JURNAL VENUS
Vol. 13, No. 2, September 2025, pp. 95-107
p-ISSN 2338-4611 | e-ISSN 2798-0995

Analysis of the Use of Radar During Navigation to Improve Shipping Safety

Sahabuddin Sunusi[1*], Barnabas Fendy Tallu[2], Sulastriani[3], Novianty Palayukan[4]

[1,2,3,4]Nautical Study Program, Politeknik Ilmu Pelayaran Makassar, Makassar, Indonesia
* sahabuddinsunusipipmakassar@gmail.com

ARTICLE INFO

Article history
Received: 14 June 2025
Revised: 25 June 2025
Accepted: 23 August 2025
Published: 10 September 2025

Keywords
Ship radar; navigation safety; false echoes; magnetron scanner; maritime operations

Corresponding author
Sahabuddin Sunusi
Nautical Study Program, Politeknik Ilmu Pelayaran Makassar, Jl. Tentara Pelajar No. 173 Makassar, 90172
Email: sahabuddinsunusipipmakassar@gmail.com

ABSTRACT

Navigation safety is a critical aspect of maritime operations, and the effective use of ship radar plays an important role in preventing navigational hazards. This study aims to analyze the use of radar in supporting navigation safety, particularly in detecting surrounding objects, monitoring weather conditions, and determining a vessel's position when visibility is limited. The study employed a qualitative research method, with data collected through interviews with ship crew members, direct observation of radar operations, and an analysis of onboard standard operating procedures. The data were analyzed descriptively to evaluate radar operation and identify factors affecting its effectiveness. The findings indicate that radar is an essential navigational instrument for enhancing situational awareness and supporting safe ship operations. However, the case study of MV Sinar Kintamani revealed that, although radar operation generally followed applicable procedures, its effectiveness was compromised by a magnetron scanner that had exceeded its recommended service life, resulting in false echoes. This condition highlights the importance of maintaining radar equipment in proper working order to ensure reliable target detection and minimize navigational risks. The novelty of this study lies in identifying the relationship between procedural compliance and equipment condition in radar-assisted navigation safety. It concludes that effective radar use requires both adherence to operational procedures and regular technical inspection and maintenance.

Copyright © 2025 The Author(s). Published by Jurnal Venus, Politeknik Ilmu Pelayaran Makassar. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0): https://creativecommons.org/licenses/by/4.0/

How to cite: Sunusi, S., Tallu, B.F., Sulastriana, Palayukan, N. (2026). Analysis of the Use of Radar During Navigation to Improve Shipping Safety. *Jurnal Venus*, *13*(2), 95-107. https://doi.org/10.48192/vns.v13i2.807

1. INTRODUCTION

Maritime transportation plays a fundamental role in national and international trade by facilitating the movement of goods through global supply chains. However, safe and efficient maritime operations depend not only on vessel seaworthiness and crew competence but also on the reliability of navigational equipment. Marine radar is one of the essential instruments used to detect surrounding targets, estimate their range and bearing, and support collision avoidance. Its importance increases during nighttime navigation, restricted visibility, and operations in congested waters, where visual observation alone may not provide sufficient information for safe navigation. Therefore, optimizing radar utilization is an important aspect of improving navigational safety and operational efficiency.

In maritime navigation, optimization involves the effective use of available equipment, information, and human resources to achieve safe and efficient operational outcomes. Radar supports this objective by providing information about surrounding targets and helping navigating officers assess

potential collision risks. When integrated with the Automatic Radar Plotting Aid (ARPA), radar can assist in tracking selected targets and estimating collision-related parameters. Nevertheless, radar information must be interpreted in conjunction with visual observations, the Automatic Identification System (AIS), Global Navigation Satellite System (GNSS) information, and other available navigational instruments. The International Maritime Organization (IMO, 2023) establishes performance standards for shipborne navigation equipment, while the International Convention for the Safety of Life at Sea (SOLAS), Chapter V, provides requirements concerning the carriage and use of navigational equipment. These provisions emphasize the importance of reliable equipment and competent operation in maintaining navigational safety.

Marine radar operates by transmitting electromagnetic energy and receiving echoes reflected from surrounding objects. The time taken for the reflected signal to return provides information about target range, while the antenna's orientation helps determine target bearing. Two commonly used marine radar frequency bands are X-band, operating at approximately 8–12 GHz, and S-band, operating at approximately 2–4 GHz. X-band radar generally provides relatively fine target resolution and is useful for detecting smaller targets under suitable conditions. S-band radar generally offers advantages in certain rain and sea-clutter conditions because of its longer wavelength. However, actual performance depends on equipment design, antenna characteristics, radar settings, target properties, and environmental conditions. Consequently, effective radar selection and operation require an understanding of the equipment's technical capabilities and limitations.

A conventional magnetron-based radar consists of several interconnected components, including a transmitter, modulator, antenna, receiver, signal-processing system, and display unit. The magnetron generates the microwave energy required for radar transmission, making it a critical component in the radar's transmission system. The antenna transmits radar energy and receives reflected signals, while the receiver and signal processor convert and process those signals into information that can be displayed to the navigating officer. Because these components function as an integrated system, a fault in one component may affect overall radar performance. In particular, magnetron deterioration or failure may reduce transmitted power and compromise target detection. However, the nature and severity of the malfunction must be established through technical inspection and diagnostic evidence rather than inferred solely from the radar display.

The importance of radar reliability is illustrated by an incident involving MV. Sinar Kintamani on November 15, 2023, while the vessel was sailing through the Selayar Strait, Indonesia. According to the preliminary account provided for this study, the vessel experienced radar problems associated with magnetron damage, resulting in inaccurate information on the radar display. Such a malfunction may affect the officer's ability to detect and monitor surrounding targets and may increase uncertainty in navigational decision-making. Nevertheless, the actual effect of the reported damage on radar performance, the extent of the inaccurate information, and the operational responses taken by the crew require examination through relevant technical records, interviews, and other available evidence.

Recent research has examined the reliability and maintenance of shipboard radar from several perspectives. Ding et al. (2021) investigated a multi-agent-based approach to reliability, maintainability, and supportability assessment for shipboard radar. Their research provides a framework for considering the relationship between equipment condition, maintenance support, and operational reliability. Basuki et al. (2021) examined preventive maintenance for Kelvin Hughes MKVII X-band navigation radar and applied techniques including Failure Mode, Effects, and Criticality Analysis (FMECA) to identify components requiring maintenance attention. These studies indicate that maintaining radar reliability requires more than responding to failures after they occur; it also requires systematic inspection, identification of potential failure modes, and appropriate maintenance planning.

Maintenance management is another important consideration in ensuring the availability of navigational equipment. Bayer et al. (2021) examined ship maintenance processes using an Input-Control-Output-Resources approach, emphasizing the importance of structured maintenance processes and resource management. In radar systems, maintenance activities may include routine operational checks, inspection of equipment condition, monitoring of operating hours, performance testing, and replacement of components in accordance with manufacturer recommendations. The magnetron has a finite service life, but its expected operating hours and replacement interval vary according to the radar model, operating conditions, and manufacturer specifications. Consequently, magnetron replacement should be based on the applicable equipment manual, operating-hour records, performance indicators, and technical inspection rather than a universal service-life assumption.

In Indonesia, research has also addressed the use and maintenance of marine radar. Malatunduh et al. (2024) examined radar optimization for safe navigation in a narrow shipping channel aboard KMP Virgo 18, highlighting the operational importance of effective radar use. Sofyan et al. (2025) investigated radar utilization to support navigation safety aboard PSV S. Panglima. These studies provide relevant national context for examining radar use in Indonesian waters. However, radar effectiveness cannot be assessed solely through operational procedures because equipment condition, maintenance history, environmental conditions, and operator competence may also affect the quality of navigational information.

Human factors constitute another important dimension of radar-related safety. Uflaz et al. (2023) analyzed the contribution of human error to ship collision risk in congested waters using an extended fault-tree analysis incorporating the SPAR-H method and evidential reasoning. Their study identified improper radar monitoring and inadequate lookout practices as relevant contributors to collision risk. This finding demonstrates that the effectiveness of radar depends not only on the technical condition of the equipment but also on the operator's ability to recognize targets, interpret displayed information, identify abnormal performance, and take appropriate action. Therefore, when radar information becomes unreliable, navigating officers must recognize the limitations of the equipment, report the malfunction, verify available information through other appropriate means, and follow established onboard safety procedures.

Standard operating procedures and crew competence are particularly important during radar operation. Operators must verify equipment readiness, select an appropriate range scale, adjust gain and tuning, and apply sea-clutter and rain-clutter controls according to the manufacturer's instructions and prevailing conditions. They must also assess target range and bearing and use plotting or tracking functions when appropriate. These adjustments must be performed carefully because inappropriate settings may suppress relevant echoes or create misleading displays. The IMO's model course on radar navigation, radar plotting, and ARPA provides a framework for operational-level training and competence (IMO, 2017). Therefore, evaluating radar malfunction should include consideration of both technical failure and the procedures followed by the navigating officers.

Radar maintenance and operational procedures should also be examined as complementary elements of a broader reliability-management approach. Preventive maintenance aims to identify deterioration before it develops into a significant equipment failure, whereas operational checks help officers recognize abnormal indications during use. Maintenance records, operating-hour data, fault reports, diagnostic results, and component replacement histories can help establish whether a reported magnetron failure was associated with inadequate maintenance, normal component deterioration, or other technical conditions. These factors should be investigated systematically rather than assuming that a single maintenance deficiency or operator error necessarily caused the incident.

Despite the existing literature on radar reliability, preventive maintenance, and human factors, important questions remain regarding the relationship between component failure and navigational decision-making in specific shipboard circumstances. Previous studies have addressed radar reliability and maintenance assessment (Ding et al., 2021; Basuki et al., 2021), maintenance-process management (Bayer et al., 2021), radar utilization in Indonesian maritime operations (Malatunduh et al., 2024; Sofyan et al., 2025), and human error associated with collision risk (Uflaz et al., 2023). However, these studies do not, by themselves, establish how the reported magnetron damage affected radar information and navigational decision-making aboard MV. Sinar Kintamani during its passage through the Selayar Strait on November 15, 2023. The relationship between the technical condition of the magnetron, the symptoms observed on the radar display, the maintenance history, and the actions taken by the navigating officers therefore requires case-specific investigation.

The research gap addressed by this study is the need to examine magnetron-related radar malfunction and its implications for navigational safety within the specific operational context of MV. Sinar Kintamani. Unlike studies that focus primarily on radar reliability assessment, preventive maintenance, or general human factors in maritime accidents, this study seeks to connect technical evidence of radar malfunction with the operational procedures and navigational responses documented in the incident. Its novelty lies in this context-specific integration of component reliability, maintenance practices, radar information interpretation, and safety-related decision-making. The study is expected to provide practical insights for improving radar condition monitoring, preventive maintenance,

component inspection and replacement, crew competence, and the management of navigational operations when radar performance is compromised.

This study aims to analyze the magnetron-related radar malfunction aboard MV. Sinar Kintamani on November 15, 2023, examine its implications for radar performance and navigational decision-making, identify contributing technical and operational factors based on available evidence, and formulate recommendations for improving radar reliability and navigational safety.

2. METHODS

This study employed a field research design using a qualitative descriptive approach supported by quantitative data. The study aimed to examine the implementation and operational performance of ship radar and identify factors contributing to its suboptimal operation. The qualitative approach was used to describe actual operational practices, officers' experiences, and challenges encountered during radar use, while quantitative data from technical records and relevant documentation were used to support the interpretation of the findings. The analysis focused on radar operation, the factors affecting its performance, and the extent to which its use supported safe navigation.

The vessel was selected as the research setting because it provided an operational environment in which radar use could be observed under actual navigational conditions. Data collection focused on radar operation, the practices adopted by officers, and technical or operational factors potentially associated with suboptimal radar performance.

The research participants consisted of ship officers who were directly involved in radar operation and navigational decision-making aboard MV Sinar Kintamani. Informants were selected using purposive sampling based on their responsibilities, experience, and familiarity with radar operation. This technique was appropriate because the study required information from personnel with direct knowledge of the equipment and its use during navigation. The number of participants was determined according to their relevance to the research objectives and the adequacy of the information obtained. The final manuscript should report the actual number of informants and their relevant positions.

The research instruments consisted of an observation guide, an interview guide, and a documentation checklist. The observation guide was used to record radar operating practices, the officers' use of radar displays and controls, and operational conditions that could affect radar performance. The interview guide was used to obtain information from ship officers regarding radar operation, encountered problems, possible causes of suboptimal performance, and measures taken to address those problems. The documentation checklist was used to examine relevant technical records, equipment documentation, maintenance records, and the radar manufacturer's operating manual, where available.

The primary analytical focus was radar operation and the factors associated with its suboptimal performance. Qualitative data consisted of observation notes and interview responses, while quantitative data consisted of relevant numerical information available in technical records and operational

documentation. The quantitative indicators examined depended on the available records and could include equipment fault records, maintenance frequency, or other documented technical parameters relevant to the research objectives. No specific performance measurements were assumed where supporting records were unavailable.

The interview and observation instruments were aligned with the research objectives and relevant technical guidance. Any formal instrument validity or reliability tests should be reported if they were actually performed. For the qualitative component, the credibility of the findings was strengthened by comparing information from observations, interviews, and technical documentation.

Data were collected through direct observation, interviews, and literature and document reviews. First, the researcher conducted direct observations of radar use aboard MV Sinar Kintamani during the Marine Practice period. The observations focused on how officers operated the equipment and on operational conditions or difficulties associated with its use. Second, interviews were conducted with selected ship officers to explore their experiences, understanding, and responses to radar-related operational problems. Third, relevant technical documents, equipment manuals, reference books, and other literature were reviewed to establish the theoretical and technical basis for interpreting the findings.

Primary data were obtained from direct observations and interviews with ship officers. Secondary data were obtained from available technical records, equipment documentation, operating manuals, and relevant literature. The information collected from these sources was organized to facilitate comparison between actual operational practices and the applicable technical guidance. Observations and interviews were conducted with the necessary authorization and without interfering with the vessel's navigational safety.

Data were analyzed using qualitative descriptive analysis supported by descriptive quantitative analysis. The qualitative analysis involved organizing the observation notes and interview responses, identifying relevant information, grouping the data into themes, and interpreting recurring patterns related to radar operation and its suboptimal performance. The process of data condensation, data display, and conclusion drawing and verification followed the qualitative data analysis framework proposed by Miles, Huberman, and Saldaña (2014).

Quantitative data obtained from technical records and documentation were organized and summarized descriptively, where numerical information was available and relevant. The findings from both data types were then compared with the equipment manufacturer's operating manual, relevant technical references, and applicable navigational safety requirements. This comparison was intended to identify discrepancies between recommended operating practices and the conditions documented during the research. The analysis was conducted manually if no specialized software was used. Conclusions were drawn by integrating the qualitative findings with the available quantitative evidence and relevant technical guidance.

The research was conducted with due consideration for participant confidentiality and vessel operational safety. Permission to conduct observations and access relevant technical records was obtained from the authorized vessel or company representative, as required. Ship officers were informed about the purpose of the research, and their informed consent was obtained before interviews. Participants' identities and any confidential operational information were protected in the research report. Photographs, internal technical records, and vessel documents were included only when the necessary authorization had been obtained. Approval from an institutional ethics committee was obtained where required by the applicable institutional policy. If such approval was required, the committee's name and approval number should be stated in the final manuscript.

3. RESULTS AND DISCUSSION

3.1. Research Results

The results of the study showed that the cause of the non-optimal function of the radar in MV. Kintamani rays was caused by several factors, including:

1) Non-Standard Radar Operating Process

a) Display and Distance Settings: Improper radar display settings, such as not being set to zero or inappropriate distances (e.g., not at 6 NM), may result in inaccurate information being displayed and difficult for the guard officer to interpret. This may hinder the proper identification of the target and increase the risk of navigation errors.

b) False Echo: False echo interference caused by repeated signal reflections or the influence of side lobes can create shadows of objects that do not correspond to reality. This can confuse the guard officer and make it difficult for them to make the right decisions regarding the navigation of the ship.

c) Radar Performance Test: Failure to perform and record radar performance tests periodically indicates a lack of attention to radar maintenance and condition evaluation. In fact, these performance tests are essential to ensure the radar is functioning properly and providing accurate information.

2) Ineffective Radar Maintenance Process

a) Unperformed Maintenance Lists: Maintenance lists that are only recorded without actually being carried out indicate a lack of commitment to radar maintenance. As a result, the radar does not function optimally and can even fail to detect important targets, such as wooden ships or fishing boats, potentially jeopardizing shipping safety.

b) Interference with Radar and Scanner Components: Interference with radar and scanner components due to electrical instability of a ship may cause damage to the radar and interfere with its function. This can occur due to an unexpected voltage surge or blackout.

c) Problems with Video Cable Connections and BP Boards: Problems with video cable connections and BP boards can cause inadequate radar signals and slow target identification. This can hinder guard officers from making quick and informed decisions, especially in emergency situations.

Radar data obtained during the study is as follows [4] :

Table 1 Data Radar MV. Sinar Kintamani

Maker : JRC
Type Radar S-Band : JMA-9933-SA
Serial No : LW 55345
Type Radar X-Band : JMA-9923-9XA
Serial No : LW 55346
Scanner Unit
Radiator : 12ft
Rotational speed : 26rpm (60Hz) and 21rpm (50Hz)
Transmitter Receiver Unit
Transmitting Frequency : 3050 ± 10Mhz
Receiver : MIC + LOG amplifier
Intermediate frequency : 60MHz
Band width : 20/6/3 Mhz
Display Unit
LCD : 23.1 inches LCD (Effective diameter more than 340mm)
Range scales : 0.125/0.025, 0.25/0.05, 0.5/0.1, 0.75/0.25, 1.5/0.25, 3/0.5, 6/1, 12/2, 24/4, 48/8, 96/16 or 120/20nm
VRM : 0-96nm (or 120nm)
Azimuth mode : Head Up/North Up/Course Up
Pre-heating Time : Within 30 s

3.2. Discussion

Radar is an electronic system used to detect and determine the position of a ship by emitting electromagnetic waves and analyzing its reflections. Radar is essential in navigation, especially in congested waters or when entering a port.

There are several radar display modes, including:

a. Head-Up: The direction of the ship's bow always points to the top of the screen.
b. Course-Up: The direction of the initial ship's bow remains above the sail, even if the ship is turning.
c. The "Head Up" mode is very beneficial for the captain to identify potential hazards.

The minimum range is the smallest distance at which a radar can accurately detect a target. Proper settings (pulse length, distance scale, gain control, and sea clutter control) are important for close-range target detection. Radar can also be used to monitor weather, such as potential rain.

The case in MV. Kintamani rays demonstrate the importance of radar in navigation. As of November 15, 2023, objects were not detected on the radar screen because the radar scanner magnetron was already over the limit. A magnetron is a device that converts electrical energy into microwaves. A false echo is a condition in which one physical target is detected as multiple targets. This can be caused by multiple echo or side lobe echo. Data from the JRC Radar Instruction Manual shows that the warranty period is one year, but the optimal time of the magnetron is about 4,000 hours of use.

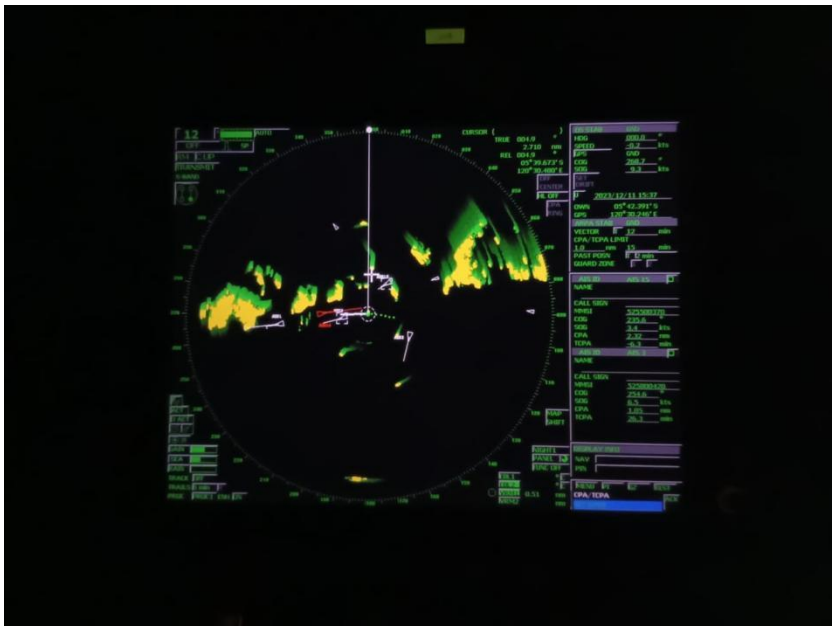


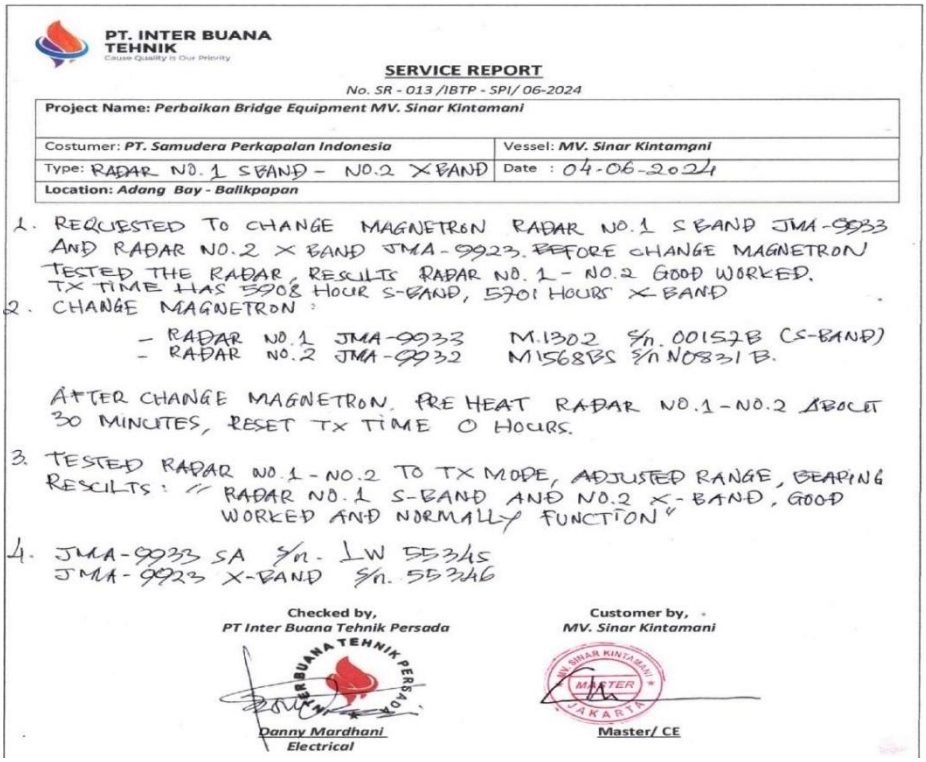
Figure 1 False Echo on MV Radar. Sinar Kintamani

Radar logs are used to record and monitor the position of ships. The information recorded includes dates and times, ship positions, weather and sea conditions, radar observations, and actions taken. Radar manuals are essential for ship officers to carry out maintenance and repair of radar systems.

The research was conducted by observation and interview methods. Interviews were conducted with Masters, Chief Officers, and Second Officers at MV. Sinar Kintamani. The results of the interviews showed that the use of radar was important for shipping safety. Officers must understand and master the use of radar. Regular maintenance is important to maintain radar performance. Radar features, such as Fast Time Constant (FTC), can be helpful in bad weather conditions so they must be used optimally The frequency of radar operation affects image quality and detection ability.

The suboptimal use of X-band and S-band radars is due to several factors that affect radar performance, such as human error, ship and environmental conditions, and problems with radar engines. The importance of radar navigation equipment maintenance, including routine checks, performance tests, magnetron replacement, and repair of damaged components.

Effective radar maintenance is important to keep the radar functioning properly. Given the condition of an old ship, if maintenance is carried out infrequently, the radar will quickly be damaged. For radar checks, we can refer to the Radar Manual Book, which helps in identifying problems with the radar. If there is an electrical problem, we can contact an electrician, and if we are unable to solve it, then we can report the damage to the company. This also happens when the writer carries out practical activities, the radar at MV.Sinar Kintamani has been replaced by the magnetron by PT. Inter Buana Tehnik (Marine Navigation & Communications).



PT. INTER BUANA TEHNIK
Cause Quality is Our Priority

SERVICE REPORT

No. SR - 013 /IBTP - SPI/ 06-2024

Project Name: *Perbaikan Bridge Equipment MV. Sinar Kintamani*

Costumer: *PT. Samudera Perkapalan Indonesia*	Vessel: *MV. Sinar Kintamani*
Type: RADAR NO. 1 S BAND - NO.2 X BAND	Date : 04-06-2024
Location: *Adang Bay - Balikpapan*	

1. REQUESTED TO CHANGE MAGNETRON RADAR NO.1 S BAND JMA-9933 AND RADAR NO.2 X BAND JMA-9923. BEFORE CHANGE MAGNETRON TESTED THE RADAR, RESULTS RADAR NO. 1 - NO.2 GOOD WORKED. TX TIME HAS 5908 HOUR S-BAND, 5701 HOURS X-BAND
2. CHANGE MAGNETRON :
   - RADAR NO.1 JMA-9933 M.1302 S/n. 001578 (S-BAND)
   - RADAR NO.2 JMA-9932 M1568BS S/n N0831B.

   AFTER CHANGE MAGNETRON. PRE HEAT RADAR NO.1-NO.2 ABOUT 30 MINUTES, RESET TX TIME 0 HOURS.
3. TESTED RADAR NO.1 - NO.2 TO TX MODE, ADJUSTED RANGE, BEARING RESULTS : // RADAR NO.1 S-BAND AND NO.2 X-BAND, GOOD WORKED AND NORMALLY FUNCTION
4. JMA-9933 SA S/n. LW 553145
   JMA-9923 X-BAND S/n. 553146

Checked by,
PT Inter Buana Tehnik Persada
Danny Mardhani
Electrical

Customer by,
MV. Sinar Kintamani
Master/ CE

Figure 2 Radar Service Report on MV Radar. Sinar Kintamani

Other forms of maintenance include replacing damaged cables, which if left unattended can cause a short circuit. Be sure to reseal the radar scanner box tightly after maintenance. If the box is not properly sealed, there is a chance that water could enter the scanner, which can cause a short circuit and interfere with the radar display. Once everything is installed, the radar is turned on again to test its ability to capture signals that appear on the radar screen.

4. CONCLUSION AND RECOMMENDATIONS

This study concludes that the radar system on board MV. Sinar Kintamani did not function optimally due to the magnetron scanner exceeding its recommended service life, which contributed to false echoes and potentially increased navigational risks. These findings highlight the importance of maintaining radar reliability and ensuring that the crew understands both the capabilities and limitations of radar equipment. Effective radar operation is essential for supporting situational awareness and making appropriate navigational decisions, particularly when navigating narrow channels where accurate target detection is critical.

To improve navigational safety, regular radar maintenance and periodic inspections should be conducted in accordance with the manufacturer's recommendations, and the magnetron scanner should be replaced when necessary. The crew should also receive appropriate training, study the Radar Manual Book, and become familiar with the functions and controls of both X-band and S-band radar systems. Radar observations should be cross-checked with other available navigational aids and visual lookout rather than relied upon as the sole basis for decision-making. This study is limited to observations and findings from a single vessel, MV. Sinar Kintamani, during the sea training period; therefore, the results

may not be generalizable to other vessels or radar systems. Future research should examine radar performance across different vessels and operating conditions, including the relationship between equipment maintenance, false echoes, crew competence, and navigational safety outcomes.

DECLARATIONS

Author contributions: All authors contributed to the preparation of this manuscript. All authors have read and approved the final manuscript.

Conflict of interest: The authors declare no conflict of interest. If any author is a member of the Jurnal Venus editorial board or reviewer team, state it here; the manuscript is then handled by another editor, and the author is excluded from all editorial decisions on it.

AI usage statement: During the preparation of this manuscript, the authors used tool name and version for purpose, e.g., language editing. The authors reviewed and edited the output and take full responsibility for the content. Generative AI was not used to produce data, analyses, findings, or references. If no AI tool was used: "The authors did not use generative AI tools in preparing this manuscript."

Ethical approval: Not applicable.

Funding: This research received no external funding.

Data availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: The authors would like to express their gratitude to all individuals and institutions who supported this research. (Include this statement only if applicable and with the consent of those acknowledged.)

REFERENCES

Anderson, E. W. (2016). Marine radar and collision avoidance. Journal of Navigation, 69(2), 389–405.

Barton, D. K. (2016). Radar system analysis and modeling. Boston, MA: Artech House.

Basuki, B., Imron, C., & Krisdiono, E. (2021). Preventive maintenance analysis on the Kelvin Hughes MKVII X-band navigation radar in warship Type-Z. JOURNAL ASRO, 12(4). https://jurnalmtasro.sttal.ac.id/index.php/ASRO/article/view/425

Bayer, D., Aydın, O., & Celik, M. (2021). An ICOR approach towards ship maintenance software development. International Journal of Maritime Engineering. https://doi.org/10.5750/ijme.v160iA1.1044

Bichou, K., & Gray, R. (2020). Maritime Logistics: A Complete Guide to Effective Shipping and Port Management (2nd Ed.). Kogan Page.

Bole, A. G., Dineley, W. O., & Wall, A. (2013). Radar And ARPA Manual: Radar, AIS And Target Tracking for Marine Radar Users (3rd Ed.). Butterworth-Heinemann.

Ding, S., Wang, M., Dong, Z., Zhou, X., & Nie, L. (2021). Multi-agent-based RMS assessment method for shipboard radar. Chinese Journal of Ship Research, 16(6), 52–60. https://doi.org/10.19693/j.issn.1673-3185.02333

Endsley, M. R. (2018). Situation awareness in navigation systems. Human Factors, 60(4), 451–465.

Hollnagel, E. (2019). Human-machine interfaces in maritime navigation. Safety Science, 119, 285–293.

International Maritime Organization (IMO). (2020). Safety of navigation and collision avoidance. London: IMO Publishing.

International Maritime Organization. (2017). Radar navigation at operational level: Radar navigation, radar plotting and use of ARPA (Model Course 1.07). IMO. https://doi.org/10.62454/KTB107E

International Maritime Organization. (2023). Performance standards for shipborne radiocommunications and navigational equipment and systems (2023 ed.). IMO. https://doi.org/10.62454/KG978E

Iryani, I. (2023). Optimizing the Use of Radar Navigation Tools in Shipping Safety in MT. GEDE (Doctoral Dissertation, Makassar Shipping Science Polytechnic).

Japan Radar Co. Ltd. (2017). Instructional Manual Book: JMA-610 River Radar Equipment. Japan Radar Co. Ltd

Lee, Y. H. (2019). Performance of S-band radar in heavy rain conditions. Ocean Engineering, 187, 106168.

Leong, M., Tan, C. K., & Koh, Y. H. (2016). High resolution radar for maritime surveillance. IEEE Transactions on Aerospace and Electronic Systems, 52(3), 1205–1216.

Malatunduh, I. K. N., Widarbowo, D., Kendek, M., Muhammad, F., Gumelar, F., & Sumarta, R. P. (2024). Optimalisasi penggunaan Radio Detection and Ranging (RADAR) untuk keselamatan dalam bernavigasi pada alur pelayaran sempit di KMP Virgo 18. Jurnal Patria Bahari, 4(1). https://doi.org/10.54017/jpb.v4i1.121

Maresca, S., Campobello, G., & Serrano, S. (2020). Radar Systems: Technologies And Applications. Journal Of Sensor and Actuator Networks, 9(4), 48. 122-132.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). Qualitative data analysis: A methods sourcebook (3rd ed.). SAGE Publications.

Muhammad Indramawan Fajrin, M. I. F. (2023). Analysis of Radar Navigation Operation to Prevent Collisions at Sea on MV NEW DEDICATION (Doctoral Dissertation, Makassar Shipping Science Polytechnic).

Nida, H. E., Sulistiana, O., & Pongkessu, A. (2026). Analisis gangguan performa radar saat bernavigasi di perairan Bunati. Didaktik: Jurnal Ilmiah PGSD STKIP Subang, 12(3). https://doi.org/10.36989/didaktik.v12i03.17897

Ölçer, A., & Ballini, U. (2015). The development of a sustainable maritime transportation system: Present and future challenges. Maritime Policy & Management, 42(5), 377–404.

Psaraftis, H. N. (2019). Green maritime logistics: The quest for win-win solutions. Cham: Springer.

Safriyuani, R. N., Allolayuk, A., & Lande, C. R. (2026). Analisis perawatan radar guna meningkatkan kelaiklautan teknis di KM. Sabuk Nusantara 37. Didaktik: Jurnal Ilmiah PGSD STKIP Subang, 12(3). https://doi.org/10.36989/didaktik.v12i03.18061

Skolnik, M. I. (2017). Radar systems: Pulse vs CW applications. New York: McGraw-Hill.

Sofyan, A. H. S., Djamaan, A., & Lestari, E. (2025). Optimalisasi penggunaan radar untuk menunjang keselamatan dalam bernavigasi di PSV S. Panglima. Jurnal Karya Ilmiah Taruna Andromeda, 9(1). https://doi.org/10.48192/ard.v9i1.763

Stimson, G. W. (2014). Introduction to airborne radar systems (3rd ed.). Raleigh, NC: SciTech Publishing.

Sudiyono. (2011). Fundamentals of Educational Research: Process and Product. Rajawali Press.

Uflaz, E., Akyuz, E., Arslan, O., Gardoni, P., Turan, O., & Aydin, M. (2023). Analysing human error contribution to ship collision risk in congested waters under the evidential reasoning SPAR-H extended fault tree analysis. Ocean Engineering, 287, Article 115758. https://doi.org/10.1016/j.oceaneng.2023.115758

Zhang, Y. X. (2015). Maritime Target Detection Using High-Resolution Radar Imaging. Journal Of Marine Science and Technology. 23(4), 345-352.