method combines the benefits of fuzzy logic and neural networks into a single framework. A collection of fuzzy IF-THEN rules that can be trained to estimate nonlinear functions control this inference system. As a result, ANFIS is regarded as a Universal Estimator. ANFIS foundation was based on (2) to (7). Jang then optimized its parameters using the chain rule and gradient descent. But in order to train data, it must ascertain the output error rate of each node. (8) through (13) show the error calculation of the ANFIS algorithm.

The following formula can be used to determine the error function if the data training sets have P numbers of inputs and the outputs of the i-th position node define Oi:

$$E_p = \sum_{m=1}^{\#L} (T_{mp} - O_{mp}^{L})^2 \quad (8)$$

Where:
E= is the error measure.
T = is the P output target vector's m component.
O= is the m component of the output vector that the P input vector actually delivers.
As a result, the error rate can be computed using:

$$\frac{\partial E_p}{\partial O_{ip}^{k}} = \sum_{m=1}^{\#k+1} \frac{\partial E_p}{\partial O_{mp}^{k+1}} \frac{\partial O_{mp}^{k+1}}{\partial O_{ip}^{k}} \quad (9)$$

Where 1 ≤ k ≤ L-1 is an internal node's error rate. In the following phase, it is given as the nodes' linear combination error rate. Therefore, for all 1 ≤ k ≤ L and 1 ≤ i ≤ #(k) using (8) and (9). Thus, we have α as a parameter of the adaptive network:

$$\frac{\partial E}{\partial \alpha} = \sum_{O*\in S} \frac{\partial Ep}{\partial O*} \frac{\partial O*}{\partial \alpha} \tag{10}$$

Where:
S= displays the group of nodes whose output is dependent on α.
Derivative for measuring overall error E in relation to α is:

$$\frac{\partial E}{\partial \alpha} = \sum_{p=1}^{p} \frac{\partial Ep}{\partial \alpha} \tag{11}$$

As a result, the revised mathematical formulas for the general parameter α which is:

$$\Delta\alpha = -\eta \frac{\partial E}{\partial \alpha} \tag{12}$$

Where:
η = is a learning rate.
the expression of the learning rate is:

$$\eta = \frac{k}{\sqrt{\sum_{\alpha} (\frac{\partial E}{\partial \alpha})^2}} \tag{13}$$

Where:
k= is the length of each gradient transition in the parametric space or the step size.

RESULTS AND DISCUSSION

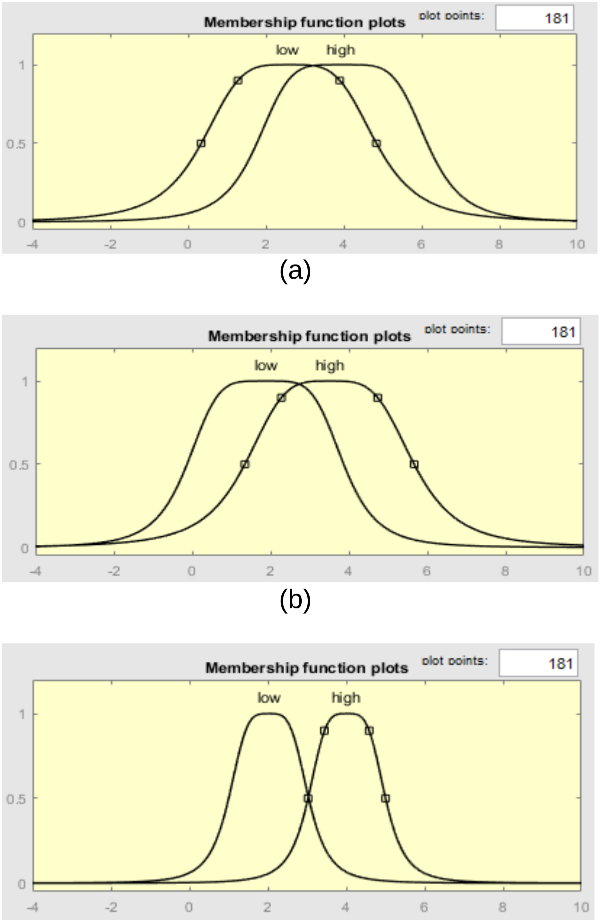
ANFIS FMEA New Proposed Model

In this section, we would like to show Indonesia's new ANFIS FMEA risk model. In order to do that, we are training the ANFIS algorithm using data in Table 1. The new model will then be tested using risk evaluation to see the validity of our new model. Therefore, the fuzzification for the ANFIS FMEA RPN Indonesia Water Operation can be seen in Figure 2, Table 4, Table 5, and (14).

Figure 2 presents the fuzzification for each RPN parameter, such as Figure 2a fuzzification for severity, Figure 2b for occurrence, and Figure 2c for detection. The fuzzification uses two linguistic variables, "high" and "low" for each RPN parameter. In Table 4, because the fuzzification uses generalized bell membership function types, we have a, b, and c values as in (3). This a, b, and c value, according to (4), (5), and (6), is the foundation of fuzzy firing strength.

Table 4. Category for Risk Level from RPN Value (Risk type modified from [29]

No	Variable	Linguistic Variable	ANFIS FMEA a	b	c
1	Severity	Low	2.25	2.027	2.59
2	Severity	High	2.19	2.403	3.956
3	Occurrence	Low	2	2.359	1.869
4	Occurrence	High	2.16	1.95	3.506
5	Detection	Low	1.021	2.002	2.024
6	Detection	High	0.9888	1.997	4.017



(a)

(b)

(c)

Figure 2. ANFIS FMEA RPN Indonesia Water Operation. (a) fuzzification for severity, (b) for occurrence, and (c) for detection.

The fuzzy was created using language variables and its approximation reasoning method [31]. With that foundation, we can say that the fuzzy rule was created based on the characteristic of qualitative elements of human expertise, which is experience-based reasoning [37] to solve the problem [38]. In conclusion, the fuzzy model was based on fuzzy rule reasoning for solving problems. Therefore, we can see that the fuzzy ANFIS rule was in general form and can be used to enhance FMEA RPN Indonesia Water Operation. In Table 5, the fuzzy rule was created automatically depending on the number of linguistic variable sets, while the fuzzy constant output is generated automatically based on the neural network backpropagation calculation method.

Then, using (3) and (7), we can develop the mathematical model for the ANFIS FMEA RPN Indonesia Water Operation. The proposed model can be seen in (14):

$$B_i = \frac{\sum_{k=0}^{n} \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^{2b_i}\right]} + \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^{2b_i}\right]} F_A^P}{\sum_{k=0}^{n} \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^{2b_i}\right]} + \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^{2b_i}\right]}} \qquad (14)$$

Where:

x = Describe input parameters such as Severity, occurrence, and Detection.

a_i= Describe the broadness of membership function input, including severity, occurrence, and detection.

b_i= Describe the shape of the curves on either side of the Severity, Occurrence, and Detection midpoint.

c_i= Describe the middle of the membership function of Severity, Occurrence, and Detection.

$\mathbf{F_A^P}$= Fuzzy constant output based on the parameters of the rule consequent.

n= ANFIS Inference/Rule firing Strength index.

$\mathbf{B_i}$= output such as weight of FMEA.

ANFIS FMEA Indonesia Water Operation New Model Result

Table 1 and the ANFIS model, (13) the Risk Priority Number can be measured using the ANFIS fitting model in Table 6. Table 6 would like to show our FMEA ANFIS model, which is built based on Table 1 data. This data will then be calculated again using the ANFIS method that we have shown in Table 4, Table 5, and (14). Table 6 shows the calculation using traditional FMEA.

Table 5. Category for Risk Level from RPN Value (Risk type modified from [29]

Rule Index	Rule Firing	Rule Output	Fuzzy Constant Output
1	If input1 is Severity Low and input2 is Occurrence Low and input3 is Detection Low	Then output1 is Very Very Low	-10.93
2	If input1 is Severity Low and input2 is Occurrence Low and input3 is Detection High	Then output1 is Very Low	18.82
3	If input1 is Severity Low and input2 is Occurrence High and input3 is Detection Low	Then output1 is Low	7.487
4	If input1 is Severity Low and input2 is Occurrence High and input3 is Detection High	Then output1 is Moderate	-7.164
5	If input1 is Severity High and input2 is Occurrence Low and input3 is Detection Low	Then output1 is High	7.683
6	If input1 is Severity High and input2 is Occurrence Low and input3 is Detection High	Then output1 is Higher	-10.3
7	If input1 is Severity High and input2 is Occurrence High and input3 is Detection Low	Then output1 is Critical	2.89
8	If input1 is Severity High and input2 is Occurrence High and input3 is Detection High	Then output1 is Very_Critical	15.34

Table 6. RPN FMEA-ANFIS versus RPN FMEA Conventional

Code	**Cause of Risk/Failure**	**S**	**O**	**D**	**RPN FMEA**	**RPN FMEA-ANFIS**	**Risk Level**
L2	Production interruption	4	1	3	12	2.05	Low
R5	Material availability	3	2	2	12	1.52	Low
S8	Lack of available human resources	2	3	2	12	1.32	Low
U3	Valve Life	2	2	3	12	2.52	Low
P2	Broken manometer	3	3	2	18	1.98	Moderate
P4	Changes in Water Pressure Increase	3	2	3	18	2.69	Moderate
S2	Change of pressure (zero pressure)	2	3	3	18	2.68	Moderate
T4	Low measuring accuracy	2	3	3	18	1.32	Moderate
R3	House Connection repair work quality is low	4	2	3	24	2.75	Moderate
S5	The location of the Chamber, which is in the body or the middle of the road	2	4	3	24	3.1	Moderate
R1	Low quality of installed material	3	3	3	27	2.94	Moderate
T6	Customer meter locations that are difficult to access	4	4	2	32	3.29	Moderate
M1	The valve cannot be operated	4	3	3	36	3.03	Moderate
P5	Existence of external work (repair of waterways by SDPU, Telkom, PLN)	3	4	3	36	3.59	Moderate
R4	The pipeline network is old	5	2	4	40	3.00	Moderate
L1	Fluctuating Pressure	4	4	3	48	3.77	Critical
N1	Lack of supply/pressure	4	3	4	48	3.96	Critical
P1	The network image does not match the pipe network in the field	3	4	4	48	4.05	Critical
Q1	Low Water Pressure	4	4	3	48	3.77	Critical
S4	GIS data inaccuracies	3	4	4	48	4.05	Critical
Q2	Concrete Surface Type	4	4	4	64	4.31	Critical

Then, it would like to compare the results based on our ANFIS FMEA and traditional FMEA. This needs to be done in order to show that our model can enhance the RPN value of the FMEA method.

Table 6 selects the same RPN FMEA value and then compares the RPN FMEA and RPN FMEA-ANFIS. From the results of the table above, it can be seen that the ANFIS algorithm improves the RPN FMEA value. As an example, in Table 1, it can be seen that L2, R5, S8, and U3 have an RPN FMEA value of 12, but in Table 6 FMEA-ANFIS, the RPN value becomes L2 2.05, R5 1.52, S8 1.32 and U3 2.52. So the priority order of the "low" risk level in Table 6 becomes U3(1), L2(2), R5(3), and S8(4). Another example can be seen at the "critical" risk level where the code L1, N1, P1, Q1, S4, Q2 with an RPN FMEA value of 48, but using the new model, the RPN FMEA-ANFIS value becomes L1 3.77, N1 3.96, P1 4.05, Q1 3.77, S4 4.05, and Q2 4.31. So the priority order of the "Critical" risk level in Table 6 becomes Q2 (1), S4 (2), P1(3), N1(4) and L1(5), Q1(6). Although ANFIS can help improve RPN FMEA values, not all can be corrected. With the example in code P1 and S4, the total RPN value has the same value. The Severity (S), Occurrence (O), and Detection (D) parameter values are the same also, and because of that, the RPN FMEA value has the same value, too, then the RPN FMEA-ANFIS model produces the same value. This research has the same conclusion as Rimantho [39]. Although Rimantho enhances FMEA or water treatment using fuzzy Mamdani and our works enhance FMEA using ANFIS for the water distribution system, both of our methods indicate that we can improve the FMEA model using computational intelligence methods.

CONCLUSION

In this paper, we propose to improve the RPN FMEA value using the ANFIS method. The data processing results by the ANFIS method prove that it can perform re-prioritization, for example, in the L2, R5, S8, and U3 code, which has an FMEA RPN value of 12. However, the RPN FMEA-ANFIS value becomes L2 2.05, R5 1.52, S8 1.32, and U3 2.52. Thus, with these results, it can be concluded that the ANFIS method can enhance the FMEA model in water operations.

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