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Improved Risk Matrix for Distribution Transformer in East Java: Analytic Network Process and Modified Total Ownership Cost

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***Abstract:* -** Many studies have been conducted on risk assessment in distribution transformers. However, previous studies have not fully considered the risk analysis and cost impact of damage to distribution transformers. In addition, the use of the Modified Total Ownership Cost Method is one comprehensive approach to calculating the cost implications of damage to distribution transformers. The use of risk matrix to determine likelihood factors and consequence factors still does not consider several factors, and the factors used often have equal weight and are interrelated. This study collects all the indicators used for probability and consequence factors in the risk matrix and applies the Analysis Network Process to give weight to those factors. The result is a more accurate risk evaluation model, supporting decision-making regarding investment in distribution transformers in East Java. A modified and weighted risk matrix was applied to 65 distribution transformers, of which 3 had low risk, 14 had moderate risk, 38 had high risk, 8 had very high risk, and 2 had extreme risk.

Keywords*:* Analytic Network Process, Distribution Transformer, Modified Total Ownership Cost, Risk Matrix.

I. INTRODUCTION

A distribution transformer is a transformer that functions to transmit electrical energy from the primary distribution circuit to the secondary distribution circuit or customer service circuit [1]. Distribution transformers are a crucial asset in the electric power distribution system [2]. These transformers carry potential risks that need to be assessed throughout their operational life, necessitating a risk assessment process to identify and understand the associated risks of each distribution transformer. Risk assessment is an activity involving planning, preparation, the creation of risk analysis documents, and the evaluation of results against criteria set by the company [3]. The objective of risk assessment is to establish a risk profile for decision-makers [4]. One method for conducting risk assessment is the use of a risk matrix [5]. A risk matrix is a graphical tool formed by pairs of the likelihood of an event occurring and the consequences of the event [6]. Reference [7] developed a risk matrix to assess distribution transformers. Likelihood factors used: load, temperature, transformer age, and insulation resistance. Meanwhile, consequence factors encompass the number of customers and the size of the distribution transformer. Oil level serves as an indicator in assessing distribution transformers [8]. Reduced oil levels harm distribution transformers [9]. Reference [10] developed an approach involving grounding resistance as an indicator in determining the overall value of distribution transformers. The application of age and historical data can be used to calculate the failure rate [11]. The failure rate provides information about whether the distribution transformer's failure rate increases, decreases, or remains constant over time through a bathtub curve [12]. In composing consequence factors, economic and environmental indicators are essential in assessing risks [4]. Reference [13] developed a concept called Modified Total Ownership Cost that can accommodate the costs borne by the owner of distribution transformers.

Analytic Network Process (ANP) is a method developed by Thomas L. Saaty that facilitates complex decision-making processes, where decisions are represented as a network accommodating the dependence and reciprocal interaction between decision-making factors [14]. References [15] - [17] employed ANP to facilitate decision-making in construction projects, risk assessment, and security assessment, respectively.

This paper will explain the creation of an improved risk matrix by collecting indicators on the likelihood and consequence from various literature, using the ANP method in the weighting process. An explanation of the basic concepts used in this research is provided in the literature review section. The methodology section outlines the steps for the development of the improved risk matrix. The results section produces a weighted and described improved risk matrix, and the use of the improved risk matrix is implemented on 65 distribution transformers in East Java. Finally, the conclusion section summarizes the main findings of the research and provides necessary recommendations.

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II. LITERATURE REVIEW

A. Risk

Risk is the effect of uncertainty on an objective [18]. It is typically defined as the product of the likelihood of an undesirable event and its consequences [19]. Risk analysis aims to comprehend the nature and characteristics of risk, including the level of risk [20]. Risk analysis involves a detailed consideration of uncertainty, risk sources, consequences, likelihood, and events [21]. Risks tend to have negative probabilities and impacts or losses for companies, society, and the surrounding environment. The scale in risk matrix assessments can be qualitative, quantitative, or a combination of both [22]. Reference [23] explains that risk is derived from the multiplication of likelihood and consequence:

$$Risk = likelihood\ x\ consequence \tag{1}$$

B. Failure Rate

The failure rate describes how often a component fails, expressed as the number of failures per unit of time, such as per year. There are various methods for estimating the failure rate of an asset, one of which involves using the Weibull Distribution [24]. The Weibull Distribution is a probability distribution first introduced by the statistician Waloddi Weibull in 1951. This distribution is commonly employed in reliability analysis across various fields and is a well-known model in probability statistics [25].

Maximum Likelihood Estimation (MLE) is utilized to estimate the parameters using the Weibull Distribution [11]. MLE is one of the parameter estimation methods that provides a high level of accuracy in estimation [26]. Reference [27] explains the MLE equation for obtaining the values of the shape parameter (β) and scale parameter (α)

$$\frac{\partial L}{\partial \alpha} = 0\ and\ \frac{\partial L}{\partial \beta} = 0 \tag{2}$$

The equation to determine the failure rate (λ)is expressed as:

$$\lambda(t) = \left(\frac{\beta}{\alpha}\right)\left(\frac{t}{\alpha}\right)^{\beta} \tag{3}$$

C. Modified Total Ownership Cost

Reference [13] developed a Total Ownership Cost calculation model that incorporates purchasing costs, no-load costs, load loss costs, maintenance costs, and residual value for a transformer. The developed model is referred to as Modified Total Ownership Cost (MTOC) can be seen in Equation 4.

$$\text{MTOC} = \sum_{d=1}^{D} PP_d + \sum_{d=1}^{D} x \sum_{m=1}^{M} (EC_d\ x\ P_0\ x\ 8760 + EC_d\ x\ P_L\ x\ 8760\ x\ K^2 + CM_d)\ x\ \frac{(1+j)^{m-1}}{(1+i)^{m-1}} - \sum_{d=1}^{D} CR_d \tag{4}$$

where:

PP : Purchase price (IDR)
D : Number of periods in which costs are updated
d : Index indicating the number of the period being studied
M : Length of a period (year)
m : Index indicating the year in a period
EC : Energy cost (IDR)
P_0 : No-load loss (kW)
P_L : Load loss (kW)
K : Load factor which is the ratio of the current load to the capacity of a transformer (%)
CM : Maintenance cost (IDR)
CR : Residual value of broken transformer (IDR)

D. Analytic Network Process

The Analytic Network Process (ANP) is a method developed by Thomas L. Saaty that facilitates the complex decision-making process. The steps in the calculation using the Analytic Network Process (ANP) method involve establishing a network model, creating a pairwise comparison matrix, determining the eigenvalue, calculating the consistency index and consistency ratio, constructing unweighted, weighted, and limiting super matrices, and final weighting [28].

The development of the network model refers to the outcomes or achievements desired in each situation or problem. The pairwise comparison matrix is used to obtain relative comparisons between elements in the network. The Saaty scale is employed in the ANP method to compare the relative importance of elements within the network. Table 1 illustrates the values of the Saaty scale [29].

Table I. Saaty Scale

Scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak (moderate) Importance	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or Demonstrated importance	An activity is strongly favored, and its dominance is demonstrated in practices.
9	Extreme important	The evidence of favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

The calculation of the eigenvector and λmax is performed to subsequently be utilized in the computation of the consistency index.

$$Eigen\ Vector = \sum(\frac{W_{ij}}{\sum W_j}) \ / \ n \qquad (5)$$

$$\lambda_{max} = (Eigen\ Vector_1\ x\ Number\ of\ Column_1) + (Eigen\ Vector_2\ x\ Number\ of\ Column_2) \ldots . n \qquad (6)$$

Consistency Index (CI) is a calculation used to assess the consistency of comparisons within a pairwise comparison matrix. The smaller the CI value, the more consistent the comparisons [29]. Consistency Ratio (CR) is a ratio used to measure the consistency of comparisons within a pairwise comparison matrix. The matrix is considered consistent if the CR value of the matrix is ≤ 0.1. If the consistency ratio is more than 0.1, the decision-maker needs to revise their decisions [30].

$$CI = \frac{\lambda_{max} - \mathrm{n}}{n-1} \qquad (7)$$

$$CR = \frac{CI}{RI} \qquad (8)$$

Table II. Random Index (RI)

Order Matrix	Random Index
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.45
9	1.49

The unweighted super matrix is a matrix composed of column vectors representing priorities. These priorities are obtained through pairwise comparisons between nodes that are part of a cluster based on the eigenvector values. The comparison value between two elements is 0 if the two elements do not influence each other [31].

The weighted super matrix is a matrix used to depict the contribution of elements in various clusters within a network system. It is calculated by multiplying the unweighted super matrix by the cluster matrix.

The limiting super matrix is a super matrix obtained by multiplying the matrix itself until the row and column values in the super matrix are equal [31]. The final step in this ANP approach involves assigning weights, which is done by ranking the alternative values from the limiting super matrix previously obtained. The assessment with the highest value in the limiting super matrix is considered the most important alternative [32].

III. METHODOLOGY

This research utilizes factors that have been applied in previous studies and assesses the scale of the same indicators by applying the methods used in prior research. Subsequently, interval calculations are performed for two indicators, namely failure rate and modified total ownership cost (MTOC). In the final stage, weighting is determined for the indicators applied in the assessment of probability and consequences using the Analytic Network Process.

IV. DEVELOPING IMPROVED RISK MATRIX AND IMPLEMENTATION

The development of the risk matrix in this research employs a 5x5 matrix with five risk classification levels. The development of the likelihood factor is carried out by utilizing factors previously developed by [7]-[8], and [10]-[11]. The utilization of seven likelihood factors includes insulation resistance, earth resistance, age, load, temperature, oil level, and failure rate.

On the other hand, the development of the consequence factor involves factors previously developed by [7] and [13]. The application of consequence factors comprises four factors: replacement cost, environmental impact, number of customers, and customer complaints.

The failure rate calculation is conducted on a population using censored data, specifically data from assets that are still in operation and data from assets that have failed. The values for the shape and scale parameters are determined using the maximum likelihood estimation method and are obtained as 1.610 and 132.917, respectively. Utilizing equation (3), failure rate values can be observed in Table III.

Table III. Failure Rate

Years	Failure Rate
1	0.00000460
2	0.00001405
3	0.00002699
4	0.00004289
5	0.00006144
...	...
43	0.00196595
45	0.00211530
47	0.00226876

Utilizing equation (4), the MTOC values can be observed in Table IV.

Table IV. MTOC Value

Distribution Transformer	MTOC
DT1	IDR 122.004.486
DT2	IDR 201.309.760
DT3	IDR 237.368.456
DT4	IDR 302.770.187
DT5	IDR 353.885.799
DT6	IDR 405.852.694
DT7	IDR 509.112.104
DT8	IDR 610.006.921
DT9	IDR 729.266.071
DT10	IDR 847.296.641
DT11	IDR 906.040.894
DT12	IDR 1.178.205.178

In the weighting process using the Analytic Network Process (ANP) method, this research involves 25 and 23 experts in the weighting of likelihood and consequence factors, respectively. These experts have backgrounds in the potential damage to distribution transformers, business, the environment, and distribution systems, with a minimum of 10 years of experience.

During the pairwise comparisons, the obtained consistency ratio is less than 0.1. The final weighting for the likelihood and consequence factors is presented in Table V.

Table V. Final Weighting

Factor	Alternative	Weighting
Likelihood	Insulation resistance	0.116
	Earth resistance	0.052
	Age	0.065
	Load	0.104
	Temperature	0.089
	Oil Level	0.093
	Failure Rate	0.165
Consequence	Replacement cost	0.087
	Environmental impact	0.100
	Number of customers	0.200
	Customer complaints	0.216

Following the determination of scales and weighting for each likelihood and consequence factor, an improved risk matrix was formulated with the described and weighted factors. The explanation of the improved risk matrix can be observed in Table VI.

Table VI. Improved Risk Matrix

Factors	Scale					Weight
	1	2	3	4	5	
Insulation resistance (MΩ)	>900	601–900	500–600	300–499	<300	0.170
Earth resistance (Ω)	<5	5–10	10–20	20–50	>50	0.076
Age (years)	<5	5–10	11–15	16–20	>20	0.095
Load (%)	<20	20–49	50–65	66–75	>75	0.152
Suhu (ºC)	20–29	30–34	35–40	41–50	>50	0.130
Oil Level	Very High	High	Medium	Low	Very Low	0.136
Failure Rate	0 - 0.00045283	0.00045284 - 0.00090566	0.00090567 - 0.00135850	0.00135851 - 0.00181133	0.00181134 - 0.00226416	0.242

Replacement cost (IDR millions)	<211	212-422	423-633	634-844	>844	0.145
Environmental impact	Environmental pollution occurs, and the impact on the environment can be resolved immediately.	Environmental pollution occurs, and the impact on the environment can be resolved in less than one month	Environmental pollution occurs, and the impact on the environment can be resolved within more than one month	Environmental pollution occurs, and the environmental impacts are permanent and cannot be resolved immediately.	Environmental pollution occurs, and the environmental impacts are permanent and cannot be overcome.	0.165
Number of customers (customers)	<11	11–40	41–70	71–150	>150	0.332
Customer complaints	Customer complaints to the contact center	Customer complaints by visiting the office directly	Customer complaints via newspaper or social media	Customer complaints highlighted by national media or lawsuits by individual customer	Demonstration by customers or class action by a group of customers	0.358

In this research, 65 distribution transformers located in the East Java Province, Indonesia, have been assessed. The assessment process was divided into two parts: likelihood assessment and consequence assessment. Likelihood and consequence assessments were conducted by evaluating 7 and 4 predetermined factors, respectively. The assessment results were then converted into a prepared scale. The following steps multiply the assessment scale values by the weights assigned to each factor, resulting in two assessment outputs: likelihood score and consequence score which can be seen in Table VII. The final step in this risk assessment was to combine the likelihood score and consequence score into a 5x5-sized risk matrix. Fig.1 illustrates the risk profile of distribution transformers.

Table VII. Risk Assessment Score

Distribution Transformers	**Likelihood Score**	**Consequence Score**
DT1	2.454	2.499
DT2	2.818	2.831
DT3	2.324	1.855
DT4	2.549	2.473
...	**...**	**...**
DT61	2.183	2.141
DT62	2.174	2.996
DT63	2.188	1.497
DT64	1.721	3.141
DT65	1.659	1.664

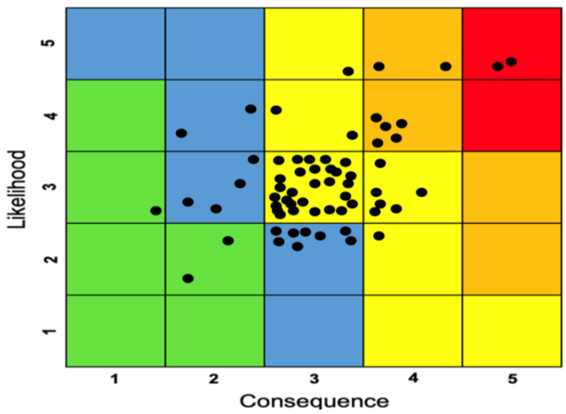

Fig1. Risk Profiling on 65 Distribution Transformers

CONCLUSION

In conclusion, this study has introduced an enhanced risk matrix model for distribution transformers, offering a more thorough perspective. The incorporation of the Analytic Network Process method allows for the calculation of weights assigned to each factor. The creation of this upgraded risk matrix can be utilized by companies as a reliable decision-making tool for activities involving distribution transformers, providing more precise guidance.

In providing further details about the analysis results, out of the total 65 distribution transformers assessed for risk, three transformers were classified as having low risk. Additionally, there were 14 distribution transformers with risks categorized as moderate. A total of 38 distribution transformers indicated a high level of risk, while eight other distribution transformers had a very high level of risk. Finally, two distribution transformers were identified to have an extreme level of risk.

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