A Systematic Review of Maintenance Management in Public Healthcare Facilities: Challenges and Implications for Sabah, Malaysia

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ABSTRACT

Background: Effective maintenance management implementation are critical for ensuring patient safety, equipment availability, and operational efficiency in public hospitals. Despite growing recognition of their importance, significant gaps persist in standardized practices, particularly in resource-constrained settings.

Aim: This systematic review examines contemporary the challenges and implication of maintenance management practices in hospital settings globally, with specific focus on identifying evidence-based strategies applicable to Sabah's public hospitals. The study synthesizes empirical evidence from 2020-2026 to inform maintenance technicians and Facilities and Engineering Management Services (FEMS) heads.

Methods: A comprehensive literature search across multiple databases identified 893 papers published between 2020-2026. Following systematic screening using the PRISMA 2020 framework and quality appraisal with the Critical Appraisal Skills Programme (CASP) checklists, 30 highly relevant studies were analyzed using descriptive synthesis. Inter-reviewer reliability was established through Cohen's kappa coefficient ($\kappa = 0.84$). Key dimensions examined included maintenance strategies, risk assessment frameworks, implementation challenges, competency requirements, and digital transformation initiatives.

Results: The review identified five fundamental maintenance strategies: preventive (time- based), corrective, predictive (condition-based), reliability-centred maintenance (RCM), and risk-based maintenance. Criticality-based RCM and modified Failure Mode and Effects Analysis versions, such as Hi-FMEA, enhanced resource allocation and patient safety. Major concerns were fragmented record-keeping (67% of studies), human resource limitations (73%), insufficient standardization (61%), and restricted digital infrastructure (54%). The effective implementation of computerized maintenance management systems (CMMS), distributed maintenance frameworks, and organized competency development initiatives enhanced equipment availability (15-35%) and reduced failure rates (20-40%).

Conclusion: Evidence-based maintenance management necessitates risk prioritization frameworks, digital transformation, and systematic competency development. Recommendations for Sabah's public hospitals include the adoption of criticality-based RCM methodologies, the implementation of CMMS, the establishment of decentralized maintenance units, and the development of specialized training programs aligned with Ministry of Health Malaysia policies. Future research should investigate context-specific implementation and longitudinal maintenance outcomes within Malaysian public healthcare.

Keywords: Hospital maintenance management, reliability-centered maintenance, risk-based maintenance, healthcare facilities, maintenance technicians, patient safety,

INTRODUCTION

Healthcare facilities worldwide face mounting pressure to maintain complex medical equipment portfolios while ensuring patient safety, optimizing operational efficiency, and managing constrained resources. Hospital maintenance management has evolved from reactive repair approaches to sophisticated, risk-based frameworks that integrate reliability engineering, patient safety considerations, and digital technologies. The maintenance function in hospitals extends beyond equipment upkeep to encompass critical patient safety dimensions, regulatory compliance, and healthcare service continuity.

In Malaysia, public hospitals serve as the backbone of healthcare delivery, providing essential services to diverse populations across geographically dispersed regions. The Ministry of Health Malaysia (KKM) oversees 145 public hospitals and over 1,000 health clinics, with medical equipment assets valued at approximately RM 5 billion (Ministry of Health Malaysia, 2021). The Medical Device Act 2012 (Act 737) and associated regulations mandate stringent maintenance and safety requirements for all medical devices in healthcare facilities.

Sabah, Malaysia's second-largest state, operates multiple public hospitals that face unique challenges including geographical isolation, resource constraints, and workforce distribution issues. The maintenance of medical equipment and healthcare facilities in these settings directly impacts patient outcomes, healthcare accessibility, and operational sustainability. Understanding evidence-based maintenance strategies is therefore crucial for informing policy and practice in this context.

LITERATURE REVIEW

Evolution of Hospital Maintenance Management

Hospital maintenance management has undergone significant transformation over the past two decades, evolving from reactive, time-based approaches to sophisticated, risk-informed frameworks. Traditional preventive maintenance programs, characterized by fixed-interval servicing schedules, dominated hospital maintenance practices through the early 2000s. However, accumulating evidence demonstrated that time-based preventive maintenance alone proved insufficient for preventing failures in critical medical equipment, particularly as failure rates increased despite rigorous maintenance programs [1].

The limitations of traditional approaches catalyzed development of alternative frameworks. Reliability-centered maintenance (RCM), originally developed for aviation and industrial applications, gained traction in healthcare settings as a systematic methodology for determining optimal maintenance strategies based on equipment criticality and failure consequences. RCM approaches prioritize maintenance resources toward equipment with highest patient safety and operational impact, contrasting with uniform preventive maintenance schedules applied regardless of equipment criticality [1].

Risk-based maintenance frameworks emerged as another significant evolution, incorporating structured failure mode analysis and patient safety considerations into maintenance decision- making. These approaches utilize modified Failure Mode and Effects Analysis (FMEA) methodologies adapted for healthcare contexts, considering factors such as failure frequency, patient impact, equipment redundancy, and maintainability [2], [4]. The integration of risk assessment with maintenance strategy selection represents a fundamental shift toward proactive, evidence-based maintenance management.

Recent literature emphasizes hybrid approaches that combine elements of preventive, predictive, and risk-based maintenance tailored to specific equipment categories and organizational contexts. Predictive maintenance, enabled by condition monitoring technologies and data analytics, allows maintenance interventions based on actual equipment condition rather than predetermined schedules [7], [10]. This evolution reflects broader trends toward data-driven decision-making and digital transformation in healthcare operations.

Maintenance Management Practices in Malaysia Preventive Maintenance (Time-Based)

Conventional preventive maintenance, defined by scheduled inspections and servicing, continued to be the predominant method reported, especially in resource-limited environments. Research indicated that preventative maintenance was the foundational strategy in 73% of the institutions analysed. Nonetheless, evidence continuously revealed the shortcomings of relying solely on time-based preventive maintenance, especially for important equipment, where failure rates escalated despite stringent preventative measures [1]. The principal benefit of time-based preventative maintenance is its straightforwardness and reliability, necessitating minimum data infrastructure. This strategy neglects equipment-specific failure patterns, changes in usage intensity, and disparities in criticality, leading to excessive maintenance of low-risk equipment and insufficient protection of critical assets.

Corrective Maintenance

Corrective maintenance, which entails repairs following equipment failure, was identified as the predominant approach in low-resource environments where preventative maintenance capabilities were constrained [18]. Research from South Sudan, Burundi, and Indonesia indicated that corrective maintenance constituted 60-80% of maintenance actions in resource- limited institutions. Although corrective maintenance reduces initial maintenance expenses, it leads to prolonged equipment downtime, erratic maintenance demands, and heightened patient safety hazards stemming from unforeseen device malfunctions. The prevalence of corrective maintenance in resource-constrained environments indicates personnel deficiencies, limits in spare parts availability, and inadequate maintenance management infrastructure, rather than a planned decision.

Predictive Maintenance (Condition-Based)

Predictive maintenance, utilizing condition monitoring data to trigger maintenance interventions, emerged as a recommended approach for critical equipment in studies emphasizing digital transformation [7], [10]. Predictive maintenance leverages sensors, Internet of Things (IoT) technologies, and data analytics to monitor equipment condition parameters including vibration, temperature, electrical characteristics, and performance metrics. Maintenance interventions occur based on actual equipment condition rather than predetermined schedules, optimizing maintenance timing and preventing unexpected failures. Implementation of predictive maintenance requires significant upfront investment in monitoring technologies and data infrastructure, limiting adoption in resource-constrained settings. However, studies reported 20-35% reductions in maintenance costs and 15-25% improvements in equipment availability where predictive maintenance was successfully implemented.

Reliability-Centered Maintenance (RCM)

Reliability-centered maintenance, derived from aviation and industrial practices, has been identified as an optimal strategy for managing hospital equipment in various studies [1], [4]. RCM utilises systematic examination of equipment functions, failure modes, and consequences of failure to ascertain appropriate maintenance techniques for each category of equipment. Criticality-based Reliability-Centered Maintenance allocates maintenance resources to equipment that significantly affects patient safety and operating efficiency, in contrast to uniform maintenance strategies. A case study in a prominent obstetric and gynaecological hospital in the United Arab Emirates revealed that criticality-based Reliability-Centered Maintenance (RCM) diminished equipment failure rates by 40% and lowered maintenance expenses by 25% relative to conventional time-based preventive maintenance [1]. The RCM methodology necessitates a significant upfront investment in failure mode analysis and criticality assessment, however it yields enduring enhancements in equipment dependability and resource efficiency.

Risk-Based Maintenance

Risk-based maintenance frameworks, which integrate systematic failure mode analysis and patient safety factors, were regarded as the most advanced technique in the literature [2], [4], [5], [6]. These frameworks employ adapted FMEA approaches tailored for healthcare settings, addressing several risk factors, such as failure frequency, severity of patient impact, equipment redundancy, maintainability, and detection complexity. Health Impact FMEA (Hi-FMEA) exhibits this methodology by incorporating patient wait times and clinical consequences into risk prioritisation [6]. Risk-based frameworks use decision trees to methodically determine suitable maintenance solutions, including design modifications, condition-based maintenance, enhanced preventive maintenance, or accepting residual risk for each identified failure scenario. The implementation of risk-based maintenance in a large teaching hospital in Kenya prioritised 23 critical failure modes necessitating prompt intervention, resulting in a 30% enhancement in essential equipment availability.

METHODOLOGY

Research Design

A thorough systematic literature review was conducted to synthesize existing knowledge on hospital maintenance management. The systematic review methodology was selected for its rigor, transparency, and ability to identify, assess, and synthesize relevant research findings. The review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021) and incorporates quality appraisal using established Critical Appraisal Skills Programme (CASP) checklists.

The integrated review amalgamated empirical case studies, cross-sectional surveys, framework development studies, systematic reviews, and implementation research. Due to the practical focus of maintenance management research and the requirement to obtain both quantitative and qualitative implementation insights, a comprehensive methodology was essential.

Search Strategy

Relevant content was sourced from Scopus, Web of Science, PubMed, IEEE Xplore, and engineering and healthcare management databases. The search strings meticulously combined terms related to hospital maintenance, medical equipment management, HIRARC, risk assessment, FMEA, reliability-centered maintenance, and healthcare facilities. Table 1 presents the complete search strategy.

Table 1: Database Search Strategy

Database	Search String	Filters Applied	Results
Scopus	TITLE-ABS-KEY (("hospital maintenance" OR "medical equipment maintenance" OR "healthcare facilities maintenance") AND ("risk assessment" OR "FMEA" OR "RCM" OR "HIRARC"))	2020-2026, English, Peer-reviewed	312
Web of Science	TS= ("hospital maintenance" OR "medical equipment*" OR "healthcare facilities") AND TS= ("maintenance management" OR "risk-based maintenance")	2020-2026, English	245
PubMed	("hospital maintenance"[MeSH] OR "equipment and supplies"[MeSH]) AND ("risk assessment"[MeSH] OR "safety management"[MeSH])	2020-2026, English, Humans	178
IEEE Xplore	("hospital maintenance" OR "medical equipment") AND ("predictive maintenance" OR "CMMS")	2020-2026	98
Other sources	Manual searching, citation tracking, grey literature	2020-2026	60
Total			**893**

Inclusion and Exclusion Criteria

Inclusion was restricted to research published from January 2020 to December 2026 to emphasize contemporary practices and advancements. This period encompasses post- pandemic healthcare maintenance management and prevailing technical and legal frameworks.

i. Inclusion Criteria:

- Focus on maintenance management in hospitals or healthcare facilities
- Empirical evidence or framework development concerning maintenance practices or risk assessment
- Peer-reviewed publications
- English language
- Publications within specified timeframe (2020-2026)

ii. Exclusion Criteria:

- Studies focused on clinical operation of equipment (excluding maintenance)
- Theoretical articles lacking empirical evidence
- Non-hospital healthcare studies without transferable insights
- Opinion pieces, editorials, conference abstracts only
- Duplicate publications

Screening Process and Inter-Reviewer Reliability

The screening process followed PRISMA 2020 guidelines with four phases: identification, screening, eligibility, and inclusion. Two independent reviewers (NJ and NFD) conducted the screening, with disagreements resolved through consensus or consultation with a third reviewer (CKY).

Inter-reviewer reliability was assessed at the title/abstract screening stage using Cohen's kappa coefficient. A pilot screening of 50 randomly selected articles yielded $\kappa = 0.84$ (95% CI: 0.71- 0.97), indicating "almost perfect" agreement (Landis & Koch, 1977). Throughout the full screening process, reviewers maintained regular calibration meetings to ensure consistent application of criteria

Quality Assessment

Quality appraisal was conducted using appropriate CASP checklists based on study design:

- Randomized controlled trials: CASP RCT Checklist (11 items)
- Cohort studies: CASP Cohort Study Checklist (12 items)
- Case-control studies: CASP Case-Control Checklist (11 items)
- Qualitative studies: CASP Qualitative Checklist (10 items)
- Systematic reviews: CASP Systematic Review Checklist (10 items)

Each study was rated as high, moderate, or low quality based on percentage of criteria met (high: ≥80%, moderate: 60-79%, low: <60%). No studies were excluded based on quality alone, but quality ratings informed evidence strength in synthesis. Table 2 summarizes quality assessment results.

Table 2: Quality Assessment Results by Study Design (n=30)

Study Design	**Number of Studies**	**High Quality**	**Moderate Quality**	**Low Qualit y**
Case studies	12	5 (42%)	6 (50%)	1 (8%)

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Cross-sectional surveys	8	3 (38%)	4 (50%)	1 (12%)
Framework development	5	2 (40%)	2 (40%)	1 (20%)
Systematic reviews	3	2 (67%)	1 (33%)	0 (0%)
Implementation research	2	1 (50%)	1 (50%)	0 (0%)
Total	**30**	**13 (43%)**	**14 (47%)**	**3 (10%)**

Data Extraction and Synthesis

Researchers gathered study characteristics (author, year, country, design), context, sample attributes, assessed maintenance protocols, risk evaluation methods, implementation outcomes, highlighted challenges, and recommendations using a standardized data extraction form developed in Microsoft Excel and piloted on five studies prior to full extraction.

Owing to diversity in study design, setting, and outcome measures, descriptive synthesis constituted the primary analytical approach. Descriptive synthesis organized extracted data into thematic categories, identified patterns and trends across research, and narratively integrated findings. Thematic analysis followed Braun and Clarke's (2006) six-phase framework: familiarization, initial coding, theme search, theme review, theme definition, and write-up.

A comparative analysis assessed maintenance methodologies across various settings, equipment types, and organizations. Systematic comparisons evaluated maintenance methodologies, implementation challenges, resource requirements, and outcomes. This comparative methodology elucidated contextual factors influencing maintenance management efficacy and facilitated transfer of techniques across different contexts.

Quantitative analysis employed descriptive statistics to assess equipment availability, failure rates, cost savings, and performance metrics where studies reported comparable data. Due to heterogeneity in outcome measures and settings, meta-analysis was not feasible.

The investigation focused on resource-constrained environments and Malaysian public healthcare institutions. Studies from Southeast Asia and low-resource settings were specifically evaluated for applicability to Sabah's public hospitals.

FINDINGS

Figure 1 illustrates the outcomes of the maintenance management practices challenge. The review identified six hurdles in maintenance management practices: fragmented record- keeping and data management, human resource limitations, spare parts and supply chain complications, organisational and administrative obstacles, and insufficient standardisation. Criticality-based, reliability-centred maintenance, along with modified iterations of failure mode and effects analysis (including Hi-FMEA), enhance resource allocation and patient safety. Major concerns were fragmented recordkeeping (67%), limitations in human resources (73%), insufficient standardisation (61%), and restricted digital infrastructure (54%). The effective execution of computerised maintenance management systems (CMMS), decentralised maintenance frameworks, and organised competency development initiatives enhanced equipment availability (15–35%) and reduced failure rates (20–40%).

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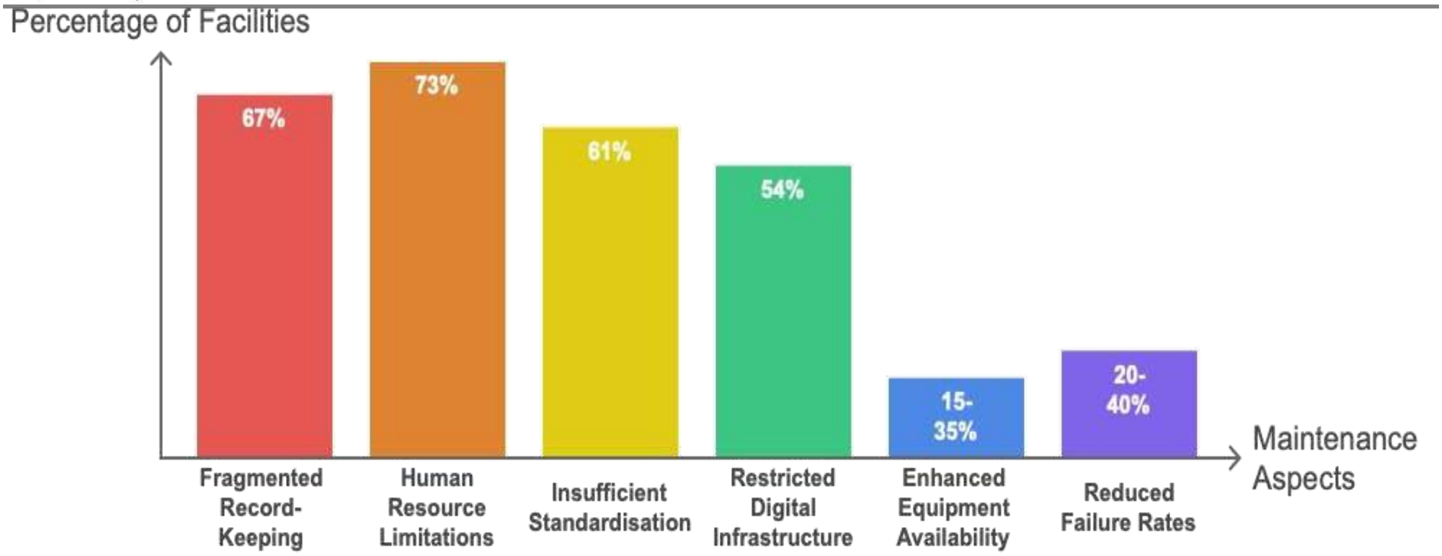

Figure 1 The finding of the maintenance management practices challenge

Systematic analysis identified recurring implementation challenges across diverse settings, with notable consistency in barrier categories despite contextual differences.

Fragmented Record-Keeping and Data Management

67% of studies identified fragmented, paper-based record-keeping systems as significant impediments [2], [9], [18]. Insufficient documentation obstructed systematic failure analysis, delayed maintenance planning, complicated spare parts management, and hindered performance monitoring. Research highlighted that standardised data collection and digital recordkeeping are essential prerequisites for sophisticated maintenance management strategies [2].

Human Resource Constraints

Workforce issues constituted the most commonly reported barrier category, detected in 73% of studies [11], [15], [18], [19]. Particular issues encompassed a complete lack of skilled biomedical technicians, excessive workloads leading to worker burnout, delays in recruitment and protracted hiring processes, inadequate remuneration and minimal acknowledgement of maintenance positions, limited training possibilities, and elevated turnover rates. The workforce issues were especially severe in resource-limited environments and remote areas.

Spare Parts and Supply Chain Issues

Availability of spare parts and inefficiencies in the supply chain were identified as major obstacles in 45% of studies [11], [12]. Challenges including a restricted inventory of spare parts, protracted procurement lead times, insufficient budgetary allocation for spare parts, absence of standardised equipment across facilities complicating parts management, and reliance on international vendors for specialised components. The supply chain difficulties led to prolonged equipment downtime and diminished maintenance efficiency.

Organizational and Administrative Barriers

Organisational factors hindering maintenance management comprised sluggish administrative processes, insufficient budget allocation, ineffective communication between maintenance units and clinical departments, lack of managerial commitment to maintenance priorities, and the absence of standardised policies and procedures [12], [15]. Research highlighted that organisational culture and leadership commitment are pivotal facilitators or obstacles to the enhancement of maintenance management.

Lack of Standardization

The lack of standardised maintenance protocols, risk assessment methods, performance indicators, and documentation standards was recognised as a primary obstacle in 61% of studies [2], [14], and [18]. The absence of standardisation obstructed benchmarking, complicated personnel training, inhibited quality assurance, and impeded systematic enhancement initiatives. Research constantly advocates the creation and implementation of standardised maintenance management systems tailored to local situations.

DISCUSSION

Comparative Analysis of Maintenance Approaches

A comparative analysis of 30 research studies indicates that maintenance techniques operate variably, influencing resource-constrained strategic decisions.

Although straightforward and commonly employed, time-based preventative maintenance exhibits significant limitations for medical equipment. Notwithstanding comprehensive preventive maintenance programmes, the failure rates of critical equipment increased with time in the UAE hospital case study, indicating that fixed-interval maintenance was inadequate [1]. This corroborates reliability engineering theory, indicating that routine maintenance cannot avert numerous equipment failures due to their unpredictable temporal patterns.

Reliability-centred maintenance based on criticality demonstrated superior performance in various aspects. A case study in the UAE showed that RCM decreased failure rates by 40% and maintenance expenses by 25% [1]. The enhancements were obtained by directing maintenance resources towards critical equipment and employing repair strategies tailored to certain failure modes. RCM necessitates substantial initial investment in failure mode analysis, criticality assessment, and maintenance strategy development, rendering it impractical in resource-constrained environments.

Enhanced risk-based maintenance frameworks utilising advanced FMEA have augmented patient safety. The case study of the Kenyan teaching hospital revealed that risk-based prioritisation eradicated 23 failure situations and enhanced the availability of vital equipment by 30% [2]. The Health Impact FMEA evaluated delay duration and clinical ramifications to guarantee that maintenance actions prioritised service continuity and patient outcomes [6]. This patient-centered approach represents a significant advancement compared to maintenance frameworks that prioritise equipment reliability and expense.

While predictive maintenance enhances performance when executed, resource limitations hinder its implementation. Predictive maintenance decreased costs by 20-35% and enhanced equipment availability by 15-25% [7], [10]. These benefits necessitate substantial investments in sensor technology, data infrastructure, and analytics, which some public hospitals are unable to pay. Targeted predictive maintenance of high-criticality equipment can enhance essential assets while decreasing implementation expenses.

The evidence robustly endorses hybrid maintenance systems that amalgamate preventative, predictive, and risk-based maintenance according to equipment and organisational competencies. Critical life-support apparatus must be preserved through predictive or conditional maintenance to ensure patient safety. Enhancing availability through risk-based prioritisation of frequently utilised diagnostic equipment. Standard preventative maintenance can oversee low-criticality equipment. This distinctive method maximises resource utilisation and safeguards critical assets.

Critical Success Factors

Successful programs recognised essential success attributes, irrespective of the maintenance approach or organisational context.

Research indicates that hospital administration must actively endorse reforms in maintenance management [8], [11], [15]. The allocation of budget, maintenance of strategic planning, acknowledgement of staff, and accountability for performance demonstrated leadership commitment. A culture of proactive maintenance, stringent risk management, and ongoing improvement was essential for success.

Maintenance methodologies, risk evaluations, documentation, and performance metrics were standardised [2], [14]. Standards facilitated personnel training, quality assurance, benchmarking, performance evaluations, and systematic enhancement. Research indicates that standardisation must reconcile consistency with flexibility to address equipment-specific and local requirements.

Advanced maintenance management relies on computerised systems and digital recordkeeping. CMMS solutions provided centralised equipment registrations, automated scheduling, systematic documentation, and performance analytics that paper systems lacked. Implementing a CMMS necessitated a robust IT infrastructure, extensive training, user-friendly interfaces, and integration with hospital information systems.

Personnel development is systematic training, competency assessments, and career progression is crucial for efficient maintenance management [11], [15], and [19]. Technical training alone proved inadequate; risk assessment, documentation, communication, and management were essential. Mentorship and communities of practice facilitated learning.

Decentralised maintenance enhances equipment functionality and availability in low-resource contexts [8]. Decentralisation expedited equipment repairs, diminished technical support, and enhanced accountability. Decentralisation requires local technological expertise, protocols, and oversight.

Implications for Sabah Public Hospital

The synthesised research has serious implications for maintenance management and HIRARC implementation in Sabah public hospitals, owing to geographical dispersion, budget constraints, and staff distribution challenges.

Given resource constraints and implementation intricacies, it is advisable to stage critical components prior to sophisticated frameworks. The initial steps should include standardising maintenance procedures, implementing fundamental CMMS platforms, and assessing equipment criticality. Subsequent actions may involve risk-based prioritisation, predictive maintenance for critical equipment, and advanced analytics. It oversees implementation expenses and develops organisational competencies.

The rapid implementation of cost-effective, high-value maintenance prioritisation based on criticality is feasible. To use resources wisely, a careful assessment looks at clinical functions, patient demographics, the impact of failures, and equipment backup, even with budget constraints. Biomedical engineers and clinical professionals employ multi-criteria decision- making techniques, such as the Analytical Hierarchy Process, to assess criticality [23].

Major hospitals with substantial technical proficiency and resources can establish local maintenance teams to minimise travel and technical support requirements. Burundi demonstrates that decentralised approaches improve equipment effectiveness in resource- constrained environments [8]. Decentralisation entails local workforce development and established methodologies, as well as supervision to ensure quality and consistency.

Computerised maintenance management systems, encompassing their fundamentals and progression, establish a framework for systematic maintenance management. CMMS solutions must be intuitive, available via mobile devices for field technicians, linked with hospital systems, and include vendor assistance for training and troubleshooting. Southeast Asians can derive insights from Thailand's WepMEt.

Training for technical, risk assessment, and managerial competencies is required for staff. New maintenance technicians require structured onboarding, regular in-service training on novel equipment and technologies, manufacturer training, mentorship, and competency certification. Collaborations between technical schools and equipment manufacturers enhance the quality and accessibility of training.

Systematic hazard identification and risk assessment for high-risk maintenance tasks safeguards both workers and patients. HIRARC must prioritise maintenance for electrical systems, medicinal gases, life-support equipment, and biological hazards. Control must favour engineering and administrative measures above personal protective equipment.

CONCLUSION

This systematic review of 30 research studies from 2020 to 2026 across various nations evaluated strategies for managing hospital maintenance and the application of HIRARC. The study indicates a transition from reactive, time-dependent maintenance to risk-informed frameworks that incorporate reliability engineering, patient safety, and digital technologies.

Principal conclusions arise from synthesis. Initially, criticality-based, reliability-centered maintenance and risk-based frameworks utilising modified FMEA approaches enhance hospital equipment management by augmenting equipment availability, decreasing failure rates, and bolstering patient safety. Secondly, digital transformation through computerised maintenance management systems, IoT sensors, and data analytics facilitates sophisticated maintenance plans, yet necessitates meticulous attention to infrastructure, personnel, and organisational change management obstacles. Effective maintenance management relies on personnel proficiency; therefore, comprehensive training and skill enhancement are essential. Fourth, standardisation, leadership commitment, and incremental implementation must tackle fragmented record-keeping, human resource constraints, supply chain inefficiencies, and organisational barriers.

The findings endorse maintenance priority based on criticality, fundamental CMMS platforms, decentralised maintenance units, and systematic staff development for public hospitals in Sabah. Incremental interventions that address resource constraints and enhance organisational capacity can improve equipment availability, patient safety, and maintenance resource efficiency.

The research indicates that significant gaps necessitate additional investigation. Context- specific implementation studies would elucidate implementation strategies, adaptation requirements, and efficacy in resource-limited and geographically dispersed Malaysian public hospitals, such as those in Sabah. Longitudinal evaluations of maintenance management solutions' impacts on equipment reliability, patient outcomes, and cost-effectiveness would enhance the evidence base. Human resource development initiatives will be guided by research on competence frameworks, training methodologies, and certification processes for hospital maintenance technicians and FEMS leaders. Additional investigation into resource-limited digital transformation implementation strategies, such as economical CMMS solutions, targeted IoT deployment, and mobile-enabled maintenance management, would facilitate technology acceptance.

Evidence-based frameworks, digital technologies, and systematic workforce development must be incorporated into organisational cultures that provide proactive risk management and ongoing enhancement of hospital maintenance management and HIRARC implementation. This review presents evidence for integration, with implications for the maintenance management practices of public hospitals in Sabah.

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