Implementation of Predictive Maintenance on Defense Radar Using FMECA Method and PHP Software to Support Maintenance Action Decision Making

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Abstract. The operational readiness of the defense radar is crucial in protecting the country's sovereignty from aerial threats. Proper monitoring of radar health status needs to be continuously developed to support high operational performance. Prioritizing equipment repairs through appropriate predictive maintenance will assist radar technicians in making maintenance action decisions, thereby preventing fatal breakdowns. This study aims to add maintenance techniques to defense radar with predictive maintenance so that the system can predict critical failures and prevent catastrophic breakdowns. The Failure Mode Effect and Criticality Analysis (FMECA) method analyze all possible losses, then calculates the risk priority number (RPN) and implements the PHP software to provide visualization priority suggestions for handling failures in non-emergency conditions. The main finding in this paper is built-in test equipment (BITE) system integration on all subsystems at the radar station to support technicians in monitoring the radar health status in one screen and support the decision-making action for performing maintenance. The implication of this study can be useful in developing maintenance technology for electronic, mechanical, and industrial systems with system complexity to help find critical components that need more profound attention.

Keywords: Electronic System, FMECA, Predictive Maintenance, Risk Priority

1 Introduction

Strong air defense is essential to provide security for a country and its residents in daily activities. One of the devices in air defense is the military defense radar, an electronic device for early warning detection of possible aerial threats [1]. Defense radar can detect enemies and guide fighter pilots or weapons in interceptions, repelling off attacks, and striking strategies. It is conceivable that when there is an aerial threat, but the radar system for detecting it is in poor condition, this will cause security to be out of control

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[2]. Furthermore, the country will suffer loss and even life casualties for its citizens or residents. The radar must be able to support the aerial defense in prime condition.

The readiness level of the defense radar can be known from various aspects, one of which is maintenance applied. Corrective maintenance is reactive maintenance when equipment failure has occurred, so that component repairs and replacement are needed, this will cause a decrease in radar performance even to the point where the system is inactive for an unmeasured time. Preventive maintenance is used to anticipate radar problems that can potentially cause fatal damage to the material and people who work on it. The development of preventive maintenance can be in the form of predictive maintenance, namely exploiting the furthest useful life before the component or module is damaged or decreases in performance, thereby reducing the cost, effort, and time required while the system is inactive, but can also be carried out when the system remains active [3], [4]. The interesting thing to develop in the maintenance system that has been formed is to look for a breakthrough for the maintenance system by applying the Failure Mode Effect and Criticality Analysis (FMECA) method to study the failure modes up to the critical level in the overall defense radar system, resulting in predictive maintenance innovations for monitoring the condition of the defense radar.

Critical failures that may occur in the defense radar system must be watched out for, and more effective anticipatory steps are sought. The defense radar already has a built-in test equipment (BITE) system to monitor the health and condition of components or modules, but it still has limitations. Sometimes when a critical failure occurs, the system cannot detect and localize the possibility of equipment experiencing problems. This causes problems for technicians in finding components that cause loss and detecting other components that are affected by the failure and require a lot of time. The system must be deactivated for a relatively long period to check the impact damage due to the critical failure occurrence. Technicians, as authorized personnel to carry out maintenance, need time to check the entire system to ensure the level of performance of the radar system is in prime condition.

FMECA is a prevalent method in system failure and criticality analysis to improve the performance of a system [5]. FMECA is an extension step of the Failure Mode and Effect Analysis (FMEA) by considering criticality analysis [6]. The FMECA collects all failure mode information from failure data, causes, effects, and risks associated with each component and subsystem represented by Risk Priority Number (RPN) [7]. Furthermore, the RPN value is used for the criticality analysis of the system to consider predictive maintenance and general preventive maintenance or corrective maintenance. FMECA can be applied in the electronics field to make it easier to record failure modes in each defense radar subsystem and collaborate with information technology and the internet network.

The world of technology development leads to innovation that influences operations. The development of the internet and computer technology forms the basis of Internet of Things (IoT) technology for information data real-time applications [8]. Currently, one of the most compact information and programming systems is the Hypertext Preprocessor (PHP), which is general purposes open-source programming in terms of web development [9]. The PHP programming has the advantage of being able to combine various web template systems, content management, and frameworks. Those advantages offered by PHP are used in this study as an engine for designing interfaces between radar systems and technicians.

From the literature reviews above and the problems described, developing critical failure prediction innovations using FMECA combined with PHP programming simulations is still very board. This study aims to design an information system that shows the status of the defense radar system with FMECA data from all modules on the radar system. The health status of the equipment in each module displayed on a screen provides predictions of critical failures that may arise and advises technicians on which components should be prioritized for maintenance or repair before critical failure or system breakdown occurs.

2 Materials and Methods

The materials and methods used in this study include defense radar, FMECA as a criticality analysis method for critical failures, and PHP programming techniques. The framework design of a predictive maintenance prototype for a defense radar can be explained as follows.

2.1 The Capabilities of Defense Radar

Radar or radio detecting and ranging is a technology for detecting the presence of objects and measuring the distance between transmitters of electromagnetic wave signals and these objects. The working principle of radar in general is that radio wave signals emitted into the air will hit objects and bounce back to the radar equipment, reflected wave signals are received and processed as detected airborne objects. To calculate the distance and motion of these objects, the Doppler effect is used. The reflected wave signal data is processed and then displayed on the operator's monitor screen. The complexity of the increasingly sophisticated radar components requires accurate monitoring [10].

Air defense radar has advantages such as a surveillance coverage radius of more than 300 km from the epicenter for early detection, electronic warfare capabilities, and the ability to support radar operators in directing fighter pilots for combat tactics. The BITE system provides information when a failure occurs in the radar system and its performance. Additional technology in the defense radar is equipped with a mission control system in the task of monitoring air security strategy, a long-range communication system to guide fighter pilots and coordinate tactics with other radar station operators, and a power supply system as a provider of stable electrical energy support. Fig. 1 shows the relationship between the radar principle and the electronics system diagram that built the radar system.

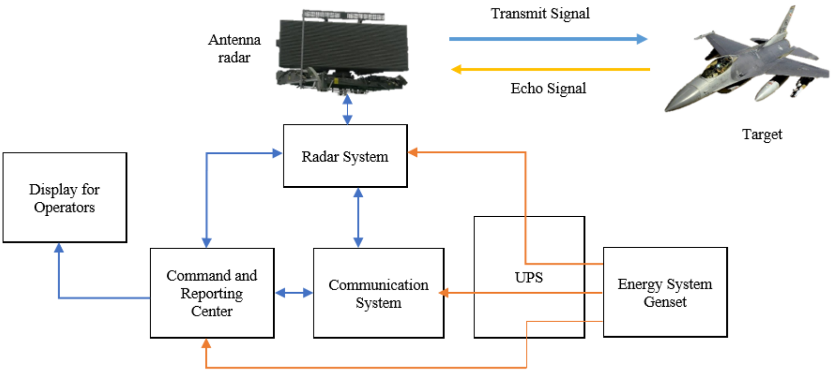

Fig. 1. Block Diagram Radar Principle

2.2 Maintenance for Defense Radar

The radar system needs special treatment to maintain the level of readiness and operational performance, so proper maintenance is needed according to the situation and condition of the system. There are three general types of radar maintenance, namely corrective maintenance, preventive maintenance, and predictive maintenance. The defense radar also has a built-in test equipment (BITE) system, which can provide information on the status of the radar and recommendations for specific maintenance actions. BITE functions as a system that monitors system parameters, then controls the operation of the system accurately to ensure the reliable performance of electronic equipment [11]. BITE provides information regarding problem finding for the purpose of assisting with maintenance, equipment testing, and system integration. [12], [13].

2.3 Failure Mode Effect and Criticality Analysis (FMECA)

Failure mode effect and criticality analysis are methods used to prevent the occurrence of various forms of component failure, predict faults, and then help find optimal and economical solutions. By implementing this method, the system can identify potential system, subsystem, or component failures, depending on the database it has. This method gives priority to all potential problems to determine possible actions or countermeasures. FMECA is a powerful method for analyzing the reliability and safety of equipment because the data is presented and easy to use [14]. The FMECA method identifies the behavior of system severity (Severity index), the level of probability of failure occurrence (Occurrence index), and the level of detection capability by technicians (Detection index). This identification calculates the risk priority value (Risk Priority Number or RPN) by calculating it in equation 1.

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

- The severity index defines the severity classification for each failure mode of each system. It is inputted into the FMECA calculation based on the consequences for each part of the radar system.
- The occurrence index assesses the frequency of occurrence of the same failure in a subsystem to determine how often the failure mode occurs.
- The detection index analyzes and measures the system's ability and technicians' capability to detect and report problems related to each system component and failure mode.

Risk priority number (RPN) as an additional calculation in criticality analysis. The RPN value is the multiplying result of the Detection Index (D) * Severity Index (S) * Occurrence Index (O). Each on a scale of 1 to 10, it means the highest RPN value is 10x10x10 = 1000. A failure with a high RPN value indicates that the failure has a very severe impact, difficult to detect, and almost unavoidable. On the contrary, if the occurrence is infrequent, the occurrence index will be one, and the RPN value will decrease to 100. Criticality analysis allows us to focus on the highest risk that must be addressed and should be treated immediately.

2.4 PHP Programming Technique

Programming in designing a web-based information management system through PHP (Hypertext Preprocessor). PHP is an open-source general-purpose programming language in web development [8], [15]. The advantages of PHP include the characteristics of the C, Perl, and Java programming languages, with code that can be embedded in HTML or HTML5. Another advantage is that it can be used to combine various web template systems, frameworks, and content management. The use of PHP in this research is as a process engine for making interfaces between radar systems and operators or technicians. Information technology utilizes connections using the internet network to collect data quickly, making it easier for users to take immediate action based on the information data received correctly.

2.5 Weibull Distribution

The Weibull distribution calculates the probability of system equipment failure so that the period between one failure and the next can be estimated [16]. The Weibull distribution is applied in this study to see the range of failures that occur until the equipment is inoperable or damaged. Two forms of the Weibull distribution are distinguished by their parameters. Cumulative Distribution Function (CDF) can be expressed in a closed form. The three-parameter version of the Weibull distribution CDF can be written as in equation 2.

$$F(x) = 1 - exp\left[-\left(\frac{x-y}{\eta}\right)^{\beta}\right];\ \ x > \gamma \tag{2}$$

The reliability function R(x) is a survival function commonly used in biomedical applications, which expresses the probability that a subject or device exceeds a predetermined value. The reliability function of the Weibull distribution with two parameters can be seen in equation 3.

$$R(x) = Prob\,[X > x] = exp\left[-\left(\frac{x}{\eta}\right)^{\beta}\right];\;\; x > 0 \tag{3}$$

Further measurements that can be made are calculating the mean time between failure (MTBF) for repairable equipment or the mean time to failure (MTTF) for non-repairable equipment [17]. Calculating the average failure rate (means failure rate) can be expressed through the interval from x1 to x2 in equation 4.

$$\bar{\lambda} = \frac{\int_{x_1}^{x_2}(x)dx}{x_2 - x_1} = \frac{\Lambda(x_2) - \Lambda(x_1)}{x_2 - x_1} = \frac{x_2^{\beta} - x_1^{\beta}}{\eta^{\beta}[x_2 - x_1]} \tag{4}$$

3 Result and Discussion

This section describes the results of the research data and its discussion, which contains the design of the hierarchical structure of the radar for all system items, the PHP prototype design based on the radar FMECA database, and additional predictive maintenance to support the decision-making process for technicians in the maintenance action plan.

3.1 Hierarchy Components Structure on the Whole Defense Radar System

The structure design for the component assessment shows hierarchical levels based on FMECA data identified by the technician. It aims to determine the extent to which the critical failure relationship of a subsystem or component impacts other subsystems. Radar system information data is traced from the highest level to the solid-state component or module level to gather detailed information according to local BITE information on each respective subsystem. The defense radar is calculated up to the fourth level subsystem data of the entire radar system, as shown in Fig. 2. FMECA measurements provide RPN values that indicate priority components. When there is a decrease in system performance, the RPN value can be used to predict critical elements that need to be maintained immediately. The results of the RPN for critical components can be shown in Table 1.

3.2 PHP Design Prototype Based on FMECA for Defense Radar

The designed software architecture was built using MySQL as the item database server on the radar system, which can accommodate the Severity index, Detection index, and Occurrence index. The PHP programming is used to map and code the algorithm according to the initial input data from FMECA, then the value changes dynamically according to the movement of the simulation time.

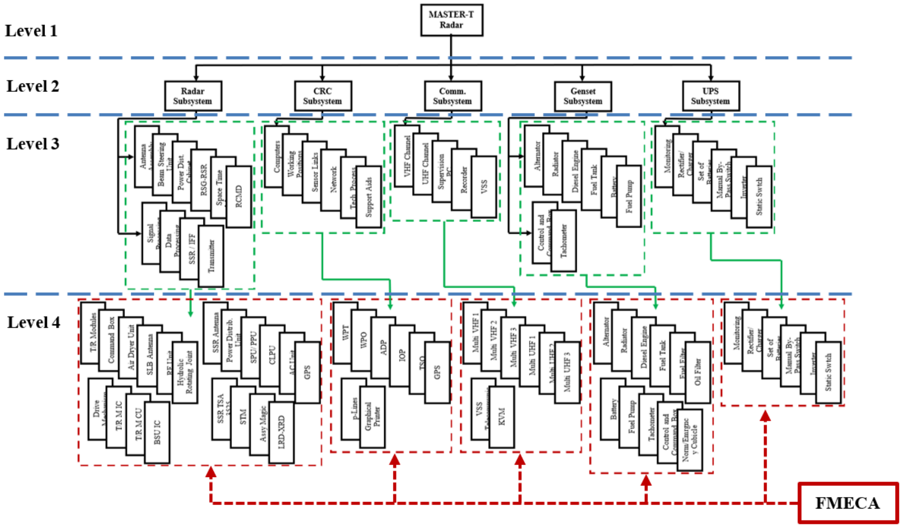

Fig. 2. Hierarchy structure scheme on defense radar

Table 1. RPN value calculation result for defense radar

NO	SUB/LOCATION	ITEM	S	O	D	CRIT	RPN
1	Genset - Engine	Diesel Engine	10	6	5	9	300
2	Radar - CBIT	Power Supply – 918	7	6	7	5	294
3	Radar - CBIT	32 Logic Input Card	7	7	6	4	294
4	Radar - SSR	EQ. Power Supply	8	7	5	4	280
5	Radar - SSR	IFF TSA2525	8	7	5	8	280
6	Genset - Engine	Alternator	9	5	6	8	270
7	Radar - CBIT	Assy Magic Card	7	6	6	6	252
8	Radar - CBIT	Thermostat - 926	7	6	6	4	252
9	Radar - CBIT	Circuit Breaker – 977	7	6	6	4	252
10	Radar - PDC	Command Box	7	5	7	6	245
11	Radar - SSR	AAU Mode S	7	7	5	6	245
12	Radar - CBIT	Fuse – 991	8	7	4	4	224
13	Radar - RSG-RSR	Reference Unit	7	5	6	7	210
14	Radar - RSG-RSR	Synthesizer Unit	6	5	7	6	210
15	Radar -Trans	HD Single Board CP	7	6	5	5	210

3.3 Predictive Maintenance Addition for Decision-Making Action

Critical failures prediction can be known from RPN calculation data processing by the FMECA method combined with diagnosing problems detected, thus localizing the estimation of problematic subsystems. Predictive maintenance is added by calculating the Weibull distribution of each component to determine its remaining life. Technicians can determine component maintenance time based on reliability and remaining life. One of the samples for calculating the Weibull distribution on the radar component is shown in Fig. 3.

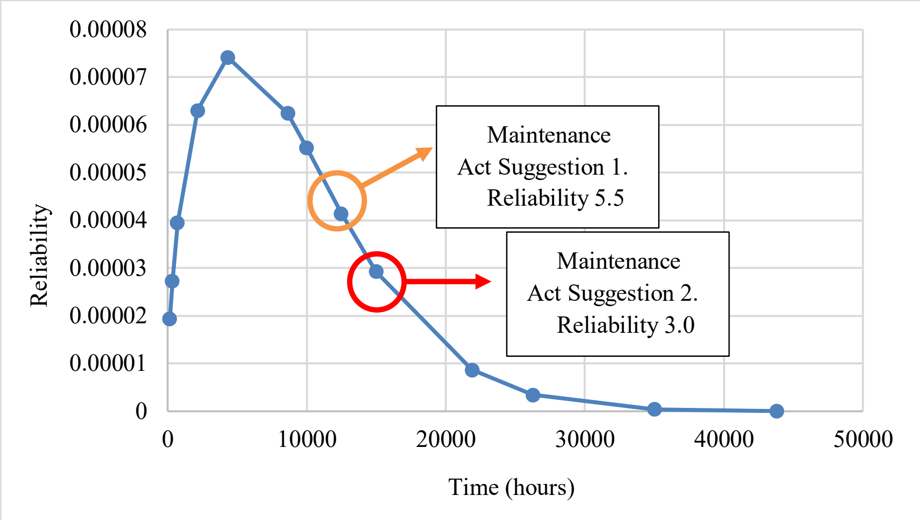

Fig. 3. Weibull distribution calculation for predictive maintenance on radar component

4 Conclusion

The FMECA method in defense radar maintenance succeed more advanced maintenance than the conventional that already used into predictive maintenance, which is capable of predicting potential critical failures. From the data obtained from the FMECA method, 300 types of components and modules were obtained. The highest RPN value is a Diesel engine with a value of 300, this RPN value is a reference in sorting the monitoring priorities of critical components. The results of a case study on one of the components, namely the Ventilation unit, can explain that by calculating the Weibull distribution, the maintenance prediction for scenario one is obtained at 10,000 hours of component usage. While the maintenance prediction for scenario 2 is 15,000 hours of component use. This can prevent one of the failures from happening in the future.

Simulation prototypes using PHP can make a difference in monitoring the overall radar system health faster for technicians and operators to expect of helping best recommendation or making decisions regarding a sequence of maintenance actions that must be execute directly according to the RPN order that appears on the system monitoring. The FMECA method can come up with priority calculations for critical failures that must be done right away, and the application of the Weibull distribution can contribute information on the right time to conduct maintenance or reparation to extend the operational life with the given remaining useful life (RUL) information.

Future Work. The application of predictive maintenance and FMECA data processing through PHP programming is still a simulation, this can be developed to collect data directly from the radar system in real time. Hand-shaking research needs to conduct and succeed between the defense radar system and the PHP programming monitoring system.

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References

1. J. Wang, B. Deng, and C. Li, "Development and Current Situation of Radar Performance Parameter Measurement Simulation Training Platform," in *IOP Conference Series: Materials Science and Engineering*, May 2020, vol. 799, no. 1.
2. J. N. Roux and J. H. Van Vuuren, "Real-time threat evaluation in a ground-based air defence environment," *ORiON*, vol. 24, no. 1, pp. 75–101, 2008.
3. F. Calabrese, A. Regattieri, L. Botti, and F. G. Galizia, "Prognostic health management of production systems. New proposed approach and experimental evidences," in *Procedia Manufacturing*, 2019, vol. 39, pp. 260–269.
4. M. Pecht and M. Kang, *Prognostics and health management of electronics : fundamentals, machine learning, and internet of things*. IEEE Press: Hoboken, USA. 2018.
5. B. Suharjo, O. Sri Suharyo, A. Bandono, S. Tinggi Teknologi Angkatan Laut, and S. Surabaya Indonesia, "Failure Mode Effect And Criticality Analysis (Fmeca) For Determination Time Interval Replacement Of Critical Components In Warships Radar," *J. Theor. Appl. Inf. Technol.*, vol. 31, no. 10, 2019, [Online]. Available: www.jatit.org
6. H. C. Liu, X. Q. Chen, C. Y. Duan, and Y. M. Wang, "Failure mode and effect analysis using multi-criteria decision-making methods: A systematic literature review," *Comput. Ind. Eng.*, vol. 135, pp. 881–897, Sep. 2019.
7. Y. Du, L. Liao, and L. Wang, "Failure mode, effects and criticality analysis of remanufactured machine tools in service," *Int. J. Precis. Eng. Manuf.*, vol. 18, no. 3, pp. 425–434, 2017.
8. G. W. Ren, M. Yu, D. S. Yin, S. Y. Huang, H. C. Xu, and M. Yuan, "Design and optimization of integrated energy management network system based on internet of things technology," *Sustain. Comput. Informatics Syst.*, vol. 30, Jun. 2021.
9. A. Gunawan, "Selection Of Web-Based Framework for System Development using AHP (Analytic Hierarchy Process) Method in PT. XYZ," in *2020 International Conference on Information Management and Technology (ICIMTech)*, 2020, pp. 148–152.
10. A. J. Wileman and S. Perinpanayagam, "Failure mechanisms of radar and RF systems," in *Procedia CIRP*, 2013, vol. 11, pp. 56–61.
11. B. J. Pandu, "Bite Controller for ESM Systems Controller for ESM Systems," 2016.
12. M. Pecht, M. Dube, M. Natishan, R. Williams, J. Banner, and I. Knowles, "Evaluation of built-in test," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 37, no. 1, pp. 266–271, 2001.
13. P. Dai and W. Yu, "Overview of radar digital circuit fault detection technology," in *2020 IEEE 5th Information Technology and Mechatronics Engineering Conference (ITOEC)*, 2020, pp. 88–92.
14. M. Ohring and L. Kasprzak, *Reliability and failure of electronic materials and devices*. Academic Press, 2014.

15. A. Prisacaru, P. J. Gromala, M. B. Jeronimo, B. Han, and G. Qi Zhang, "Prognostics and health monitoring of electronic system: A review," in *2017 18th International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems, EuroSimE 2017*, May 2017.
16. J. McCool, *Using the Weibull distribution : reliability, modeling, and inference*. John Wiley & Sons, 2012.
17. F. Afsharnia, "Failure rate analysis," in *Failure Analysis and Prevention*, IntechOpen, 2017.