

Towards Sustainable Asset Modernisation: An Energy Management Systems (EMS)-Based Integration Framework

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Abstract

In South Africa, many industrial activities rely heavily on legacy infrastructure. The legacy systems have components, hardware, and software that were developed and manufactured decades ago and were not developed to accommodate energy management and monitoring technologies. This study aims to develop a practical Energy Management Systems (EMS)-based integration framework to assist organisations with older infrastructures. A mixed-methods approach was used: the quantitative component was a survey, and the qualitative insights were drawn from semi-structured interviews. The survey helped identify how certain challenges were, while interviews added an analytical depth from experts who worked directly with Energy Management and Monitoring Systems (EMMS) and asset modernisation. The results identified both technical and operational challenges facing sustainable asset modernisation. The results also showed that when EMMSs are rolled out in a planned and structured way, organisations can achieve noticeable savings and quick payback periods. Based on the results, a framework with three main parts, technical, operational, and economic, was developed. The proposed framework can be used by individuals from different departments within an organisation. For managers and engineers, the framework offers a practical guide to balancing technology, people, and financial planning, ultimately creating a pathway for EMMS modernisation of legacy systems.

Keywords

Energy Management Systems (EMS), Legacy Infrastructure, Asset Modernisation, Sustainability, and Integration Framework.

1. Introduction

Energy management and monitoring systems have become increasingly important in energy sustainability and reducing carbon emissions (Mishra & Singh, 2023). Industrial systems designed decades ago did not account for energy-efficiency requirements (Irani et al., 2023; Gilchrist et al., 2008). Today, the industrial world has adopted clean energy systems and policies that support the efficient use of energy (Fieldler & Mircea, 2012; Garcia et al., 2017). These new policies require legacy systems to be upgraded to align with the future; therefore, legacy systems need to be integrated with and modernized by newer energy management and monitoring systems (Araujo et al., 2018; Rinaldi et al., 2023). The integration of these systems will enable legacy systems to be upgraded and enable information to be analysed and stored on and off-board storage facilities (Fernandes et al., 2024). The use of energy management and condition-monitoring systems, and the adoption of sustainable practices, are crucial to ensuring the reliability and operational efficiency of industrial equipment and processes (Ingemarsdotter et al., 2020; Matshidze, 2022).

The modernisation of legacy systems will allow for real-time control and monitoring of assets, where the data obtained can be used for predictive maintenance, monitoring the system's downtime (Ingemarsdotter et al., 2020) and increasing the system's overall energy efficiency. In South Africa, many organisations still use legacy infrastructure to perform

their daily tasks. The legacy systems often entail hardware and software that were not developed with energy efficiency standards and policies in mind (Gilchrist et al., 2008). The lack of standards and policies has led to modern technology and legacy systems being incompatible, resulting in costly replacements or complete system overhauls. Additionally, the incompatibility makes it difficult to maintain the systems, leading to longer operational downtime and greater maintenance challenges. Therefore, this study explores integrating modern energy management and monitoring systems into South Africa's legacy industrial infrastructure to enhance efficiency, minimise operational disruptions, and advance national sustainability objectives.

1.1 Objectives

To ensure this research remains focused on the key aspects of EMMS integration, clearly defined objectives are set. These objectives are as follows:

1. To explore the key technical, operational, economic, and organisational challenges/factors influencing EMMS integration into legacy infrastructure.
2. To develop a practical EMS-based integration framework to guide EMMS implementation in legacy infrastructure.

2. Literature Review

The following literature review is organized based on the main themes related to the integration of EMMS to modernise legacy infrastructure:

2.1 Conceptual Foundation of EMMS Integration:

Energy Management and Monitoring systems are essential in achieving energy efficiency and obtaining sustainable modernisation in industrial systems, while reducing the carbon footprint (Fallahi et al., 2025). EMMS enables real-time monitoring, control, and optimisation of energy consumption, thereby reducing operational costs and improving system performance (Mischos et al., 2023). Recent studies confirm that AI-enabled and multi-agent optimisation approaches significantly enhance energy performance in modern systems (Rehman et al., 2025). However, legacy systems designed decades ago did not incorporate such technologies; in most cases, there were no standards or policies in place to enable modernisation, and recent academic reviews highlight that legacy infrastructure remains a major barrier due to the lack of interoperability frameworks (Akbulut et al., 2025). Therefore, it is crucial to upgrade and modernize legacy infrastructure. The main challenge in integrating EMMS into legacy infrastructure is that the original designs of legacy systems did not consider or incorporate newer digital technologies. Common issues in integration include system compatibility and the lack of standardised communication protocols (Rinaldi et al., 2023; Araujo et al., 2018), a challenge also highlighted in 2026 research on demand response and device-level coordination in modern energy environments (Fallahi et al., 2025). The absence of new digital technologies creates technical and operational challenges that affect organisations' finances, a trend also discussed in ACM SIGEnergy's 2026 academic reports on digitalisation barriers in energy systems (ACM SIGEnergy, 2026).

2.2 Technical and Operational Barriers

A common issue identified from the literature review is the interoperability of legacy systems and the poor documentation (Tedeschi et al., 2018). The literature reiterates that most legacy systems lack documentation that can assist in modernising them. The lack of documentation leaves organisations heavily reliant on Original Equipment Manufacturers (OEMs) and external specialists to bridge the knowledge gap, a challenge highlighted in recent academic analyses that show missing system metadata and undocumented communication pathways hinder real-time energy optimisation and integration (Fallahi et al., 2025). Furthermore, data reliability and cybersecurity are a big concern in legacy systems since data exchange between modern and legacy systems increases the vulnerability of the systems (Venkatachary et al., 2024) and leads to data leaks, etc., which aligns with findings highlighting increased cyber-exposure in hybrid legacy-modern energy environments (Rehman et al., 2025). Therefore, there is a need for robust data management frameworks; without them, organizations risk compromising decision-making accuracy and cybersecurity, a point echoed in ACM SIGEnergy's 2026 academic reports that stress the need for integrated data governance and secure interoperability layers in digitalising energy systems (ACM SIGEnergy, 2026). EMMS success is not limited only to technical challenges; it also incorporates operational and human factors. For example, the literature shows that staff resistance to learning new technologies is a major issue that leads to their rejection (Cieslak & Valor, 2025). Training and change management programs are therefore essential for developing organisational readiness, a finding supported by research indicating that organisational acceptance and human-centred

adaptation are critical to the implementation of new energy management technologies (Akbulut et al., 2025). These findings align with the growing emphasis on Industry 4.0 transitions that combine technological innovation with human-centred adaptation (Matshidze, 2022), and recent studies in 2026 emphasise that socio-technical integration barriers—such as behavioural resistance and digital skill gaps—are equally significant as technological limitations (Rehman et al., 2025).

2.3 Economic and Strategic Considerations

Implementing EMMS technologies on legacy systems requires an economic feasibility study that examines all factors that could affect the project's success. Economic considerations, such as the high initial costs of hardware, software licenses, and specialist consultation (Tedeschi et al., 2018), are a trend reinforced by evidence showing that digital energy optimisation and multi-agent control systems increase upfront investment requirements (Fallahi et al., 2025). The literature shows that most hidden costs arise when integrating EMMS with legacy systems; these costs are often difficult to plan for or foresee, a challenge also discussed in 2026 systematic reviews that highlight unforeseen integration costs related to interoperability, cybersecurity upgrades, and data exchange infrastructure (Rehman et al., 2025). Despite high initial and hidden costs, the literature shows that long-term cost savings, productivity improvements, and efficiency gains are achieved when EMMS are strategically phased, an outcome supported by ACM SIGEnergy's 2026 academic findings, which demonstrate that phased digitalisation strategies significantly enhance operational efficiency and cost recovery (ACM SIGEnergy, 2026).

2.4 Case studies in the South African Context

Toyota South Africa is a case study that demonstrates that car manufacturing plants can be modernized and achieve quantifiable savings. The implementation of EnMS at Toyota's old plant resulted in energy savings of 8.15 GWh per year, equivalent to a cost saving of R4.87 million and a payback period of 1.09 years (Toyota, 2013), which aligns with results documented in national South African EnMS programmes that recorded similar savings outcomes across local industrial sites (NCPC-SA & UNIDO, 2020). Additionally, the Standard Bank Global Leadership Centre (GLC) also provides evidence that implementing EMMS into legacy commercial buildings has a positive impact on the organisation. The Standard Bank GLC project achieved significant savings through structured EnMS and alignment with ISO 50001. Implementation of EnMS resulted in savings of 1kWh saved cumulatively across 2015–2016, which resulted in a cost saving of R903,603 within a 10-month payback period, and 1,039 carbon dioxide emissions avoided (Standard-Bank, 2013), consistent with findings from verified South African EnMS case studies, such as AfriSam's Roodepoort plant, which achieved major energy reductions through ISO-50001-aligned monitoring and optimisation programmes (AfriSam EnMS Case Study, 2021). The two case studies, Toyota and Standard Bank (GLC), show technical, operational, and financial benefits of EMMS in legacy systems. The two case studies in this article are included as contextual illustrations, not as validation of the study's findings. The inclusion of the two case studies was mainly to illustrate that modernisation projects have been undertaken before and have yielded positive results, as reflected in South Africa's national IEE and NAMA programmes, which document dozens of EnMS retrofit successes across multiple industrial sectors (UNFCCC, 2010; GEF/UNIDO, 2025).

Existing studies on EMMS integration with legacy systems often focus on specific aspects of the integration process, such as technical, operational, and economic factors; none examine all three factors in an integrated manner, a limitation confirmed by recent systematic reviews that emphasise technology-centric approaches—such as IoT, AI and BEMS optimisation—without incorporating organisational or economic modernisation requirements (Akbulut et al., 2025). The lack of frameworks that combine these dimensions of EMMS modernisation results in the asset modernisation project failing and being left at the pilot stage, a pattern also evident in reviews that show renewable integration and modernisation studies treat technical, policy, and financial barriers separately rather than holistically (Wang et al., 2025). This study aims to develop a framework connecting energy management with sustainable asset modernisation, responding directly to gaps highlighted in technical-only energy-management reviews that ignore organisational and economic integration challenges (Rehman et al., 2025; Eze, 2025).

3. Methods

The research approach adopted in this study is an exploratory/descriptive mixed-methods approach, which allows the combination of qualitative and quantitative techniques. A mixed-methods approach will provide more understanding of the challenges and benefits of EMMS in modernizing legacy systems. The mixed-methods design selected for this study is the convergent parallel design, as it provides a comprehensive understanding of the research problem (Fetters

et al, 2013). Additionally, the convergent parallel techniques were selected due to the study's time sensitivity and the unavailability of survey participants and interviewees; these techniques will ensure the study is completed on time.

3.1 Population and Sampling

Research sampling is the selection of a subset of the research population to enable the research to be feasible (Hossan et al., 2023). Different research sampling techniques are used in academia. For this study, two sampling techniques were used: purposive sampling for interviews and random or convenience sampling for questionnaires. Purposive sampling was used to select respondents based on their knowledge, experience, and relevance to the research topic (Palinkas et al., 2015). This technique also enhances the study's validity and reliability by including participants who work with EMMS and legacy systems. Random sampling and convenience sampling were selected for the survey questionnaire because, in random sampling, all the participants have an equal chance of being chosen; therefore, bias is reduced, while Convenience sampling is used when there are time constraints (Creswell and Creswell, 2017), such as in this study, participants were chosen based on their availability and willingness to participate. The bias inherent in convenience sampling was mitigated by targeting a broad pool of participants and cross-verifying the findings through data convergence with interviews.

The target population for this study included engineers, engineering managers, and maintenance personnel working in the South African industrial sector, as well as individuals who frequently deal with legacy systems. For the survey, 32 respondents participated. Since the study is exploratory, the survey sample size is sufficient for statistical analysis and pattern identification. According to Bujang et al. (2024), a minimum of 30 respondents is required for reliability. Six semi-structured interviews were conducted, which met the required number to reach data saturation (Guest et al., 2006), allowing themes to be identified and providing strong insights into the development of an EMMS framework for legacy systems.

3. Data Collection

This section presents the data collection step for the mixed method used, as follows:

4.1 Semi-structured interviews

Qualitative data were obtained through semi-structured interviews; six participants participated, with one interview lasting 30 to 45 minutes and each session including 15 questions. Each research question consisted of five questions; interview participants were selected based on several elements, such as availability, their experiences with EMMS, and if they had been involved in asset modernisation projects. The interview sessions were scheduled and conducted on Microsoft Teams, and all sessions were recorded with participants' consent. Data gathered from the interview sessions were reviewed multiple times to identify themes and patterns. After theme identification, thematic coding was conducted, capturing several significant aspects related to the research questions.

4.2 Questionnaire Design

The survey questionnaire was used to collect data from a sample using a combination of random and convenience sampling. The questionnaire was designed to have four sections: Section A, Technical Challenges and Compatibility; Section B, Operational Impact and Downtime; Section C, Economic Considerations and ROI; and two open-ended questions. Sections A-C each had 5 questions on a 1-5 Likert scale. The survey sample comprised 32 participants from the energy management and asset modernisation industry. The projects that they were involved in included the design and implementation of EMMS into legacy industrial assets. Selecting industry professionals ensured that the information they shared was based on personal experience and relevant to the study. All participants were fully informed about the study's purpose, their rights, and the voluntary nature of their participation. All personal identifiers were removed from the survey and interviews, and participants provided written consent.

4.3 Ensuring Reliability and Validity

Data convergence was achieved by converging and cross-verifying data from different sources within the same professional network, in this case, quantitative and qualitative data (Fetters et al., 2013). The interview sessions provided information from participants' experiences and challenges in the field. They identified technical challenges they faced while implementing EMMS into legacy infrastructure. Additionally, the sessions highlighted the operational and financial impact of EMMS on the organization. The quantitative data from the surveys examined challenges from a broader perspective, including technical, operational, and economic factors, drawing on both experience and literature. These findings explored how EMMS challenges can be solved and how the benefits can be

used to enhance legacy infrastructure modernisation. After the two datasets were obtained and analysed individually, the findings were compared and cross-referenced; the two datasets showed converging themes, validated insights, and addressed any inconsistencies. The data convergence technique ensured that findings were not based solely on a single data source but on multiple sources from the same professional population, thereby strengthening their validity. The study's reliability was achieved through performing a pilot study for each section of the data collection, semi-structured interviews, and a survey questionnaire. In the pilot study, two participants were selected to assist in identifying any wording that could confuse participants, clarify the questions, and ensure the survey questions aligned with the research questions and captured relevant responses.

4.4 Data Analysis

The qualitative data were analysed using the thematic analysis proposed by (Braun and and Clarke, 2006). The semi-structured interviews were designed to elicit first-hand accounts from professionals in the energy management and modernisation industry. The themes emerged through open coding, labelling key phrases and patterns from the interview sessions. The recurring themes were grouped and categorized. The survey questionnaire findings were analysed using descriptive statistics, with responses from participants presented as frequency distributions, percentages, and bar charts to show trends and levels of agreement across different questions. The quantitative analysis did not include inferential tests such as regression and correlation analysis, but focused on describing and comparing response trends to highlight consensus among respondents.

5. Results and Discussion

The findings from the questionnaire insights and interviews highlight the technical challenges, operational factors, and economic considerations that affect the integration of EMMS on legacy infrastructure in South Africa. The findings provide a comprehensive understanding of key elements that influence the successful implementation of EMMS integration into legacy infrastructure.

5.1 Quantitative Results

5.1.2 Technical challenges and compatibility issues

This section investigates the results of the first objective: the technical challenges being faced when integrating EMMS with legacy infrastructure. Figure 1 presents the results of the five questions, with a legend summarising them. Among the respondents, most indicated that Q1 (legacy infrastructure lacks compatibility) and Q3 (retrofitting requires major hardware modifications) received strong agreement (66%). Q1 and Q3 were followed by Q4, which spoke about interoperability as a key challenge (60%) in asset modernisation. Further analysis shows that physical limitations and compatibility issues between new and old systems pose major challenges, sometimes forcing a full system overhaul rather than retrofitting or replacement. Furthermore, Q2: outdated communication protocols received mixed reactions from the respondents, with 40% agreement and 46% neutral. This means that communication protocols remain an issue, but they can be addressed using various strategies, such as signal converters.

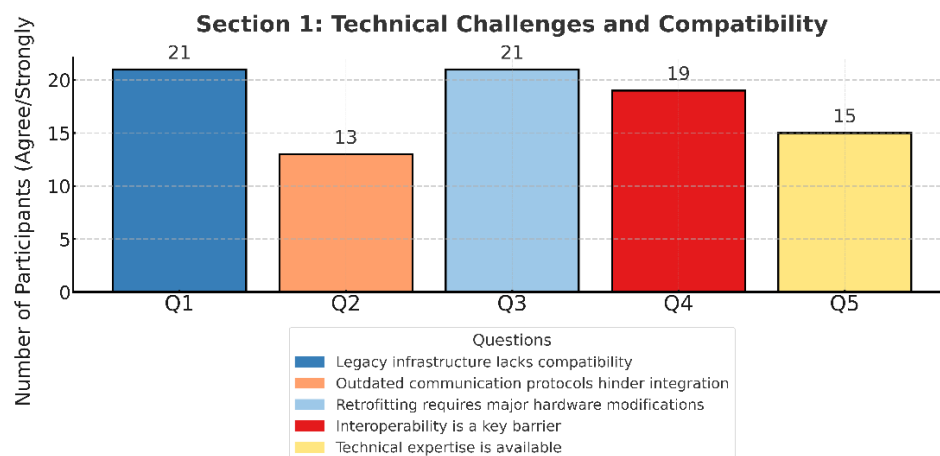


Figure 1. Technical challenges and compatibility issues

The findings reveal that most technical challenges encountered are not limited to hardware but also include software, such as communication protocols and interfacing software.

5.1.3 Operational Impact and Disruptions

The integration of EMMS into legacy infrastructure has several operational impacts, as the survey responses presented by Figure 2 focused on challenges related to the operational impact when implementing EMMS on legacy infrastructure. Five questions were asked, and participants' responses were recorded and illustrated below. 88% of participants are confident that integrating EMMS can improve real-time monitoring and reduce downtime (Q6). However, 44% of participants say the integration causes significant downtime during implementation (Q7). The findings show that 88% of respondents believe that integration improves long-term efficiency, indicating recognition of the long-term impact of modernisation despite short-term challenges. It was also noted that staff training reduces integration challenges and ensures that operators have a comprehensive understanding of the system and its benefits.

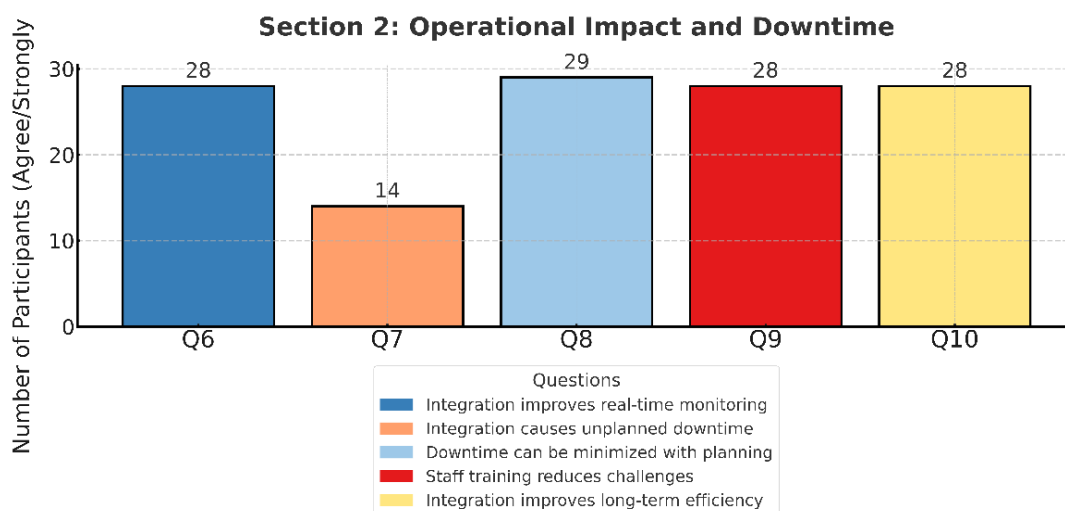


Figure 2. Operational impact and downtime

The findings demonstrate that short-term vs. long-term trade-offs are essential in deciding whether to modernize a legacy system or buy a new one. Almost all initial implementations of EMMS can disrupt processes, but when properly planned and with operators trained, organizations can achieve long-term efficiency gains.

5.1.4 Economic Considerations and ROI

The data demonstrates several economic factors; they are not limited to financial considerations but also include non-financial ones. The results represented by Figure 3 show that the greatest agreement came from Q12: 84% of participants say that integrating EMMS into legacy infrastructure has a high potential to deliver measurable cost savings to the organization. Participants (75%) say that modernisation has a positive impact on the long-term productivity of the organizations (Q15). Participants also noted that high initial costs have a significant influence (72%) on asset modernisation (Q11), confirming that cost is a major barrier, while the return-on-investment timeframes were noted as varied and will depend on the magnitude of the modernisation project.

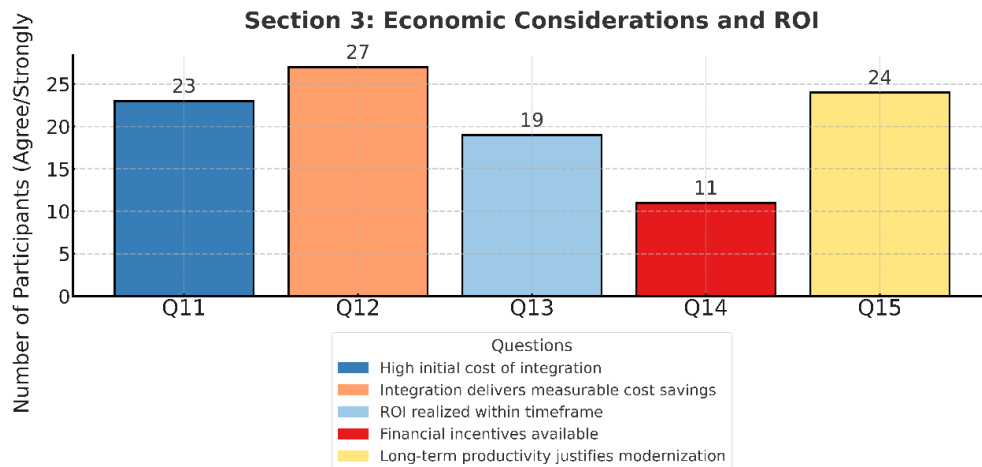


Figure 3. Economic consideration and ROI

According to the findings, there are high initial costs when integrating EMMS into legacy infrastructure, but the long-term impact of implementing the system is very beneficial to the organisation.

5.2 Qualitative Results

5.2.1 Participants Demographic

Qualitative data were collected through semi-structured interviews with six professionals in the field of energy management. The six participants are enough for the data to reach a saturation point, according to (Guest et al., 2006). Table 1 shows the demographics of the participants. The semi-structured interviews comprised both Engineering Managers and Engineers. Four participants were Engineering Managers, each with 7-15 years of organizational experience and between 5-10+ years of involvement in Energy Management and Monitoring Systems (EMMS) and asset modernisation. Two participants were engineers, with between 6-15 years of organizational experience and 4-10+ years of exposure to EMMS projects. Since the research study was conducted in an exploratory manner, the participants had mainly an engineering background, which constrained the diversity of perspectives. Further studies will include a broader range of perspectives to capture the viewpoints of individuals such as operations personnel, maintenance personnel, and policy makers.

Table 1. Demographics for semi-structured interviews

	Role	Experience in Organization	Experiences with EMMS and asset modernisation
Participant 1	Engineering Manager	11-15 years	>10 years
Participant 2	Engineering Manager	11-15 years	7-10years
Participant 3	Engineering Manager	11-15 years	>10 years
Participant 4	Engineering Manager	7-10 years	5-7 years
Participant 5	Engineer	11-15 years	10> years
Participant 6	Engineer	6-8 years	4-5 years

The participants had both managerial and technical experience, offering a blend of managerial expertise and technical know-how in asset modernization. Since the findings are based on firsthand experience and align with the literature, they can be considered reliable. The next section will present the themes and codes identified after analysis of the qualitative data from the semi-structured interview

5.2.2 Presentation of Themes

The qualitative data from the interviews were analysed to identify important themes and patterns represented by Table 2. After analysis, themes were identified, and codes with similar characteristics were grouped into categories that reflect recurring concepts and shared experiences. Each theme includes an indication of the frequency of codes within that theme, which shows how many participants mentioned the theme and its codes in the interview sessions. The themes and codes were extracted from interviews with the six participants. Table 2 It is a summarised version of the themes and codes identified.

Table 2. Identified codes and themes

Theme	Codes	Frequency
System Compatibility Challenges	Difficulty linking new monitoring platforms with older hardware, limited standardisation, and reliance on custom fixes or workarounds	6
Information and Knowledge Gaps	Incomplete or missing technical records; dependence on outside experts;	5
Data and Safety Concerns	Unreliable data or delayed data, poor data validation methods, and exposure to cybersecurity threats	4
Operational Disruptions	Unplanned downtime during rollout; changes to normal scheduling; interruptions in daily workflow.	6
People and Culture	Reluctance among staff to adopt new systems; fear of constant monitoring.	5
Skills and Training Needs	Shortage of trained personnel; limited confidence in operating new tools; need for capacity building and upskilling	6
Improved Maintenance Approaches	Moving away from fixed schedules to predictive, data-driven maintenance, using EMMS insights to prevent failures.	5
Investment and returns	Varying timelines for cost recovery, short, medium, or long-term payback, depending on project size and scope	4
Cost of Modernisation	Extra expenses for licenses, specialized tools, and consultancy services that raise overall project costs	6
Asset Replacement Decisions	Weighing the benefits of retrofitting versus full replacement, balancing upfront savings with equipment lifespan	3
Measuring Value	Using both financial measures (cost savings, payback) and non-financial measures (productivity, reduced risk) to assess success.	4
Pilot Testing Phased Rollout	Using trial projects or phased implementation to test feasibility, reduce risks, and scale gradually.	4
Data Quality and Validation	Ensuring data capture and analysis accuracy; building trust in EMMS-generated information before acting on it.	5

Frequency coding is a method of counting how often a code is mentioned by interview participants. It allows for transparency; however, it is not sufficient for a thorough thematic analysis.

5.3 Key Findings

The data analysis of the questionnaire and semi-structured interviews showed strong alignment. The findings from the two datasets complement each other in most cases; the surveys highlighted common challenges. At the same time, the interviews provided practical examples from EMMS professionals who work with such systems daily. The major findings from both datasets are system compatibility, staff training, and return on investment as the main issues across all research questions. These combined insights led to the development of a framework that brings together the technical, operational, and economic aspects of EMMS modernisation. Table 3 outlines the practical application of the developed framework.

Table 3. Framework for integrating EMMS into legacy systems

Framework Component	Survey Findings	Interview Findings	Application in Practice
Technical	• High agreement that system compatibility is a major challenge • Interoperability and retrofitting are recurring issues	• Protocol incompatibility is a serious barrier • Dependence on OEMs due to missing documentation • Concerns about data reliability	• Conduct early technical audits • Plan for protocol standardization • Allocate resources for documentation and expert support
Operational	• Downtime and workflow disruptions were major operational challenges • Skills and training gaps reduce effectiveness	• Strong cultural resistance noted • Training deficiencies reinforced • External collaboration (OEMs) is seen as important for reducing disruptions	• Prioritize structured training programs • Implement change management strategies • Use phased rollouts with external technical support
Economic	• ROI expected within 2–5 years • High upfront costs for licenses/tools • Both financial and non-financial metrics are important	• Hidden costs identified (consultants, tools) • Trade-offs between retrofitting and new investments • non-financial benefits highlighted (risk reduction, productivity)	• Apply life-cycle cost analysis • Measure both financial and non-financial benefits • Use phased/pilot projects to reduce risk

The proposed framework primarily focused on three elements directly related to the research questions: the technical, operational, and economic aspects of EMMS integration. Data from the surveys and questionnaire highlight key challenges, including system compatibility, data reliability, staff training, and the need for careful change management. The economic aspect examines long-term planning related to costs and productivity gains.

6. Conclusion

The proposed framework, developed from the study, provides important insights into the technical, operational, and economic challenges encountered in EMMS and asset modernisation projects. The study identified common technical challenges, including system compatibility, outdated or missing documentation, and data reliability. The combination of these challenges can halt or even lead to the cancellation of an asset modernisation project; however, they can be addressed through the practical framework proposed and comprehensive planning. This framework serves as a guide for determining which parts to investigate when planning to modernize a system using EMMS. It identifies the major challenges one may face and provides mitigation strategies to address them, enabling the successful implementation of EMMS within legacy infrastructure.

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