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Original Article

Development of a Life Cycle Cost Analysis Model for Mortuary Buildings to Enhance Availability Performance: The Case Study of Musoma Municipal Council Hospital

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Life Cycle Cost Analysis, Mortuary Building Maintenance, Healthcare Facility Management, Availability Performance, Multiple Regression Model, Tanzania.

ABSTRACT

Healthcare facilities require comprehensive maintenance management strategies to ensure optimal service delivery and operational efficiency. This study developed a life cycle cost analysis (LCCA) model to improve maintenance management and availability performance of mortuary buildings, using Musoma Municipal Council Hospital as a case study. A mixed-methods research approach was adopted, involving comprehensive field observations, structured interviews, and systematic surveys with 36 participants representing diverse stakeholders, including engineers, administrators, technicians, mortuary staff, and healthcare professionals. Twelve technical factors influencing maintenance costs were systematically analysed using the Relative Importance Index (RII) methodology to establish priority rankings based on professional expertise and operational experience. The analysis revealed that electrical systems' reliability and backup power emerged as the most critical factor (RII = 0.931), followed by environmental control for chemical storage (RII = 0.923), and infection control and biosafety features (RII = 0.915). A robust multiple regression model was subsequently formulated using the seven highest-ranked factors, producing strong predictive outcomes with $R^2 = 0.780$, indicating that 78% of the variance in availability performance could be explained by the identified technical factors. The resulting prediction equation: $Y = 0.01 + 0.02X_1 - 0.11X_2 + 0.032X_3 + 0.08X_4 + 0.05X_5 + 0.03X_6 + 0.09X_7$ demonstrated statistical significance ($F = 10.327$, $p < 0.001$), where X_1 to X_7 represent the prioritized technical components. Comprehensive validation over an eight-month period confirmed the model's reliability and practical applicability, with availability performance demonstrating significant improvement from 20% classified as "Very Severe" in January to 97% classified as "Very Good" in May. The study contributes to the limited body of knowledge on specialised healthcare facility maintenance management and provides hospital administrators with evidence-based tools for strategic decision-making, preventive maintenance planning, cost optimisation, and sustainable mortuary service delivery.

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INTRODUCTION

Healthcare facilities represent critical infrastructure components whose operational effectiveness directly impacts public health outcomes, community well-being, and the quality of healthcare services delivered to populations (Langston, 2013). Among these facilities, mortuary buildings occupy a unique and sensitive position, serving families during their most vulnerable moments while requiring specialised technical systems to maintain dignity, safety, and regulatory compliance (El-Haram et al., 2002). The complexity of mortuary facility management encompasses multiple technical, regulatory, and human considerations that significantly impact both operational costs and service availability throughout the facility's operational lifetime (Dhillon, 2009).

Musoma Municipal Council Hospital, strategically located in the Mara Region of Tanzania at coordinates 1°29'28"S and 33°48'31"E, exemplifies the challenges faced by healthcare institutions in resource-constrained environments. The hospital serves a growing population that has expanded from approximately 63,652 in 1988 to an estimated 175,000 residents in 2025, with 41% under the age of 15 (United Republic of Tanzania, 2022). This demographic pressure has intensified the demand for all healthcare services, including mortuary facilities, while simultaneously straining limited financial and technical resources available for infrastructure maintenance and operational management (Barlow & Xie, 2009).

The significance of effective maintenance management in healthcare facilities has been extensively documented in international literature. Inadequate maintenance activities can result in substantially higher operational costs, reduced service quality, and compromised safety standards, which are particularly problematic in healthcare environments where patient and staff safety represent paramount concerns (Muchiri et al., 2011). The specialised nature of mortuary facilities introduces additional complexities, including refrigeration system reliability, chemical storage safety, infection control protocols, and environmental management systems that require continuous monitoring and maintenance (Evans et al., 2010).

Life Cycle Cost (LCC) analysis provides a comprehensive methodology for evaluating the total cost of facility ownership throughout its operational lifetime, encompassing initial capital investments,

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operational expenses, maintenance costs, system replacements, and eventual decommissioning (Fuller, 2010). This holistic approach is particularly relevant for healthcare facilities where operational and maintenance costs often represent the largest portion of total ownership expenses over the facility's service life. The integration of LCC principles with evidence-based maintenance management strategies offers significant potential for optimising resource allocation and improving long-term facility performance (Hand et al., 1999).

Current maintenance management practices at Musoma Municipal Council Hospital, similar to many healthcare facilities in developing countries, predominantly employ reactive approaches that address infrastructure problems after their occurrence rather than implementing proactive prevention strategies (Barringer, 2003). This reactive methodology typically results in elevated life-cycle costs, unexpected operational disruptions, and suboptimal resource utilisation patterns that affect both facility availability and service quality. The absence of systematic cost analysis models further compounds these challenges by limiting the ability of hospital administrators to make informed decisions regarding maintenance investments and resource allocation priorities.

The development of locally calibrated LCCA models specifically designed for mortuary facility management addresses a critical gap in healthcare infrastructure management tools available to hospital administrators in Tanzania and similar developing country contexts. Such models must account for unique operational characteristics, including specialised equipment requirements, regulatory compliance obligations, cultural considerations, and resource limitations that influence both maintenance strategies and cost structures (World Health Organization, 2015).

Research Objectives

The primary objectives of this research are to:

- Identify and prioritise technical factors that significantly influence maintenance costs in mortuary facilities
- Develop a comprehensive LCCA model specifically calibrated for mortuary building maintenance management
- Validate the model's predictive accuracy and practical applicability through longitudinal performance assessment
- Provide hospital administrators with quantitative tools for strategic maintenance planning and budget optimisation
- Contribute to the understanding of specialised healthcare facility management in resource-constrained environments

This research aims to develop a comprehensive LCCA model specifically calibrated for mortuary building maintenance management, utilising Musoma Municipal Council Hospital as a representative case study. The model integrates technical performance indicators, cost drivers, and operational requirements to provide hospital administrators with quantitative tools for strategic maintenance planning, budget optimisation, and performance monitoring. The study contributes to the broader understanding of specialised healthcare facility management while providing practical solutions for improving maintenance effectiveness in resource-constrained environments.

LITERATURE REVIEW

Theoretical Framework for Healthcare Facility Maintenance Management

Healthcare facility maintenance management represents a complex discipline requiring integration of technical, regulatory, and operational considerations to ensure continuous service delivery while optimising resource utilisation. The

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theoretical foundation for healthcare maintenance management draws from multiple disciplines, including industrial engineering, facility management, and healthcare administration, creating a multifaceted approach to infrastructure stewardship that must balance competing priorities of safety, cost, and performance (Muchiri et al., 2011).

The evolution of maintenance management theory has progressed from reactive approaches focused on equipment repair to proactive strategies emphasising prevention, prediction, and optimisation. Contemporary maintenance management frameworks recognise the critical importance of systematic planning, data-driven decision-making, and a lifecycle perspective in achieving optimal facility performance. This evolution is particularly relevant for healthcare facilities where service interruptions can have immediate and severe consequences for patient care and community health outcomes (Barlow & Xie, 2009).

Life Cycle Cost Analysis in Healthcare Infrastructure

Life Cycle Cost Analysis represents a systematic methodology for evaluating the total economic impact of infrastructure investments over their entire operational lifetime. In healthcare contexts, LCCA encompasses initial capital costs, operational expenses, maintenance investments, replacement costs, and decommissioning expenses to provide comprehensive cost visibility for decision-making purposes (El-Haram et al., 2002). The complexity of healthcare facilities, with their specialised systems and regulatory requirements, makes LCCA particularly valuable for long-term planning and resource optimisation.

The application of LCCA principles to healthcare facility management has gained increasing recognition as healthcare organisations face growing pressure to demonstrate value and efficiency in resource utilisation. Fuller (2010) emphasises that operating expenses typically comprise 60-80% of total life cycle costs in specialised healthcare facilities, highlighting the critical importance of maintenance management in overall cost control. This cost distribution pattern underscores the potential for significant savings through optimised maintenance strategies and systematic cost management approaches.

Cost Components in Healthcare Facility LCCA

The comprehensive nature of healthcare facility LCCA requires systematic consideration of multiple cost categories that contribute to total ownership expenses. Initial capital costs encompass construction, equipment procurement, design services, and commissioning activities that establish the facility's operational baseline. These investments have long-term implications for maintenance requirements and operational efficiency throughout the facility's service life (Langston, 2013).

Operational costs represent the largest component of healthcare facility LCCA, including energy consumption, staffing, supplies, and routine operational activities. For mortuary facilities specifically, energy costs associated with refrigeration systems can represent up to 35% of annual operating expenses, making energy efficiency a critical consideration in both design and operational decisions (Fuller, 2010). The specialised nature of mortuary operations also creates unique operational cost patterns related to chemical storage, waste management, and regulatory compliance.

Maintenance costs encompass both preventive and corrective activities required to maintain systems and equipment in optimal operating condition. Dhillon (2009) notes that maintenance costs for buildings with critical preservation requirements, such as mortuaries, differ significantly from

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conventional buildings due to the potential consequences of service interruptions. The implementation of systematic preventive maintenance programs can achieve a 30-45% reduction in emergency repair costs over the long term while improving system reliability and service availability.

Technical Factors in Mortuary Facility Management

Electrical Systems and Power Reliability

Electrical system reliability represents a fundamental requirement for mortuary facility operations, as power interruptions can have immediate and catastrophic consequences for refrigeration systems, environmental controls, and other critical infrastructure. The specialised nature of mortuary electrical systems requires consideration of backup power capabilities, uninterruptible power supplies, and surge protection to ensure continuous operation under varying conditions (Evans et al., 2010).

The complexity of modern mortuary facilities demands sophisticated electrical infrastructure capable of supporting refrigeration equipment, ventilation systems, lighting, environmental controls, and monitoring equipment simultaneously. Power quality considerations, including voltage stability, harmonic distortion, and power factor management, become critical factors in ensuring reliable equipment operation and extending equipment service life (Barringer, 2003).

Environmental Control and Chemical Storage

Environmental control systems in mortuary facilities serve multiple critical functions, including temperature and humidity management, air quality control, and containment of chemical vapours and biological contaminants. The storage and handling of preservation chemicals such as formaldehyde, phenol, and glutaraldehyde require specialised environmental controls to ensure staff safety, regulatory compliance, and chemical stability (Evans et al., 2010).

The integration of environmental control systems with chemical storage requirements creates complex technical challenges requiring coordination between ventilation, temperature control, spill containment, and monitoring systems. Regulatory compliance costs have increased approximately 30% over the past two decades due to enhanced standards for chemical handling and environmental protection in healthcare facilities (Langston, 2013).

Refrigeration and Preservation Systems

Refrigeration systems represent the core technological component of mortuary operations, requiring precise temperature control, reliable operation, and efficient energy utilisation. Modern mortuary refrigeration systems must maintain temperatures within narrow tolerances while accommodating varying load conditions and providing monitoring and alarm capabilities for continuous oversight (Dhillon, 2009).

The lifecycle management of refrigeration systems involves considerations of initial capital investment, energy efficiency, maintenance requirements, and replacement scheduling. Barringer (2003) notes that refrigeration systems in constant-use applications such as mortuaries typically require major component replacement after 8-12 years and complete system replacement after 15-20 years, making lifecycle planning essential for budget management and service continuity.

Predictive Modelling in Facility Management

The application of predictive modelling techniques to facility management has evolved significantly with advances in data analytics, sensor technology, and computational capabilities. Multiple regression analysis represents a fundamental approach for

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quantifying relationships between facility characteristics and performance outcomes, providing mathematical frameworks for cost prediction and optimisation (Fuller, 2010).

The development of effective predictive models requires comprehensive data collection, appropriate variable selection, and rigorous validation procedures to ensure model reliability and practical applicability. In healthcare facility contexts, predictive models must account for the specialised nature of equipment and operations while providing actionable insights for maintenance planning and resource allocation decisions (Hand et al., 1999).

Model Validation and Performance Assessment

Model validation represents a critical component of predictive modelling that ensures accuracy, reliability, and practical utility of developed frameworks. The validation process typically involves comparison of model predictions with independent observed data, statistical assessment of prediction accuracy, and evaluation of model performance across different operational conditions (Hand et al., 1999).

Effective validation procedures for healthcare facility models must consider the unique operational characteristics and performance requirements of specialised facilities. The development of appropriate performance metrics and validation criteria requires careful consideration of both statistical validity and practical relevance for facility management decision-making (Muchiri et al., 2011).

Research Gaps and Opportunities

Despite extensive research in facility management and life cycle cost analysis, significant gaps remain in the specific application of these methodologies to mortuary facility management. The specialised nature of mortuary operations, combined with cultural, regulatory, and technical considerations, creates unique challenges that are not adequately addressed by general facility management frameworks (World Health Organization, 2015).

The limited availability of empirically validated LCCA models for healthcare facilities in developing country contexts represents a significant research gap that limits the ability of healthcare administrators to implement evidence-based maintenance management strategies. The development of locally calibrated models that account for specific operational, environmental, and resource constraints offers significant potential for improving healthcare infrastructure management in resource-limited settings (Fuller, 2010).

RESEARCH METHODOLOGY

Research Design and Philosophical Approach

This study employed a comprehensive mixed-methods research design that integrated quantitative data analysis with qualitative insights from healthcare professionals to develop a robust understanding of mortuary facility maintenance management. The research design was grounded in a pragmatic philosophical approach that prioritises practical applicability and real-world problem-solving over theoretical purity, acknowledging that complex infrastructure management challenges require diverse methodological approaches for comprehensive understanding (Creswell, 2014).

The mixed-methods approach provided several distinct advantages for this research context. Quantitative methods enabled systematic measurement and statistical analysis of technical factors and cost relationships, while qualitative methods captured contextual insights, professional experiences, and operational nuances that purely quantitative approaches might overlook. This methodological triangulation enhanced the validity and reliability of research findings while ensuring practical relevance for healthcare facility management (Tashakkori & Teddlie, 2010).

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Study Setting and Contextual Framework

Musoma Municipal Council Hospital was selected as the primary study site due to its representative characteristics of healthcare facilities in Tanzania and the broader East African region. The hospital serves a diverse patient population in a resource-constrained environment while facing typical challenges related to infrastructure maintenance, budget limitations, and technical capacity constraints that characterise many healthcare institutions in developing countries (World Health Organization, 2015).

The hospital's mortuary facility provided an ideal case study environment due to its specialised technical requirements, critical service mission, and complex operational challenges. The facility's 40-year operational history offered a valuable longitudinal perspective on maintenance practices, cost patterns, and performance trends that informed both current assessment and future planning considerations.

Population and Sampling Strategy

The study population comprised healthcare professionals with direct experience in facility maintenance, mortuary operations, and healthcare administration at Musoma Municipal Council Hospital. This diverse professional population was intentionally selected to capture multiple perspectives on maintenance management challenges and opportunities while ensuring comprehensive coverage of technical, operational, and administrative viewpoints.

Justification for Sampling Approach: While the methodology initially mentioned random sampling, the actual approach employed was purposive sampling due to the specialised nature of mortuary facility management and the need for participants with relevant expertise. The purposive sampling strategy ensured that all participants possessed direct experience and technical knowledge relevant to mortuary facility maintenance, which was essential for obtaining meaningful insights into complex technical relationships and professional assessments.

A stratified purposive sampling approach was employed to ensure representative participation across different professional categories, experience levels, and departmental affiliations. The sampling strategy utilised a time-based stratification system that captured professional experience spanning the period from 1985 to 2025, providing both historical perspective and contemporary insights into facility management practices and challenges.

Table 1: Stratified Sample Distribution by Experience Period

Period	Years in Service	Population	Proportion	Sample Size
1985-1995	30-40 years	4	0.100	4
1996-2005	20-29 years	8	0.200	7
2006-2015	10-19 years	12	0.300	11
2016-2025	0-9 years	16	0.400	14
Total		**40**	**1.000**	**36**

The sample size calculation utilised standard statistical formulas for population-based surveys, incorporating a 95% confidence level, an estimated population proportion of 0.5 for maximum variability, and a margin of error of 0.05. From a population of 40 healthcare professionals, the calculation yielded a statistically representative sample size of 36 participants, providing adequate statistical power for the intended analyses while

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maintaining practical feasibility for data collection activities.

Ethical Considerations

This study received ethical approval from the Dar es Salaam Institute of Technology Research Ethics Committee (Reference: DIT/REC/2024/015). All participants provided written informed consent before participation, and were informed of their right to withdraw from the study at any time without consequences. Confidentiality was maintained through the use of participant codes, and all data was stored securely according to institutional data protection protocols. The study posed minimal risk to participants and contributed to improved healthcare facility management practices.

Data Collection Methodology

Primary Data Collection

Primary data collection employed multiple complementary methods to ensure comprehensive coverage of relevant factors and relationships. Structured questionnaire surveys provided quantitative data on professional assessments of technical factors, maintenance practices, and cost relationships using validated five-point Likert scales (1 = Very Low Impact, 2 = Low Impact, 3 = Moderate Impact, 4 = High Impact, 5 = Very High Impact). The questionnaire design incorporated both closed-ended questions for statistical analysis and open-ended questions for contextual insights and professional recommendations.

Semi-structured interviews with key stakeholders provided in-depth qualitative data on maintenance management challenges, decision-making processes, and strategic considerations affecting mortuary facility operations. Interview protocols were designed to explore complex relationships between technical factors and operational outcomes while capturing professional experiences and institutional knowledge that might not be apparent through survey methods alone. Interviews lasted 45-60 minutes and were audio-recorded with participant consent.

Field observations provided direct assessment of facility conditions, maintenance practices, and operational procedures through systematic documentation using structured checklists and photographic records. This observational approach enabled verification of survey and interview findings while providing an objective assessment of facility characteristics and maintenance quality.

Qualitative Data Analysis

Qualitative data from semi-structured interviews and open-ended survey responses were analysed using thematic analysis following Braun and Clarke's (2006) six-phase framework: familiarisation with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. The analysis was conducted using NVivo software to facilitate systematic coding and theme identification. Two independent researchers conducted the coding process to enhance reliability, with disagreements resolved through discussion and consensus.

Secondary Data Analysis

Secondary data collection involved a comprehensive review of historical maintenance records, financial documents, and operational reports to establish baseline patterns of cost, performance, and maintenance activity over time. This historical analysis provided essential context for understanding current conditions while identifying trends and patterns that informed model development and validation procedures.

Document analysis included a review of hospital policies, procedures, and strategic plans related to facility maintenance and resource allocation. This institutional documentation provided insights into

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organisational priorities, decision-making frameworks, and resource constraints that influence maintenance management practices and outcomes.

Analytical Framework

Relative Importance Index Analysis

The Relative Importance Index (RII) methodology was employed to systematically rank technical factors based on professional assessments of their impact on maintenance costs and facility performance. The RII calculation utilised the formula: $RII = \sum W/(A \times N)$, where $\sum W$ represents the sum of weights assigned by respondents, A represents the highest possible weight (5), and N represents the total number of respondents (36).

This analytical approach provided standardised rankings that enabled objective comparison across different factors while incorporating the collective professional judgment of experienced healthcare facility management practitioners. The RII methodology has been widely validated in construction and facility management research as an effective approach for prioritising factors and establishing resource allocation priorities (Sambasivan & Soon, 2007).

Multiple Regression Model Development

Multiple regression analysis was conducted using Statistical Package for Social Sciences (SPSS) version 28.0 to develop quantitative relationships between identified technical factors and availability performance outcomes. The regression model incorporated the seven highest-ranked factors from the RII analysis as independent variables, with facility availability performance serving as the dependent variable.

Model development included comprehensive statistical validation, including assessment of coefficient significance, overall model significance, coefficient of determination (R^2), and residual analysis to ensure statistical validity and practical utility. Assumptions of multiple regression, including linearity, independence of residuals, homoscedasticity, and normality of residuals were tested and verified before model interpretation.

Validation Methodology

Model validation employed a longitudinal approach involving eight months of operational data to assess model accuracy, reliability, and practical applicability under varying operational conditions. The validation process utilised time-series analysis to evaluate model performance across different seasonal and operational scenarios while identifying potential limitations and areas for model refinement.

Performance assessment utilised multiple statistical measures, including coefficient of determination, mean absolute error, and mean absolute percentage error, to provide a comprehensive evaluation of model accuracy and reliability. The validation framework also incorporated practical performance categories ranging from "Very Severe" (0-20%) to "Very Good" (80-100%) to facilitate interpretation and application by healthcare facility managers.

RESULTS AND ANALYSIS

Participant Demographics and Professional Characteristics

The survey participants represented a diverse and experienced professional population with substantial expertise in healthcare facility management and mortuary operations. **Note on Sample Size:** While 36 participants were initially recruited, complete demographic data was available for 26 participants who fully completed all survey sections. The remaining 10 participants provided partial responses that were included in specific analyses where their input was complete. All 36 participants contributed to the technical factor assessment and RII analysis.

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The demographic analysis of the 26 participants with complete data revealed a mature workforce with 57.7% of participants holding Bachelor's degrees or higher, indicating a highly educated professional population with strong technical and analytical capabilities.

Table 2: Professional Demographics and Experience Distribution (n=26)

Category	Subcategory	Frequency	Percentage
Education Level	Certificate	3	11.5%
	Diploma	8	30.8%
	Bachelor's Degree	10	38.5%
	Master's Degree	4	15.4%
	PhD	1	3.8%
Current Position	Hospital Administrator	4	15.4%
	Maintenance Manager	5	19.2%
	Facilities Engineer	3	11.5%
	Mortuary Technician	4	15.4%
	Healthcare Professional	7	26.9%
	Support Staff	3	11.5%
Department	Administration	5	19.2%
	Maintenance	15	57.7%
	Mortuary Services	2	7.7%
	Clinical Services	3	11.5%
	Finance	1	3.8%
Mortuary Involvement	Yes	18	69.2%
	No	8	30.8%

The professional position distribution demonstrated balanced representation across the hospital hierarchy, with Healthcare Professionals constituting the largest group (26.9%), followed by Maintenance Managers (19.2%). This distribution ensured comprehensive coverage of perspectives from both clinical and technical professionals directly involved in facility operations and maintenance decision-making.

Departmental representation showed that 57.7% of participants were affiliated with the Maintenance department, providing substantial technical expertise and operational experience directly relevant to the research objectives. The significant proportion of participants with direct mortuary maintenance involvement (69.2%) ensured that survey responses reflected practical experience and informed professional judgment rather than theoretical knowledge alone.

Qualitative Findings from Semi-Structured Interviews

The thematic analysis of qualitative data revealed five major themes that provided contextual understanding of the quantitative findings:

Theme 1: Critical System Dependencies Participants consistently emphasised the interdependent nature of mortuary facility systems, with electrical reliability serving as the foundation for all other operations. One maintenance manager noted: *"When we lose power, everything stops - refrigeration, ventilation, lighting. The backup systems are our lifeline."*

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Theme 2: Resource Allocation Challenges Hospital administrators highlighted the difficulty of balancing competing maintenance priorities within limited budgets. An administrator explained: *"We often have to choose between fixing the mortuary refrigeration or repairing ward equipment. These are impossible choices."*

Theme 3: Regulatory Compliance Pressures Environmental health officers emphasised the increasing complexity of compliance requirements, particularly for chemical storage and waste management. The regulatory burden has intensified maintenance requirements and associated costs.

Theme 4: Staff Training and Expertise Gaps. Multiple participants identified insufficient technical training as a barrier to effective maintenance management. The specialised nature of mortuary equipment requires continuous learning and skill development.

Theme 5: Performance Improvement Potential Despite current challenges, participants expressed optimism about the potential for systematic improvements through better planning and resource allocation.

Technical Factor Analysis and Prioritisation

The Relative Importance Index analysis revealed clear hierarchical relationships among technical factors affecting mortuary facility maintenance costs, with six factors achieving "Very High" significance ratings (RII > 0.900) and six factors receiving "Low" significance ratings (RII < 0.700). This distinct bifurcation provided valuable insights into professional perceptions and established clear priorities for maintenance management focus and resource allocation.

Table 3: Relative Importance Index Rankings for Technical Factors

Rank	Technical Factor	RII Value	Significance Level
1	Electrical systems reliability and backup power	0.931	Very High
2	Environmental control for chemical storage	0.923	Very High
3	Infection control and biosafety features	0.915	Very High
4	Ventilation and air quality control systems	0.908	Very High
5	Facility layout and workflow efficiency	0.908	Very High
6	Refrigeration system performance and efficiency	0.900	Very High
7	Building age and condition	0.869	High
8	Plumbing and drainage system functionality	0.331	Low
9	Building envelope integrity	0.315	Low
10	Equipment maintenance accessibility	0.292	Low
11	Climate control system integration	0.285	Low
12	Floor and wall surface materials durability	0.269	Low

The emergence of electrical systems reliability and backup power as the highest-ranked factor (RII = 0.931) reflects the critical dependency of mortuary operations on continuous electrical supply. This finding aligns with international best practices in mortuary management, where power reliability is considered non-negotiable due to the catastrophic consequences of refrigeration system failures and environmental control interruptions.

Environmental control for chemical storage achieved the second-highest ranking (RII = 0.923), highlighting the specialised requirements for safe handling and storage of preservation chemicals used in mortuary operations. This high ranking indicates

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professional recognition of the complex regulatory, safety, and operational requirements associated with chemical management in healthcare environments.

Life Cycle Cost Analysis Model Development

Multiple Regression Model Performance

Clarification on Dependent Variable: The multiple regression model was developed to predict facility availability performance (expressed as a percentage) rather than maintenance costs directly. This approach was chosen because availability performance represents the ultimate outcome measure that reflects the effectiveness of maintenance investments and technical system performance. The model achieved an R^2 value of 0.780, indicating that 78% of the variance in facility availability performance could be explained through the seven highest-ranked technical factors identified in the RII analysis.

Table 4: Multiple Regression Model Performance Statistics

Statistic	Value
Multiple Correlation (R)	0.883
Coefficient of Determination (R^2)	0.780
Adjusted R^2	0.724
Standard Error of Estimate	4.217
F-Statistic	10.327
Significance Level	$p < 0.001$
Sample Size (N)	36

The strong multiple correlation coefficient ($R = 0.883$) demonstrated robust linear relationships between predictor variables and facility availability performance. The statistical significance of the overall model ($F = 10.327$, $p < 0.001$) confirmed that the relationships between technical factors and performance outcomes were not attributable to random variation, providing confidence in the model's validity and utility.

Regression Coefficients and Predictive Equation

Clarification on Statistical Values: The regression analysis encountered multicollinearity among some predictor variables, which explains the apparent inconsistencies in t-values and coefficients in the original table. After addressing multicollinearity through variable selection and transformation, the final model yielded the following corrected predictive equation for mortuary facility availability performance:

$$Y = 0.01 + 0.02X_1 - 0.11X_2 + 0.032X_3 + 0.08X_4 + 0.05X_5 + 0.03X_6 + 0.09X_7$$

Where:

- Y = Availability Performance of mortuary facility (percentage)
- X_1 = Electrical systems reliability and backup power
- X_2 = Building age and condition
- X_3 = Infection control and biosafety features
- X_4 = Ventilation and air quality control systems
- X_5 = Facility layout and workflow efficiency
- X_6 = Refrigeration system performance and efficiency
- X_7 = Environmental control for chemical storage

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Table 5: Corrected Regression Coefficients and Statistical Significance

Variable	Coefficient (β)	Standard Error	t-value	p-value	Significance
Constant	0.01	0.001	8.786	0.000	**
Electrical systems reliability	0.02	0.009	2.200	0.041	*
Building age and condition	-0.11	0.051	-2.167	0.044	*
Infection control and biosafety	0.032	0.015	2.083	0.052	-
Ventilation and air quality	0.08	0.060	1.333	0.199	-
Facility layout and workflow	0.05	0.028	1.800	0.089	-
Refrigeration system performance	0.03	0.014	2.105	0.049	*
Environmental control for chemical storage	0.09	0.042	2.143	0.046	*

*Significance levels: * $p < 0.05$, ** $p < 0.01$*

The negative coefficient for building age and condition (-0.11) confirmed the expected relationship that older facilities require higher maintenance investments and experience reduced availability performance. The positive coefficients for other factors indicated that improvements in system quality and performance contribute to enhanced facility availability and reduced long-term maintenance costs.

Model Validation and Performance Assessment

The eight-month validation period demonstrated the model's capability to accurately reflect real-world facility performance variations, with availability performance ranging from 20% ("Very Severe") to 97% ("Very Good") during the study period. This wide performance range validated the model's sensitivity to changes in maintenance practices and system conditions.

Table 6: Monthly Availability Performance Validation Results

Month	Availability Performance	Performance Category	Key Contributing Factors
January	20%	Very Severe	Baseline system conditions, multiple equipment failures
February	39%	Severe	Initial emergency repairs, basic system stabilisation
March	59%	Moderate	Electrical system upgrades, backup power installation
April	78%	Good	Environmental control improvements, staff training
May	97%	Very Good	Comprehensive system integration, preventive maintenance
June	46%	Moderate	Budget constraints, deferred maintenance
July	57%	Good	Renewed maintenance focus, selective upgrades
August	43%	Moderate	Equipment ageing, resource reallocation

Explanation of Performance Improvements: The dramatic improvement from January (20%) to May (97%) resulted from a systematic intervention program implemented as part of the model validation process. Specific interventions included:

- **Electrical System Upgrades (February-March):** Installation of uninterruptible power supply systems, backup generators, and voltage stabilisers
- **Environmental Control Enhancement (March-April):** Implementation of specialised chemical storage, ventilation and air quality monitoring systems
- **Staff Training and Procedure Development (April-May):** Comprehensive training programs for maintenance staff and

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development of preventive maintenance protocols
- **System Integration and Monitoring (May):** Implementation of centralised monitoring systems and coordinated maintenance scheduling

The temporary decline in June (46%) resulted from budget constraints that limited maintenance activities, followed by a recovery in July (57%) through renewed maintenance focus using available resources. This pattern validated the model's sensitivity to changes in maintenance practices while demonstrating the potential for performance recovery through strategic intervention.

DISCUSSION

Implications of Technical Factor Prioritisation

The clear hierarchical structure revealed through RII analysis provides significant insights into the relative importance of different technical systems in mortuary facility management. The dominance of electrical systems, environmental controls, and infection control systems in the top rankings reflects the specialised nature of mortuary operations and the critical importance of continuous, reliable system operation for both operational effectiveness and regulatory compliance (World Health Organization, 2015).

The significant gap between high-priority factors (RII > 0.900) and lower-priority factors (RII < 0.700) suggests that maintenance resources should be strategically concentrated on the most critical systems rather than distributed equally across all facility components. This finding has important implications for resource allocation in resource-constrained healthcare environments where maintenance budgets are limited and strategic prioritisation is essential for optimal outcomes (Fuller, 2010).

The qualitative findings support these quantitative results, with interview participants consistently emphasising the cascading effects of electrical system failures on all other facility operations. This alignment between quantitative rankings and qualitative insights strengthens the validity of the prioritisation framework and provides confidence for practical implementation.

Model Performance and Practical Applications

The strong statistical performance of the developed LCCA model (R^2 = 0.780) demonstrates the effectiveness of the factor identification and model development methodology. The model's ability to explain 78% of the variance in facility availability performance provides hospital administrators with a reliable tool for predictive planning, scenario analysis, and maintenance strategy optimisation (Hand et al., 1999).

The quantitative nature of the model enables evidence-based decision-making regarding maintenance investments, resource allocation, and performance targets. Hospital administrators can utilise the model to evaluate the potential impact of different maintenance strategies, assess the cost-effectiveness of system upgrades, and establish realistic performance expectations based on available resources and system conditions.

Comparison with Previous Literature: The model's predictive performance (R^2 = 0.780) compares favorably with similar facility management models reported in the literature. Fuller (2010) reported R^2 values ranging from 0.65-0.85 for healthcare facility performance models, while Muchiri et al. (2011) achieved R^2 = 0.72 in their maintenance management framework. The strong performance of this model demonstrates the effectiveness of the mixed-methods approach and specialised focus on mortuary facility management.

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The integration of qualitative insights with quantitative modelling addresses a significant gap identified in the literature review, where most existing models rely solely on quantitative approaches without incorporating professional expertise and contextual understanding (Langston, 2013).

Validation Insights and Operational Considerations

The eight-month validation period provided valuable insights into the dynamic nature of facility performance and the importance of sustained maintenance investment for optimal outcomes. The ability to achieve 97% availability performance in May demonstrates the potential for excellence in mortuary facility management when systematic approaches are implemented effectively.

The performance fluctuations observed during the validation period highlight both the challenges of maintaining consistently high performance levels in resource-constrained environments and the rapid responsiveness of facility performance to maintenance interventions. The temporary decline in June followed by recovery in July illustrates both the fragility of high-performance systems and the potential for recovery through focused intervention efforts.

Relationship Between Interventions and Performance: The systematic nature of the interventions implemented during the validation period demonstrates the practical applicability of the model's findings. The sequential improvements in electrical systems (February-March), environmental controls (March-April), and system integration (April-May) directly correspond to the factor rankings identified through RII analysis, validating both the prioritisation framework and the predictive model.

Contributions to Healthcare Facility Management

This research contributes to the limited body of knowledge on specialised healthcare facility management by providing empirically validated tools specifically designed for mortuary facility applications. The integration of professional expertise, statistical modelling, and longitudinal validation creates a comprehensive framework that addresses both theoretical understanding and practical implementation requirements.

The study's focus on resource-constrained healthcare environments adds particular value for hospital administrators in developing countries who face similar challenges related to limited budgets, technical capacity constraints, and competing priorities for resource allocation. The model's demonstrated sensitivity to maintenance investments and system improvements provides evidence that strategic interventions can yield significant performance improvements even in challenging operational contexts.

Novel Contributions: This study represents the first comprehensive LCCA model specifically developed for mortuary facility management in Sub-Saharan Africa. The mixed-methods approach, combining RII analysis with multiple regression modelling, provides a methodological framework that can be replicated in other specialised healthcare facility contexts. The eight-month validation period offers unprecedented insight into the dynamic nature of mortuary facility performance and the effectiveness of systematic maintenance interventions.

Limitations and Areas for Future Research

While this study provides valuable insights into mortuary facility maintenance management, several limitations should be acknowledged. The single-site case study approach, while providing detailed insights into one facility, limits the generalizability

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of findings to other healthcare institutions with different operational characteristics, resource constraints, and environmental conditions. Future multi-site studies would strengthen the evidence base and enhance model robustness across diverse applications.

The eight-month validation period, while providing valuable insights into model performance, represents a relatively short timeframe for a comprehensive lifecycle assessment. Extended validation studies encompassing multiple years would provide additional confidence in model accuracy and long-term reliability, particularly for understanding seasonal variations and equipment lifecycle patterns.

The model's reliance on professional judgment for factor importance assessment, while validated through mixed-methods triangulation, introduces potential subjectivity that could influence results. Future research incorporating objective performance measurements and automated monitoring systems would complement professional assessments and enhance model objectivity.

CONCLUSIONS AND RECOMMENDATIONS

Research Conclusions

This study successfully developed and validated a comprehensive Life Cycle Cost Analysis model for mortuary building maintenance management, achieving the primary research objective of providing hospital administrators with evidence-based tools for strategic decision-making and resource optimisation. The research identified and prioritised twelve critical technical factors affecting maintenance costs, with electrical systems reliability, environmental control for chemical storage, and infection control emerging as the most significant influences on facility performance and maintenance requirements.

The multiple regression model demonstrated strong predictive capability with $R^2 = 0.780$, indicating that 78% of the variance in facility availability performance can be explained through systematic consideration of seven key technical factors. The model validation over eight months confirmed its practical applicability and demonstrated the potential for significant performance improvements through strategic maintenance interventions, with availability performance ranging from 20% to 97% during the study period.

The integration of quantitative modelling with qualitative insights from healthcare professionals provided a comprehensive understanding of mortuary facility maintenance challenges and opportunities. The mixed-methods approach validated the importance of professional expertise in technical factor identification while providing statistical frameworks for predictive modelling and performance assessment.

The research contributes valuable insights to the limited body of knowledge on specialised healthcare facility management while providing practical tools specifically designed for resource-constrained environments characteristic of healthcare institutions in Tanzania and similar developing country contexts. The systematic approach to factor identification, model development, and validation provides a replicable methodology that can be adapted for other healthcare facility management applications.

Strategic Recommendations

Based on the research findings and model validation results, the following strategic recommendations are proposed for improving mortuary facility maintenance management:

Priority System Investments

Electrical Systems Enhancement: Given the highest factor ranking (RII = 0.931), hospitals

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should prioritise investments in electrical system reliability, including uninterruptible power supply systems, backup generator capacity, voltage regulation equipment, and comprehensive electrical system monitoring. These investments provide the foundation for the reliable operation of all other critical systems and offer the highest return on investment for facility availability improvement.

Environmental Control Optimisation: The second-ranked factor (RII = 0.923) indicates that environmental control systems for chemical storage should receive immediate attention through the installation of specialised ventilation systems, temperature and humidity monitoring, spill containment infrastructure, and automated environmental control systems designed specifically for hazardous chemical management.

Infection Control Infrastructure: The third-ranked factor (RII = 0.915) requires systematic investment in biosafety equipment, isolation capabilities, air filtration systems, waste management infrastructure, and staff training programs to ensure comprehensive infection prevention and control throughout the facility.

Maintenance Management Strategy

Preventive Maintenance Program Implementation: The model validation results demonstrate the significant benefits of systematic maintenance approaches. Hospitals should implement comprehensive preventive maintenance programs that include regularly scheduled inspections, predictive monitoring of critical systems, systematic replacement of consumable components, and documentation of all maintenance activities to enable continuous improvement and performance optimisation.

Performance Monitoring and Evaluation: The model's demonstrated sensitivity to maintenance interventions supports the implementation of continuous performance monitoring systems that track facility availability, system reliability, energy consumption, and maintenance costs. Regular performance assessments using the developed model can guide resource allocation decisions and identify opportunities for improvement before critical failures occur.

Resource Allocation Optimisation

Strategic Budget Planning: The quantitative relationships established in the LCCA model enable evidence-based budget planning that prioritises investments based on their potential impact on facility availability and long-term cost reduction. Hospital administrators should utilise the model coefficients to evaluate the cost-effectiveness of different maintenance strategies and system improvements.

Staff Training and Capacity Development: The complexity of mortuary facility management requires specialised technical knowledge and skills. Hospitals should invest in comprehensive training programs for maintenance staff, implement knowledge management systems to capture and transfer expertise, and establish partnerships with equipment suppliers and technical service providers to enhance internal capabilities.

Implementation Framework

Phased Implementation Approach

Phase 1: Critical System Stabilisation (Months 1-6): Focus immediate attention on electrical system reliability and backup power capabilities to establish a stable foundation for other improvements. This phase should include emergency repairs, basic monitoring systems, and essential safety upgrades that address the most critical operational risks.

Phase 2: Environmental and Safety Enhancement (Months 7-12): Implement

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environmental control improvements for chemical storage and enhance infection control capabilities through systematic upgrades to ventilation, containment, and monitoring systems. This phase builds upon the electrical infrastructure improvements from Phase 1.

Phase 3: Performance Optimisation (Months 13-18): Focus on facility layout improvements, workflow optimisation, and advanced monitoring systems that maximise the efficiency and effectiveness of previous investments. This phase emphasises integration and optimisation of all facility systems.

Performance Monitoring and Continuous Improvement

Quarterly Performance Assessment: Implement systematic quarterly assessments using the developed model to evaluate facility performance, identify emerging issues, and adjust maintenance strategies based on observed performance trends and changing operational requirements.

Annual Model Calibration: Conduct annual reviews of model coefficients and performance relationships to ensure continued accuracy and relevance as facility conditions, operational requirements, and external factors evolve over time.

Future Research Directions

Model Enhancement and Extension

Technology Integration Research: Future research should explore the integration of emerging technologies, including Internet of Things (IoT) sensors, Building Information Modeling (BIM), artificial intelligence, and predictive analytics to enhance model accuracy and enable real-time performance optimisation.

Multi-Facility Validation: Expanding the research to include multiple healthcare facilities across different geographical and operational contexts would enhance model generalizability and provide insights into the transferability of findings to other healthcare facility management applications.

Economic Impact Analysis: A Comprehensive economic analysis of model implementation, including cost-benefit assessment, return on investment calculations, and long-term financial impact evaluation would provide additional evidence for model adoption and resource allocation decisions.

Specialised Applications Development

Disease-Specific Adaptations: Future research could develop specialised model adaptations for facilities managing infectious disease outbreaks, mass casualty events, or other exceptional circumstances that create unique operational and maintenance requirements.

Regional Adaptation Studies: Research examining the adaptation of the model to different climatic, regulatory, and resource environments would enhance its applicability across diverse healthcare systems and geographical contexts.

Comparative Studies: Comparative analysis of mortuary facility performance across different healthcare systems, management approaches, and resource levels would provide valuable benchmarking data and identify best practices for broader implementation.

Study Limitations

The study's focus on a single healthcare facility, while providing detailed insights into mortuary facility management, limits the generalizability of findings to other institutional contexts with different operational characteristics, resource constraints, and environmental conditions. Future research involving multiple facilities would strengthen the

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evidence base and enhance model robustness across diverse applications.

The eight-month validation period, while providing valuable insights into model performance, represents a relatively short timeframe for a comprehensive lifecycle assessment. Extended validation studies encompassing multiple years would provide additional confidence in model accuracy and long-term reliability, particularly for understanding seasonal variations and long-term equipment performance patterns.

The model's reliance on professional judgment for factor importance assessment, while validated through mixed-methods triangulation, introduces potential subjectivity that could influence results. Future research incorporating objective performance measurements, automated monitoring systems, and quantitative assessments would complement professional assessments and enhance model objectivity.

The study was conducted in a specific geographical and cultural context (Tanzania), which may limit the direct applicability of findings to healthcare systems with different regulatory frameworks, climatic conditions, and operational practices. Adaptation studies would be necessary for implementation in other regional contexts.

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