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Reliability of the Weather Radar at BBMKG Region III Using the Failure Mode and Effect Analysis (FMEA) Method

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Abstract – One of the main roles of BMKG in Serving the public is to provide weather forecast information. The accuracy of such information highly depends on the operational condition of the instruments used, including weather radar as one of the primary tools. A reliable weather radar ensures the generation of accurate observational data, which forms the basis of weather forecasting. This study aims to assess the reliability of the weather radar operated by BBMKG Region III Badung, which has been in service for over 15 years. The evaluations were conducted using the Failure Mode and Effect Analysis (FMEA) method based on the latest calibration data from 2024. The analysis revealed several significant potential failures, particularly in the receiver component, with Risk Priority Number (RPN) values exceeding 100. These findings indicate a high level of risk that could affect the radar's sensitivity in detecting rainfall. Nevertheless, the weather radar at BBMKG Region III remains capable of identifying rainfall intensity ranging from light to very heavy.
Keywords: Weather radar, BMKG, Reliability, FMEA, Receiver, Rainfall intensity.

I. INTRODUCTION

Radar stands for Radio Detection and Ranging. It is a system that utilizes electromagnetic waves to detect, measure distance, and map objects such as aircraft, motor vehicles, as well as to obtain information related to weather conditions or precipitation. The operating principle of radar is based on the transmission of electromagnetic waves into the atmosphere and the reception of their reflections from detected objects. In the field of meteorology, this system is known as a weather radar, which functions to detect the presence of clouds and predict the likelihood of rainfall. Meteorological radar is one of the primary instruments at surface observation stations used for monitoring atmospheric and environmental conditions. This radar plays a vital role in supporting early warning systems for extreme weather events such as floods, tornadoes, and storms, which can pose significant risks to public safety and cause damage to infrastructure and economic activities [1].

Weather radar is one of the most essential primary instruments at BBMKG Region III, as the data it produces serves as a key reference for weather forecasting. According to information from forecasters, the radar's sensitivity has declined. Additionally, preventive maintenance reports have indicated potential issues with the receiver component. Therefore, a reliability study of the weather radar at BBMKG Region III is necessary to assess the extent to which performance degradation, particularly in the receiver component, affects the accuracy of rainfall intensity data displayed by the radar.

To assess the reliability level of the weather radar, a method capable of identifying potential system failures is required. This study employs the Failure Mode and Effect Analysis (FMEA) method to analyze the reliability of the weather radar at BBMKG Region III, particularly in response to reported issues such as reduced sensitivity and the suboptimal performance of the receiver component [2][3].

Through this study, which applies the Failure Mode and Effect Analysis (FMEA) method to the 2024 weather radar calibration data, it is expected that the reliability level of the BBMKG Region III weather radar in displaying rainfall intensity data can be determined. The results of this research are anticipated to serve as a reference and provide recommendations for improving the performance of the weather radar in the future.

II. METHODS

This study employs a quantitative approach, as it aligns with the use of the *Failure Mode and Effect Analysis* (FMEA) method. Through this method, the impact of each potential failure on the system can be analyzed. Subsequently, failures are identified and evaluated by assessing the level of risk using the *Risk Priority Number* (RPN) value.

A. Reliability

According to Ebeling, reliability is the probability that a machine or equipment will operate without failure during the course of its operation. Meanwhile, Dhillon and Rice define reliability as the likelihood that a unit will function normally when used under specific conditions, and at a minimum, perform as expected within established standards. Reliability is based on statistical theory, with its primary objective being to ensure that a system can perform its intended function under specified operational conditions for a defined period of time [5].

Generally, reliability theory can be classified into four main categories: component and system reliability, structural reliability, human reliability, and software reliability. The term item used in the definition of reliability encompasses all elements, including components, subsystems, and entire systems that can be considered as a single functional unit [6].

B. Receiver Unit in Weather Radar

According to this study, the author identified issues in the receiver component of the weather radar at BBMKG Region III. This finding is further supported by preventive maintenance reports indicating potential malfunctions in the component.

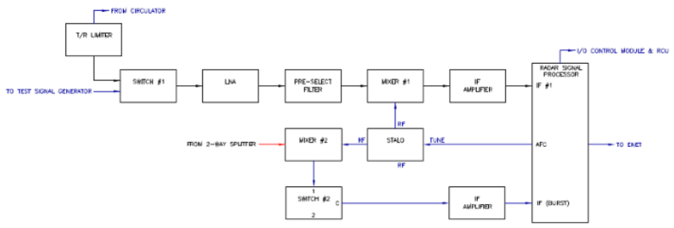

Figure 1. Receiver Block Diagram (Signal Flow)

Figure 1 illustrates the calibration data acquisition process conducted on the weather radar receiver component. The process begins with the use of a signal generator, which emits a specific frequency that is then directed into the switch component. The switch functions to control the opening and closing of the signal path, determining which signal will be passed through as the main input. This signal is then fed into the Low Noise Amplifier (LNA), which amplifies weak signals without introducing additional noise. The amplified signal then passes through the pre-select filter, which filters the signal to match the operational frequency range of the weather radar. Subsequently, the signal enters the mixer, where it undergoes down-conversion to an intermediate frequency (IF). The IF signal is then sent to the IF amplifier, which further amplifies it to a level suitable for digital processing. In the final stage, the signal is transmitted to the signal processor, where it is transformed into meaningful information such as rainfall intensity, target detection, range, and velocity measurements in Figure 2.

Figure 2. Weather Radar Display

Table 1. Rainfall Intensity Categories

Rainfall Intensity Categories	dBz Values	mm/h
Light Rain	22 – 35	1-5
Moderate Rain	35 - 45	5-10
Heavy Rain	45 - 55	10-20
Very Heavy Rain	>55	>20

Table 2. Occurrence

Description	Occurrence	Rating
Frequently fails	Very High	10-9
Failures occur continuously	High	8-7
Failures are very rare	Moderate	6-4
Failures that occur are very minor	Low	3-2
Almost no failures	Not Significant	1

Table 3. Severity

Description	Severity	Rating
Impact involving risk caused by system failure	Critical	10
System error causes serious impact	Very High	9
System does not work	High	8
The system operates but cannot perform optimally	Moderate	7
The system can still operate safely but with performance degradation	Low	6
Performance gradually decreases	Very Low	5
Minor impact on system performance	Slight Impact	4
Slightly affects system performance	Minimal	3
Insignificant impact on system performance	Very Slight	2
No impact on the product	No Effect	1

C. Failure Mode and Effect Analysis (FMEA) Method

FMEA is a structured procedure used to identify and prevent as many potential failure modes as possible. It is a methodology that can be applied to evaluate the likelihood of failures occurring within a system, process, design, or service, described in Table 2. The identification of potential failures is carried out by assigning scores to each failure mode based on three main aspects: the likelihood of occurrence, the severity of the failure, and the ability to detect it [7].

Table 4. Detection

Description	Detection	Rating
Inspection is unable to detect the potential cause and failure mode	Very Unlikely	10
Inspection has a very low probability of detecting the potential cause and failure mode	Extremely Low	9
Inspection has a low probability of detecting the potential cause and failure mode	Very Low	8
Inspection has a very slight probability of detecting the potential cause and failure mode	Slight	7
Inspection has a low probability of detecting the potential cause and failure mode	Low	6
Inspection has a moderate probability of detecting the potential cause and failure mode	Moderate	5
Inspection has a moderately high probability of detecting the potential cause and failure mode	Moderately High	4
Inspection has a high probability of detecting the potential cause and failure mode	High	3
Inspection has a very high probability of detecting the potential cause and failure mode	Very High	2
Failure cause and mode will almost always be detected by the inspection	Almost Certain	1

The Risk Priority Number (RPN) is a mathematical product of three key factors: the severity of the effect, the likelihood that a cause will lead to a failure associated with the effect (occurrence), and the probability of detecting the failure (detection). The formula for calculating the RPN is shown as follows [7][8]:

$$RPN = S \times O \times D \quad (1)$$

Explanation:
RPN = (Severity rating) × (Occurrence rating) × (Detection rating).

D. Research Flow

FMEA is a structured procedure used to identify and prevent as many potential failure modes as possible. It is a methodology that can be applied to evaluate the likelihood of failures occurring within a system, process, design, or service. The identification of potential failures is carried out by assigning scores to each failure mode based on three main aspects: the likelihood of occurrence, the severity of the failure, and the ability to detect it [7].

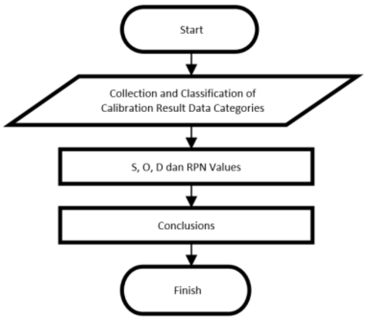

Figure 3. Flowchart Research Flow

Figure 3 illustrates the research flow undertaken by the author. The study begins with the collection of calibration data from the weather radar. Once the data is gathered, it is categorized based on the level of deviation identified in the dataset. Based on this categorization, the values of Severity, Occurrence, and Detection are determined for each potential failure. Subsequently, the Risk Priority Number (RPN) is calculated as the basis for risk prioritization. The final stage of this research involves drawing conclusions based on the results of the conducted analysis.

III. RESULT AND DISCUSSION

In this study, the data used is derived from the most recent weather radar calibration conducted in 2024. The selection of this data is based on its relevance to the research focus, as the calibration process involves the radar receiver components. The results of this calibration significantly affect the radar's performance, particularly in terms of the accuracy of rainfall intensity measurements.

A. Calibration Result Data

This section provides the calibration result from the year 2024. The data consists of several tables, including a power table (dBm) with a range from -10 to -100 dBm; an expected table (dBz), which contains standard values converted from power measurements (dBm) into dBz, also representing rainfall intensity; and a measured table (dBz), which presents the actual results obtained from the calibration process. Furthermore, a diff table (dB) is included, showing the correction or deviation values between the expected and measured data in dBz. These deviation values will then be classified by the author into several categories to facilitate the subsequent analysis process.

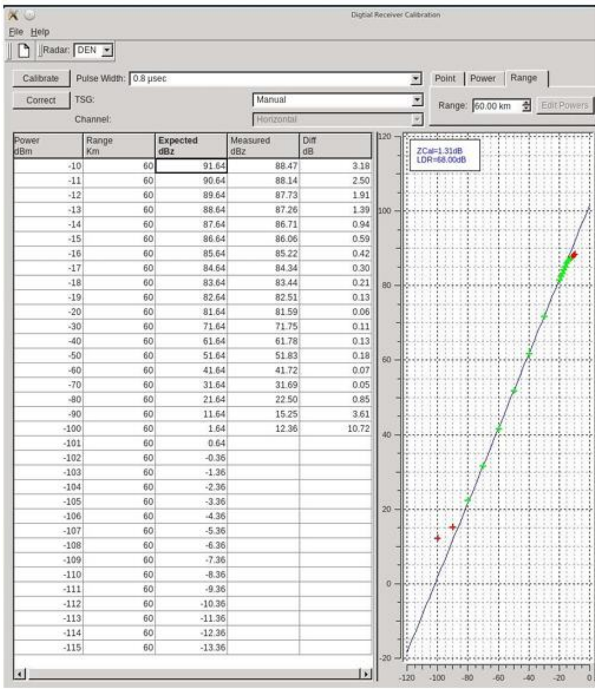
Figure 4. Calibration Result Data for the Year 2024

B. Category Classification of Calibration Result Data

At This stage is a continuation of the previous process, in which the obtained diff (dB) or deviation values are classified into specific categories. The purpose of this classification is to facilitate the calculation of the severity, occurrence, and detection values. The deviation values (diff in dB) are categorized into four groups, as presented in Table 5 [10][11].

Table 5. Category Classification

Category	Deviation Range (dB)	Explanation
Normal	0-1	The deviation is considered very small, indicating the radar system is operating optimally.
Minor Deviation	1 – 1.5	The deviation is noticeable but still within tolerance; monitoring is recommended.
Moderate Deviation	1.5 - 3	The deviation has become significant and may affect data accuracy.
Major Deviation	>3	The deviation is large, potentially impacting calibration results and data quality.

Figure 5 illustrates how the calibration result data used in this study, specifically the diff (dB) values, are classified into several categories based on the criteria outlined in Table 5. This classification is determined according to the tolerance values applicable in the weather radar calibration process.

Table 6. Category Classification of the 2024 Calibration Result Data

Power dBm	Range Km	Expected dBz	Measured dBz	Diff dB	Kategori
-10	60	91.64	88.47	3.17	Major
-11	60	90.64	88.14	2.50	Moderate
-12	60	89.64	87.73	1.91	Moderate
-13	60	88.64	86.96	1.68	Moderate
-14	60	87.64	86.71	0.93	Normal
-15	60	86.64	86.06	0.58	Normal
-16	60	85.64	85.22	0.42	Normal
-17	60	84.64	84.34	0.3	Normal
-18	60	83.64	83.44	0.2	Normal
-19	60	82.64	82.51	0.13	Normal
-20	60	81.64	81.59	0.05	Normal
-30	60	71.64	71.75	-0.11	Normal
-40	60	61.64	61.78	-0.14	Normal
-50	60	51.64	51.83	-0.19	Normal
-60	60	41.64	41.72	-0.08	Normal
-70	60	31.64	31.69	-0.05	Normal
-80	60	21.64	22.5	-0.86	Normal
-90	60	11.64	15.25	-3.61	Major
-100	60	1.64	12.36	-10.72	Major

C. Determining the Values of S, O, D & RPN (Risk Priority Number)

At this stage, the calibration result data that has been categorized is further processed by assigning rating values for severity, occurrence, and detection, in accordance with the criteria previously described in Table 7.

Table 7. S, O, & D Values

Deviation Category	Severity	Occurrence	Detection
Major Deviation	8	8	2
Moderate Deviation	5	5	4
Minor Deviation	3	3	6
Normal	1	1	9

Table 8. RPN Values

Power dBm	Diff dB	Kategori	Severity	Occurrence	Detection	RPN
-10	3.17	Major	8	8	2	128
-11	2.50	Moderate	5	5	4	100
-12	1.91	Moderate	5	5	4	100
-13	1.68	Moderate	5	5	4	100
-14	0.93	Normal	1	1	9	9
-15	0.58	Normal	1	1	9	9
-16	0.42	Normal	1	1	9	9
-17	0.30	Normal	1	1	9	9
-18	0.20	Normal	1	1	9	9
-19	0.13	Normal	1	1	9	9
-20	0.05	Normal	1	1	9	9
-30	-0.11	Normal	1	1	9	9
-40	-0.14	Normal	1	1	9	9
-50	-0.19	Normal	1	1	9	9
-60	-0.08	Normal	1	1	9	9
-70	-0.05	Normal	1	1	9	9
-80	-0.86	Normal	1	1	9	9
-90	-3.61	Major	8	8	2	128
-100	-10.72	Major	8	8	2	128

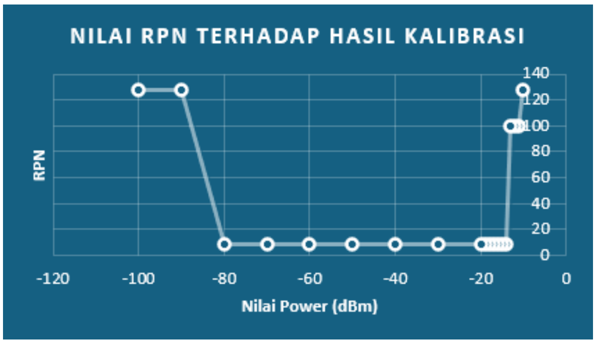

Figure 5. Risk Priority Number (RPN) Chart

The graph in Figure 5 illustrates the relationship between power values (dBm) and RPN values based on the results of the study. Several points with failure risk levels categorized as moderate and major were identified, each having RPN values greater than 100. These occur at power levels of -10, -11, -12, -13, -90, and -100 dBm in Table 8.

IV. CONCLUSION

Based on the results of the study conducted by the author using the Failure Mode and Effect Analysis (FMEA) method, it was found that in the very low power range, around -90 to -100 dBm, there was a significant increase in noise. Meanwhile, in the very high-power range, approximately -13 to -10 dBm, overload or saturation occurred in the components, leading to errors in data readings. From a reliability perspective, it was found that within the power range of -80 to -14 dBm, no system failures occurred in the receiver. When converted into rainfall intensity data (dBz), this range corresponds to approximately 22.5 to 86.7 dBz. Therefore, it can be concluded that the weather radar at BBMKG Region III has experienced a decrease in reliability, as Indicated by several failures during the calibration process of the radar receiver component. This decline is also influenced by the fact that the radar has been in operation for 15 years. Nevertheless, the weather radar is still capable of functioning in accordance with rainfall intensity categories (dBz), specifically for observing light, moderate, heavy, and very heavy rainfall.

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