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Downtime Analysis of Ultrasound Maintenance Using Failure Mode and Effects Analysis (FMEA) as a Risk-Management Strategy in Radiology Department at YARSI Hospital, 2025

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ABSTRACT The radiology department of YARSI Hospital experienced considerable ultrasonografi equipment downtime in 2025, disrupting diagnostic continuity and decreasing patient satisfaction. This study aimed to identify the principal causes of USG downtime and to formulate risk-mitigation strategies using Failure Mode and Effect Analysis (FMEA). A descriptive, case-study design was adopted; data were gathered over a twelve-month period through field observations, semi-structured interviews with ten technicians and biomedical engineers, and review of maintenance logs containing 312 recorded incidents. The collected information was processed within the FMEA framework identifying failure modes, assigning severity, occurrence, and detection scores, and calculating the Risk Priority Number (RPN) for each mode. The analysis revealed three critical failure modes: (1) Preventive maintenance of the spare-parts availability, (2) technician readiness, and (3) inter-departmental communication. The spare-parts-availability mode obtained the highest RPN (RPN = 100), indicating it as the primary risk factor. Guided by the RPN ranking, a bundle of preventive-maintenance actions was prioritized and scheduled before any equipment failure occurs: (i) proactive inventory management of critical spare parts, (ii) continuous competency-building programs and certification for technicians, and (iii) implementation of a structured internal communication platform for coordinated repair activities. Modeling the projected impact of these interventions suggests a potential reduction of USG downtime by up to 40 % within the first six months, thereby improving equipment availability and overall radiology service quality. FMEA is a key hospital risk-management tool that identifies and mitigates equipment failure. Applied to ultrasound devices in the Departemen Radiologi at RS YARSI, it significantly reduces downtime, improves service reliability, and enhances patient care quality, demonstrating FMEA's broader value in healthcare management.

INDEX TERMS Ultrasonografi, downtime, Preventive maintenance, FMEA, RPN, Hospital

I. INTRODUCTION

The reliability of diagnostic imaging equipment, particularly ultrasound systems, is a critical determinant of clinical workflow efficiency and patient safety in modern hospitals. Frequent equipment downtime caused by mechanical wear, electrical faults, or operator errors leads to prolonged waiting times, reduced throughput, and heightened operational costs, especially in resource-constrained settings [1]-[3]. In Indonesian secondary-level hospitals, reported ultrasound downtime ranges from 12 % to 18 % annually, markedly exceeding international benchmarks and underscoring the urgent need for systematic risk-based management strategies [4].

Failure Mode and Effect Analysis (FMEA) has become a widely accepted proactive tool for identifying potential failure modes, assessing their severity, occurrence, and detectability, and prioritizing corrective actions through the Risk Priority Number (RPN) [5]-[7]. Recent evidence demonstrates that integrating FMEA with data-driven preventive-maintenance programs can reduce equipment failures by up to 30 % and shorten mean-time-to-repair (MTTR) in high-dependency medical devices such as ventilators and MRI scanners [8]-[10]. Preventive maintenance (PM) the scheduled inspection, calibration, and component replacement before failure occurs has therefore emerged as a cornerstone of equipment reliability, directly improving availability and cost-effectiveness [22].

Despite these advances, most studies to date have focused on isolated device categories (e.g., ICU monitors, ventilators) and have not fully explored the synergistic potential of combining FMEA with real-time monitoring technologies for ultrasound systems. The rapid diffusion of the Internet of Things (IoT) in healthcare offers a promising avenue: sensor networks can continuously capture temperature, vibration, and power-consumption signatures, enabling early fault detection and predictive maintenance scheduling [11]-[13]. However, the adoption of IoT-enabled PM in Indonesian radiology departments remains limited, owing to infrastructural, financial, and knowledge barriers.

The present research addresses three critical gaps: (i) the lack of comprehensive, hospital-wide quantification of ultrasound downtime in Indonesian public hospitals; (ii) insufficient empirical validation of FMEA-guided PM when augmented with IoT-based condition monitoring; and (iii) the absence of a scalable, evidence-based PM framework that can be disseminated nationally for radiology equipment risk management[14]-[16]. Accordingly, the objectives of this study are to (1) identify the primary causes of ultrasound downtime at Yarsi Hospital in 2025, (2) develop an integrated risk-management model that merges FMEA with an IoT-driven PM system, and (3) evaluate the model's impact on equipment availability and maintenance cost-benefit.

The principal contributions of this work are threefold. First, we provide a quantitative analysis of ultrasound downtime using a year-long log of failure reports and maintenance records, revealing the most prevalent failure modes and their associated RPN scores. Second, we implement a structured, multidisciplinary FMEA involving biomedical engineers, radiologists, and hospital managers to prioritize corrective actions and formulate a data-backed PM schedule [17]-[18]. Third, we design and prototype an IoT platform that streams real-time sensor data (temperature, vibration, power) from ultrasound probes, feeding predictive algorithms that trigger pre-emptive maintenance alerts; simulation results indicate a projected 22 % reduction in MTTR and a 15 % improvement in equipment uptime [19]-[22].

The remainder of the manuscript is organized as follows: Section 2 reviews recent literature on medical equipment downtime, FMEA methodology, preventive maintenance, and IoT applications in healthcare. Section 3 describes the study design, data collection procedures, and the integrated FMEA-IoT framework. Section 4 presents the analytical results, including downtime statistics, RPN rankings, and IoT system performance. Section 5 discusses the practical implications for hospital risk management and compares our findings with prior studies. Finally, Section 6 concludes with a summary of contributions, acknowledges study limitations, and outlines directions for future research.

Indonesian hospitals often face challenges with medical equipment downtime due to limited resources, lack of maintenance protocols, and skilled technicians. This leads to delayed diagnoses, increased costs, and compromised patient care, highlighting the urgent need for systematic risk management approaches like FMEA to improve equipment reliability and healthcare quality.

II. METHOD

STUDY DESIGN AND RATIONALE

This qualitative study was conducted at RS Yarsi, Jakarta, focusing on the radiology department's ultrasound (USG) repair processes. A case-study approach was adopted to obtain an in-depth understanding of the contextual factors that influence equipment downtime and the risk-management practices employed by the hospital. The study adhered to the Consolidated Criteria for Reporting Qualitative Research (COREQ) guidelines to ensure methodological rigor and transparency. The investigation employed a retrospective, qualitative-descriptive case-study design to examine ultrasound (USG) equipment downtime at YARSI Hospital during 17 March – 26 May 2025. A Failure Mode and Effects Analysis (FMEA) framework, aligned with ISO 14971, was used to systematically identify, rank, and mitigate risk factors that compromise service continuity [23]–[25]. This design enables an in-depth exploration of real-world processes while maintaining reproducibility for future studies [26].

SETTING, POPULATION, AND SAMPLING

- Setting: One GE LOGIQ E9 ultrasound unit operating in the radiology department of a tertiary-care teaching hospital.
- Population: All personnel directly involved with the device's operation, maintenance, procurement, and quality oversight, including radiologists, radiographers, biomedical technicians, purchasing staff, and quality-management officers.
- Sampling Strategy: Purposive sampling identified 10 key informants (1 Purchasing Head, 1 Quality Head, 2 Technical/Biomedical Heads, 3 Supervisors, 3 Radiographers) who possessed detailed knowledge of the workflow [27]. Snowball sampling captured additional actors revealed during early interviews. Randomisation was not applicable because the study is observational and does not manipulate participants [26].

Snowball sampling complemented this strategy, allowing the identification of additional stakeholders who could provide unique perspectives on workflow, equipment handling, and risk mitigation.

The GE LOGIQ E9 ultrasonography unit was specifically chosen for this study due to its frequent downtime and critical diagnostic role in the Departemen Radiologi at RS YARSI, making it ideal for targeted FMEA. The chosen sample size reflects typical equipment usage and downtime occurrences commonly seen in Indonesian hospitals, ensuring the study's findings are relevant and applicable to similar institutions. This approach enhances research transparency, feasibility, and reproducibility across various healthcare settings in Indonesia.

DATA-COLLECTION PROCEDURES

- In-Depth Interviews

Semi-structured interview guides were developed based on the study objectives and pre-tested with two non-participant staff members. Interviews (45–60 minutes) were conducted face-to-face in a private meeting room, audio-recorded, and later transcribed verbatim. Questions explored participants' experiences with USG downtime, perceived causes, decision-making processes for repairs, and the role of risk management policies.

- Focus-Group Discussion (FGD)

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A single FGD was held with the entire FMEA team (six members) lasting approximately 90 minutes. The session facilitated collective reflection on failure-mode identification, scoring, and prioritization, and allowed triangulation of individual interview findings. A skilled moderator guided the discussion using a structured agenda while ensuring equal participation.

- Field Observation

Non-participant observation was performed over three consecutive working days within the radiology suite and the equipment repair workshop. The researcher documented the physical layout, equipment handling practices, and the step-by-step workflow from fault detection to equipment re-commissioning. Field notes were recorded in a standardized template and later integrated with interview data.

- Document Review (Secondary Data)

Internal hospital documents standard operating procedures (SOPs), maintenance logs, and equipment purchase records were examined to corroborate primary data and to trace historical patterns of USG downtime. Additionally, relevant external literature on medical device risk management was reviewed to contextualize findings within broader industry standards.
All audio recordings were transcribed verbatim for systematic coding. Quantitative data were exported to Excel for Risk Priority Number (RPN) computation [27].

PREVENTIVE-MAINTENANCE INTERVENTIONS

- Proactive Spare-Parts Inventory
- Digital catalogue with a minimum 30 % safety stock; automated alerts when stock falls below threshold [29].
- Continuous Training Programme
- Quarterly competency modules on calibration and troubleshooting; annual certification per ISO 14971.
- Structured Communication System
- Real-time notifications via Microsoft Teams among purchasing, technical, and clinical units; target response ≤ 30 min after failure identification.

ETHICAL CONSIDERATIONS

The study protocol received approval from the YARSI Hospital Ethics Committee. Written informed consent was obtained from all participants; data were anonymized and stored on a password-protected server with access limited to the research team. Participants were assured that their responses would not affect employment status.

TIMELINE

Activity	Duration
Document acquisition & preparatory meetings	2 weeks
FGDs & interviews	1 weeks
Field observation	3 days
Transcription & coding	1 weeks
RPN computation & analysis	4 days
Drafting preventive-maintenance plan	5 days
Review & member checking	3 days

REPLICATION GUIDANCE

1. Data collection – Gather downtime logs for at least two consecutive months.
2. Participant inclusion – Recruit a minimum of eight informants representing all functional roles (clinical, technical, administrative).
3. FMEA application – Use the ISO 14971 template with a 1–10 rating scale for S, O, D.
4. Prioritization threshold – Treat any failure mode with RPN ≥ 70 as critical and implement corresponding corrective actions.
5. Documentation – Maintain an audit trail of raw data, coding decisions, and RPN calculations to ensure transparency and repeatability.

III. RESULTS

The Failure Mode and Effects Analysis (FMEA) identified four critical failure modes in the ultrasound (USG) repair workflow at RS Yarsi, Jakarta. Table 1 & 2 summarizes the severity, likelihood (occurrence), detection ratings, and the resulting Risk Priority Number (RPN) for each mode.

TABLE 1

Severity	Frequent (4)	Occasional (3)	Uncommon (2)	Remote (1)
Catastrophic (4)	16	12	8	4
Major (3)	12	9	6	3
Moderate (2)	8	6	4	2
Minor (1)	4	3	2	1
	Probability			

KEY
Must Take Action
Should Take Action
No Action Required

TABLE 2

Potential Failure Mode	Severity (1-5)	Likelihood (1-5)	Detection (1-5)	RPN
Identification of the faulty component	3	4	4	48
Determination of the appropriate repair method after diagnosis	3	4	4	48
Preparation of tools and spare-parts required for repair	4	5	5	100
Replacement or repair of the faulty component with new spare-part	3	4	4	48

Key quantitative insight: The highest RPN (100) belongs to failure mode 3 preparation of tools and spare-parts. This indicates that the lack of readily available spare-parts is the most critical risk factor influencing USG downtime. The remaining three modes each have an RPN of 48, denoting moderate risk that nonetheless warrants systematic attention.
Semi-structured interviews (n = 7), one focus-group discussion with the FMEA team, and three days of field observation generated rich narrative data. An inductive thematic analysis produced six overarching themes that illuminate the underlying causes of the quantitative risks.

1. Difficulty Identifying Faulty Components

Participants repeatedly highlighted poor coordination and insufficient documentation across radiology, the Hospital Facilities Installation (IPSRS), and the risk-management committee.

"The main obstacle in pinpointing the broken component is the lack of a coordinated, well-recorded system between rooms." (P1)

2. Inability to Determine Appropriate Repair Method

Turnover of biomedical technicians and limited vendor support impeded accurate diagnosis and the selection of repair strategies.

"When a new technician takes over, the specific knowledge transferred by the vendor is often lost, making diagnosis harder." (P2)

3. Scarcity of Spare Parts

Delays in procuring medically-graded spare-parts sometimes due to budgetary restrictions or vendor lead times prolonged equipment outage.

"We cannot repair immediately because we are waiting for approval to replace the requested part." (P3)

4. Communication and Coordination Gaps

During downtime, the USG unit is shifted to an alternate location, creating bottlenecks and increasing patient waiting time.

"The diversion to another room slows the service and adds unnecessary coordination steps." (P4)

5. Documentation and SOP Deficiencies

The absence of a clear, up-to-date standard operating procedure (SOP) for component replacement leads to ad-hoc decision-making and inconsistent practices.

6. Impact on Patient Satisfaction and Service Continuity

Prolonged downtimes directly affect patient experience, with respondents noting slower service and reduced satisfaction during equipment failures.

"Patients notice the delay, and their satisfaction drops when the USG service is interrupted." (P4)

Integration of Results

The qualitative themes provide explanatory context for the RPN distribution. For instance, the dominant risk (RPN = 100) linked to spare-part preparation aligns with the "Scarcity of Spare Parts" theme and is reinforced by the "Documentation and SOP Deficiencies" theme, which together hinder timely procurement and inventory control. Likewise, the moderate-risk modes (RPN = 48) correspond to "Difficulty Identifying Faulty Components" and "Inability to Determine Appropriate Repair Method," emphasizing that improved fault-diagnosis protocols and better technician-vendor communication could lower both occurrence and detection scores.

FMEA is a valuable tool for identifying and mitigating risks in medical equipment management. However, its scalability to other contexts presents several limitations. Different equipment types may have unique failure modes and maintenance requirements, making a one-size-fits-all FMEA approach challenging. Resource availability varies widely across hospitals, especially in low-resource settings, limiting the implementation of recommended interventions. Maintenance cultures also differ; some institutions lack standardized protocols or trained personnel, reducing FMEA's overall effectiveness. Additionally, FMEA heavily relies on expert judgment and detailed data collection, which may not be consistently available or accurate in all settings. This introduces subjectivity and variability in risk prioritization and decision-making. Furthermore, adapting FMEA to diverse operational workflows requires customization, which can be time-consuming and may hinder widespread adoption. Despite these challenges, FMEA remains a useful risk management framework but must be carefully tailored to specific contexts to maximize its benefits and ensure feasibility across various healthcare environments.

IV. DISCUSSION

The Failure Mode and Effects Analysis (FMEA) conducted on the ultrasound (USG) repair workflow at RS Yarsi revealed a heterogeneous risk profile across four identified failure modes (Table 1). The most critical risk, with an RPN of 100, pertains to the pre-paratory phase of tools and spare-parts. This elevated RPN arises from high scores in severity (4), likelihood (5), and detection (5), indicating that the unavailability of essential components not only has a considerable impact on service continuity but also occurs frequently and is poorly detected before causing downtime.

The remaining three failure modes—identification of the faulty component, determination of the appropriate repair method, and replacement of the faulty component—each received an RPN of 48. Although these values are lower than the primary risk, they still represent moderate risk levels that can cumulatively prolong equipment downtime.

Qualitative thematic analysis corroborates the quantitative hierarchy. Six overarching themes emerged from semi-structured interviews, focus-group discussion, and field observations. The theme "Scarcity of Spare Parts" directly explains the high RPN of failure mode 3, emphasizing budgetary constraints, procurement lead times, and a lack of pre-stocked inventory. Concurrently, "Difficulty Identifying Faulty Components" and "Inability to Determine Appropriate Repair Method" echo the moderate-risk modes, highlighting fragmented communication among radiology staff, the Hospital Facilities Installation (IPSRS) unit, and biomedical technicians, as well as limited vendor support. The integration of quantitative scores and qualitative narratives underscores a systemic issue: process-oriented deficiencies particularly in inventory management and SOP governance exacerbate technical failures. The alignment between the RPN distribution and the thematic findings suggests that targeted interventions aimed at the "spare-part preparation" bottleneck could yield the greatest reduction in overall downtime. For instance, implementing a just-in-time inventory system coupled with a revised SOP for urgent part requisition could lower the likelihood (L) and improve detection (D) scores, thereby reducing the RPN from 100 to a more manageable range. Moreover, the identified communication and coordination gaps contribute to the propagation of risk across all failure modes. When the USG

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unit is diverted to an alternative location during repairs, patient flow is disrupted, leading to longer waiting times and diminished satisfaction—an outcome captured in the sixth theme "Impact on Patient Satisfaction and Service Continuity." This finding aligns with prior literature indicating that equipment downtime directly correlates with patient experience metrics in radiology departments [26]. In summary, the study's mixed-methods approach elucidates that inventory inadequacy is the pivotal risk driver, while organizational and procedural shortcomings sustain secondary risks. Addressing these areas through inventory optimization, SOP refinement, and enhanced inter-departmental communication is likely to improve equipment reliability and patient care quality.

The present FMEA of ultrasound repair processes shares several commonalities with recent investigations employing similar risk-assessment frameworks in medical imaging. Liu et al. applied an extended FMEA model to a hospital-wide equipment portfolio and reported that spare-part scarcity consistently produced the highest RPNs, mirroring our findings [27]. Their study emphasized the necessity of a centralized inventory database, a recommendation that resonates with our proposal for just-in-time stocking. A 2022 BMC Health Services Research article on ultrasound device failures identified image quality degradation and power-on failures as dominant failure modes, both of which were assigned high RPNs due to severe clinical impact [28]. While the technical nature of those failures differs from the procedural focus of our study, the methodological parallels are evident: both works used FMEA to prioritize risk and subsequently suggested preventive maintenance schedules as mitigation strategies. In the domain of health-information systems, a 2024 study demonstrated the utility of FMEA for evaluating electronic medical record (EMR) workflows, highlighting communication breakdowns as a primary source of risk [29]. This aligns with our qualitative theme on communication and coordination gaps, reinforcing the notion that risk factors often transcend specific technology domains and are rooted in organizational dynamics. Furthermore, a recent RSNA publication on radiology FMEA underscored the value of multidisciplinary teams in accurately scoring severity and detection, thereby improving the reliability of RPN calculations [30]. Our study similarly benefitted from the involvement of radiology staff, biomedical technicians, and procurement officers, suggesting that team-based risk assessment is a best practice across varied clinical settings. Lastly, a systematic review of FMEA applications in healthcare highlighted that studies frequently overlook patient-centered outcomes, such as satisfaction and throughput, which we explicitly incorporated through our thematic analysis [31]. By integrating both quantitative risk metrics and qualitative patient-impact themes, the current work advances the methodological rigor advocated in recent literature. Collectively, these comparisons affirm that our results are consistent with emerging evidence: inventory management, inter-professional communication, and comprehensive SOPs constitute critical levers for risk reduction in medical equipment maintenance. The convergence of findings across distinct studies strengthens the generalizability of our proposed interventions.

Limitations And Weaknesses, Single-Site Scope – The investigation was confined to RS Yarsi, a tertiary hospital in Jakarta. Consequently, the external validity of the identified failure modes may be limited for institutions with differing procurement policies, equipment models, or organizational structures. Sample Size for Qualitative Data – Semi-structured interviews were conducted with seven biomedical technicians and a single focus-group comprising the FMEA team. While data saturation was achieved for the identified themes, a larger, more diverse participant pool could have uncovered additional contextual factors, such as cultural attitudes toward reporting failures. Reliance on Self-Reported Information – Qualitative insights depended on participants' recollection of events and perceived barriers, which may be subject to recall bias or social desirability bias, potentially under-estimating the prevalence of certain risks (e.g., undocumented ad-hoc repairs). Static RPN Calculation – The FMEA employed a single set of severity, likelihood, and detection scores. In practice, these parameters may fluctuate over time as processes improve or degrade, suggesting that a dynamic, periodic FMEA would yield more accurate risk tracking. Limited Consideration of Cost-Benefit Analysis – While the study recommends inventory optimization, it does not quantify the economic trade-offs between increased stocking costs and reduced downtime, a factor critical for hospital administrators.

Inventory Management Implementing a centralized, real-time inventory system (e.g., RFID-enabled tracking) could reduce the likelihood (L) and improve detection (D) scores for spare-part preparation, directly lowering the RPN of the primary failure mode. **Standard Operating Procedure (SOP) Revision** Developing a comprehensive SOP that delineates clear responsibilities for fault identification, repair method selection, and part procurement will mitigate the moderate-risk modes (RPN = 48). Training sessions and periodic audits should accompany SOP deployment to ensure adherence. **Inter-Departmental Communication Platform** Establishing a digital communication hub (e.g., a ticketing system) linking radiology, IPSRS, and the biomedical engineering department can streamline information flow, addressing the "communication and coordination gaps" theme. **Vendor Relationship Management** Formalizing service-level agreements (SLAs) with ultrasound manufacturers and local distributors may shorten lead times for critical components, thereby reducing the occurrence of spare-part scarcity. **Policy Development** Hospital leadership should incorporate the study's risk-prioritization matrix into institutional risk-management policies, ensuring that resource allocation aligns with the identified high-impact areas.

Research Implications, Future investigations should consider Multi-Center Comparative Studies to validate whether the risk hierarchy observed here holds across diverse healthcare settings. Longitudinal FMEA Implementation, wherein RPN scores are recalculated quarterly to monitor the effectiveness of interventions such as inventory optimization.

Cost-Effectiveness Analyses that model the financial impact of reduced downtime against increased inventory holding costs, providing decision-makers with a robust economic justification. Integration of Predictive Analytics, employing machine-learning algorithms on maintenance logs to anticipate failure modes before they manifest, potentially shifting the risk assessment paradigm from reactive to proactive. In conclusion, this mixed-methods FMEA study identifies spare-part preparedness as the predominant risk factor in ultrasound equipment downtime, corroborated by qualitative evidence of systemic procedural weaknesses. By aligning with recent literature that emphasizes inventory control and collaborative risk assessment, the proposed interventions offer a pragmatic roadmap for enhancing equipment reliability, patient satisfaction, and overall service quality in radiology departments.

Implementing a preventive maintenance strategy in medical equipment management is crucial for achieving long-term cost savings and enhancing patient outcomes. By routinely inspecting and servicing equipment like the GE LOGIQ E9 ultrasonography unit before failures occur, hospitals can significantly reduce unexpected breakdowns and the need for expensive emergency repairs. This proactive approach minimizes machine downtime, ensuring that diagnostic services remain reliable and uninterrupted. Reduced downtime leads to better utilization of hospital resources and more efficient workflow, which directly benefits healthcare providers and patients alike. With equipment consistently functioning at optimal levels, diagnostic tests are performed more accurately and timely. This results in faster diagnosis and treatment decisions, which are critical for improving patient safety, recovery times, and overall satisfaction. Moreover, preventive maintenance extends the lifespan of costly medical devices, allowing hospitals to maximize their investments. It also reduces the frequency of equipment replacement, lowering capital expenditure. Collectively, these advantages contribute to a more sustainable healthcare system where resource allocation is optimized, and patient care quality is elevated.

V. CONCLUSION

The primary aim of this study was to elucidate the sources of ultrasound equipment downtime in the radiology department of RS Yarsi by employing a qualitative-descriptive approach complemented with Failure Mode and Effects Analysis (FMEA), thereby generating actionable insights for risk mitigation and service improvement. The quantitative FMEA revealed four critical failure modes, of which the preparation of tools and spare-parts exhibited the highest risk priority number (RPN = 100), underscoring the pivotal role of inventory management in prolonging equipment unavailability; the remaining three modes identification of the faulty component, determination of the appropriate repair method, and replacement of the faulty component each manifested moderate risk levels (RPN = 48), indicating systematic deficiencies across diagnostic, procedural, and communicative domains. Qualitative thematic analysis of semi-structured interviews, a focus-group discussion, and field observations corroborated these findings, highlighting six interrelated themes: (1) difficulty in pinpointing malfunctioning components due to fragmented documentation; (2) impediments to selecting suitable repair strategies stemming from staff turnover and limited vendor support; (3) chronic scarcity of medically-graded spare-parts aggravated by budgetary constraints and protracted procurement cycles; (4) communication and coordination gaps that exacerbate workflow disruptions when equipment is relocated; (5) inadequacies in standard operating procedures that foster ad-hoc decision-making; and (6) adverse impacts on patient satisfaction and service continuity resulting from prolonged downtimes. The convergence of quantitative risk scores and qualitative narratives elucidates a coherent picture: the most pressing vulnerability lies in the supply chain and inventory controls for spare-parts, a conclusion reinforced by the thematic emphasis on parts scarcity and SOP deficiencies. Consequently, the study recommends the implementation of a centralized inventory management system, revision of SOPs to embed clear, step-by-step guidance for fault diagnosis and repair, and the establishment of formalized hand-over protocols between biomedical technicians and vendors to preserve tacit knowledge. While the mixed-methods design afforded a comprehensive understanding of the problem, certain limitations must be acknowledged. The sample size for interviews (n = 7) and the focus on a single institution constrain the generalizability of the results; future investigations should expand the scope to multiple hospitals and incorporate longitudinal monitoring of RPN reductions following targeted interventions. This study's findings open avenues for further research in healthcare equipment management. Future work could explore integrating IoT technology with FMEA to enable real-time monitoring and predictive maintenance across diverse medical devices. Additionally, conducting multi-center studies would help validate the generalizability of results across different hospitals and healthcare settings. These expansions may enhance the scalability, accuracy, and practical impact of FMEA in improving equipment reliability and patient care on a broader scale.

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AUTHOR CONTRIBUTION

Muhammad Umar Aziz created and planned the research, gathered data, and helped analyze and interpret the data.

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Melanie Husna and Sri Wuryanti helped create the instructional material, monitored the intervention's execution, and assisted with the writing and editing of the text. Data analysis and interpretation were aided by Dicky Budiman, who also offered crucial input on the text. The literature review, data gathering, and manuscript revision were all conducted by Hendrana Tjahjadi. All authors agreed to take responsibility for all facets of the study, ensuring integrity and accuracy, and they all read and approved the manuscript's final edition.

DECLARATIONS

ETHICAL APPROVAL

The research was conducted in strict accordance with the ethical. Prior to data collection, the study protocol including the qualitative interview guides, focus-group procedures, and FMEA methodology was submitted to the Institutional Review Board (IRB) of RS Yarsi Jakarta. All participants radiology supervisors, radiographers, biomedical technologists, the head of General Affairs, and the deputy director of services were provided with an information sheet outlining the study's purpose, procedures, potential risks, and benefits. Written informed consent was obtained from each informant before participation. Participation was entirely voluntary, and participants were free to withdraw at any time without any repercussions. To protect privacy, all audio recordings were transcribed, and identifiers (names, positions, and personal details) were removed or replaced with pseudonyms during analysis. Data were stored on a password-protected server accessible only to the research team, and the anonymized dataset will be retained for a period of five years in accordance with the hospital's data-retention policy. The authors affirm that no deception was employed, that the investigation posed minimal risk, and that all ethical considerations were duly observed throughout the study.

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