Life-Cycle Cost Analysis And Health Technology Management Of Diagnostic Medical Equipment In Ugandan Public Hospitals: Financial Sustainability Challenges And Strategic Opportunities For Improvement.

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Abstract: Diagnostic medical equipment plays a crucial role in the modern healthcare system. They aid in accurate disease diagnosis and guide critical clinical decisions. However, many Low and Middle-Income Countries (LMICs) face persistent challenges in maintaining their functionality and sustainability. The reason is because they are often designed for countries with efficient healthcare systems and adequate resources. This article examines the life-cycle costs and financial sustainability of diagnostic medical equipment in Ugandan public hospitals. A literature-based research approach was employed basing on secondary data from World Health Organization reports, Ministry of Health reports and peer-reviewed literature articles. These were complemented by expert insights from biomedical engineers in practice. A substantial proportion of diagnostic equipment in many public hospitals experience prolonged downtime due to reactive maintenance practices, fragmented procurement systems and insufficient funds allocations for operational costs. Infrastructural challenges such as unreliable electricity supply and poor facility design also negatively impact equipment performance. The article emphasizes the importance of integrating life-cycle cost analysis into the procurement and asset management frameworks. Strengthening healthcare Technology Management systems through preventive maintenance approach, digital equipment registries, workforce development and improved procurement coordination can significantly enhance the sustainability of medical equipment. Institutionalizing these strategies will be critical in improving the diagnostic capacity and ensuring long-term resilience of Uganda's public healthcare system.

Keywords: Life-Cycle Cost Analysis, Health Technology Management, Medical device, Diagnostic medical equipment, Public hospitals, Healthcare system

1 Introduction

The third Sustainable Development Goal (SDG) pertains to Universal Health Coverage (UHC) and the provision of quality essential health services. One of the most important factors in determining a health facility's efficiency is the patient's length of stay. In an attempt to operationalize and realize effective healthcare service to its citizens, the government of Uganda, through the Ministry of Health emphasizes the importance of having properly functional medical equipment in all the public health facilities [1]. In order to provide quality healthcare to the local population in Uganda, the government recently created more district health facilities and regional referral hospitals established in every region [2]. Public hospitals account for over 40% of the entire health expenditure in several Sub-Saharan African countries, and Uganda is no exception [3], [4].

The Ugandan public health care system, however, continues to face significant challenges in providing timely healthcare services to the general public. Some of the contributing factors to this are the malfunctioning referral systems, operative capacity restrained by inadequate infrastructure and overwhelmed by emergency volume, critical workforce shortages, and prolonged downtime of medical equipment in the hospitals [5]. In many cases, the concerned stakeholders overlook the importance of timely maintenance of critical diagnostic equipment. The mentality that equipment is only serviced or repaired once it has completely broken down is widespread in low-resource settings. To ensure effective management of failures and associated costs in medical equipment procurement, maintenance, and disposal, it's important to develop a reliable approach for anticipating failures.

Furthermore, Uganda also experiences a notable deficit in medical equipment relative to World Health Organization guidelines, alongside an uneven distribution of the available equipment, especially in the area of diagnostic imaging [6]. In higher-tier facilities, modalities such as computed tomography (CT) and magnetic resonance imaging (MRI) are available, though their numbers remain limited. Uncertainties continue to be induced by the ongoing healthcare reform and the year-on-year increase in general healthcare expenditures. The expansion of patients' medical needs and healthcare providers' concern to extend the life of assets while minimizing operational costs for medical equipment remains challenging to address.

Ensuring the availability, performance, and safety of medical equipment is crucial for providing quality, reliable healthcare services in modern systems. Currently, Uganda lacks a national reporting database for medical devices in all the public hospitals. The structure of the biomedical engineers and technicians is not well-balanced. A ratio of four biomedical engineers to one biomedical technician in the referral hospitals is not a realistic and functional structure for efficient equipment management. Many healthcare facilities often manage medical device procurement, maintenance, compliance, decommissioning, and financial planning autonomously. There is very little consultation between top management, the procurement department, the engineering department, and the actual equipment users. Managing these components independently, however, is insufficient, as new factors impact medical efficiency and safety [7]. This article examines the financial and social implications of poor medical equipment life-cycle management in Ugandan public hospitals, with particular focus on frequent breakdowns, high repair costs, and reliance on donations. It shows how inadequate equipment management impacts not only the financial stability of healthcare institutions but also the quality of care and the social well-being of patient populations. Additionally, it aims to identify and evaluate existing frameworks that could promote sustainable and effective use of medical equipment in low-resource healthcare systems. The article further examines how life-cycle cost analysis influences budgeting and equipment purchasing decisions. Examining these factors demonstrates how crucial it is to incorporate thorough cost analysis into healthcare management procedures to maximize equipment use, improve resource allocation, and strengthen financial sustainability in Uganda's public health sector.

2 Literature review

The World Health Organization (WHO), in agreement with the International Medical Devices Regulatory Forum (IMDRF), defines a medical device as any article, instrument, apparatus, or machine that is used in the prevention, diagnosis or treatment of illness or disease, or for detecting, measuring, restoring, correcting or modifying the structure or function of the body for some health purpose. Medical equipment, on the other hand, is defined as medical devices requiring calibration, maintenance, repair, user training, and decommissioning, activities usually managed by clinical or biomedical engineers in the hospital.

Healthcare is a term used to describe the diagnosis, treatment and prevention of illness. It is frequently described as consisting of three sectors, primary, secondary and tertiary care [8]. Families and social networks provide informal healthcare in their homes and communities. Secondary care describes care provided by medical specialists and usually delivered within a hospital setting. Tertiary care is specialist consultative care. It usually involves admission to a hospital that provides a high level of specialist care in the management of, say, cancer or the provision of specialist surgery such as cardiac surgery or neurosurgery [9]. However, with clinical and technological developments occurring within the context of evolving social, population, and economic environments, the distinctions between primary, secondary, and tertiary care continue to blur. Nonetheless, the distinctions between these levels of care are useful when considering the spectrum of healthcare provision. Hospital efficiency is vital for the overall health system, as they use significant resources.

Figure 1 illustrates these healthcare sectors, which summarize how societies structure the healthcare system optimally to meet the need for diagnosis, treatment, and prevention of illness. The arrows indicate the referral pathways. These are bidirectional, as the objective is always to improve the health of the individual, no matter where they are in the healthcare system, and in doing so, to move the individual towards independent living in the community.

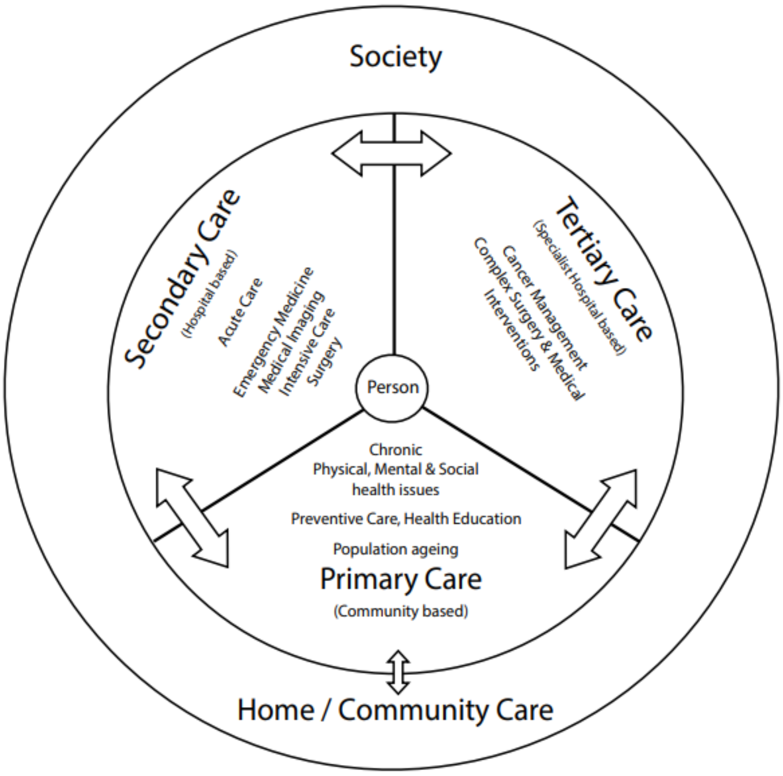

Figure 1

Showing the conceptual model of integrated healthcare delivery

An effective healthcare system heavily depends on the functionality of medical equipment. The life cycle of these medical equipment can simply be thought of as the different stages involved from the time of design conception to its end of use/decommissioning [10]. It varies globally based on infrastructure, resource allocation, and healthcare system structure. Regardless of differences, healthcare systems must manage and maintain medical devices to ensure accuracy and reliability. With the continuous technological advancements, one fact remains constant. The fact that no medical equipment or device operates to its maximum capacity reliably if not well managed. Life cycle cost (LCC) analysis involves calculating the entire/total cost of an asset over its life span. This includes costs incurred from the initial stage of acquisition, through its operation, maintenance and final disposal, [13]. Its major aim is to provide a comprehensive financial overview by considering not only the upfront purchase price but also costs like energy required for its operation, maintenance and end-of-life expenses. This is critical for proper resource allocation and decision making for long term cost-effectiveness [12] .

A fully functional healthcare system depends on how well the medical devices are maintained and managed for full reliability and accuracy. Below is a life cycle of any medical device from the planning and procurement to its end-of-life term at decommissioning.

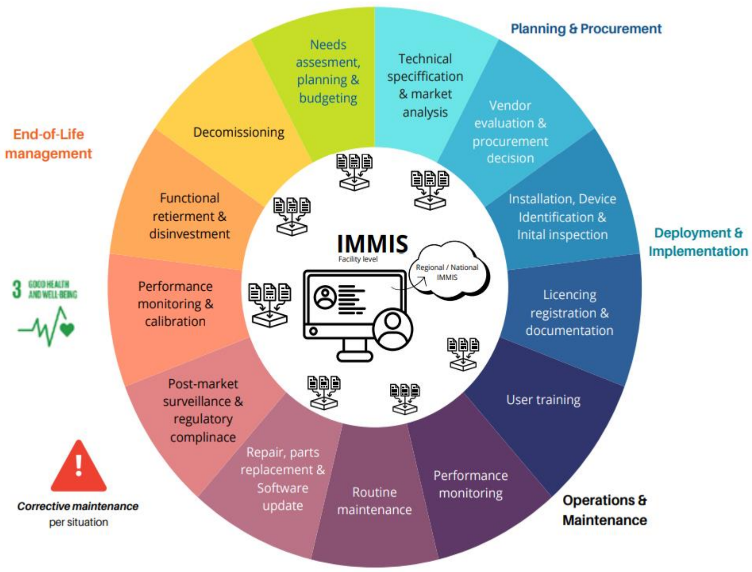

Figure 2

The life cycle of medical devices in a healthcare facility.

Source: Inventory and maintenance management system for medical devices, WHO

The very first stage entails a formal needs assessment to evaluate clinical needs and contextual requirements. It is always recommended to use evidence-based criteria when selecting medical devices. These can include technical specifications and population priorities and needs. In practice, it involves assessing whether a device's functionalities correspond with medical procedures and the local disease burdens. After identifying the requirements, the technical team should then verify the device's performance parameters (accuracy, capacity, and software features) and ensure regulatory authorities approve it and meets quality standards. Compliance with a quality management system (QMS) standard, such as ISO 13485, indicates a manufacturer's stringent practices for ensuring device safety and effectiveness [13], [14]. Another very critical aspect of the selection process is assessment of the supplier's credibility and of the support it will provide. This is extremely important that during the equipment's term of use, it will need frequent maintenance. The earlier this is put into consideration and planned for, the better the financial allocation.

Budgeting and cost are key factors in procurement choices. Decision makers should include in the purchase price to compute the total cost of ownership for a product. This covers installation, user training, planned and preventive maintenance, consumables, and energy expenses to operate. A device that is relatively cheap to acquire yet requires highly expensive consumable supplies or has a significant downtime may not be cost-effective in the long run. Procurement committees evaluate devices based on their therapeutic advantages, long-term operational costs, and compatibility with other systems. Compatibility with other equipment and information technology (IT) systems allows for seamless integration of new digital devices. Consideration of compatible devices prevent hidden expenses and technical issues [15].

Proper installation involves more than just plugging in a machine. It also includes site preparation, device performance verification, and user training to ensure safety. The first step is often ensuring that the location at which the device will be used meets all the site requirements for power supply and ventilation among others. The installation is usually done by technicians or engineers with support from the supplier's technical team if the team on ground is not very well conversant with the equipment to ensure flawless installation.After assembly, initial tests or first inspections are carried out. It involves testing and validating a device before it is used in the clinical practice. Its objective is to ensure that the device conforms with the authorized design and satisfies all defined criteria made at the needs assessment. Biomedical engineers or skilled technicians often conduct performance and safety inspections following international standards or manufacturer specifications. This phase checks that the device is functioning properly and safely after installation. Thereafter, the users of the equipment are taken through training in order to be able to use the equipment properly for the purposes it is intended for. As the equipment is used, the clinical or biomedical engineers ought to continue undertaking performance monitoring tracking for optimization, routine maintenance for prolonged life span. Medical devices, like any complex equipment, degrade or require re-calibration over time [16]. Without proper upkeep, they may fail unexpectedly or give inaccurate results, which could directly impact patient outcomes. Replacement of worn-out parts and update of software are done on the equipment depending on the need. This is a very crucial stage in the life cycle management because how long the equipment remains in good operational status relies entirely on how it is maintained at this stage.

Medical devices have a limited lifespan owing to age, wear and tear, or technical advancements. Decommissioning and disposal involve safe removal from the healthcare facility and properly disposing of it through recycling, donation, or reuse. This stage must be appropriately managed to guarantee health, environmental safety, and legal compliance. The WHO guidance emphasizes that medical equipment should be decommissioned in a structured way, with clear reasons and methods. In practice, health-care facilities should assess when a device must be taken out of use, how to do so safely and how to dispose of the device. In conjunction with reprocessing and reusable equipment, improvements in recycling are also essential to increase sustainability in medical equipment life cycles [17]. There is an absence of a widespread, effective medical recycling system because of a lack of knowledge. For example, over-classification of hazardous medical waste in hospitals results in missing recycling or reprocessing possibilities. Medical plastics that may be recycled are placed in red biohazard trash bags.

3 Methodology

The article adopted a literature-based research approach, relying on secondary data from World Health Organization and Ministry of Health reports, as well as peer-reviewed literature. These were complemented by expert insights from biomedical engineers in practice. The major emphasis was on the sequential analysis of events and factors affecting the life-cycle management of diagnostic medical equipment in Ugandan public hospitals. This approach enabled a thorough tracing of how procurement, maintenance, operation and financial sustainability challenges have evolved over time. The use of this study design also allowed for an understanding of the relationship between policy changes, technological adoption and financial outcomes within the healthcare sector.

The study area focused on public hospitals in Uganda, mostly the national and regional referral hospitals where critical diagnostic medical equipment such as X-ray machines, CT and MRI scanners and laboratory analyzers are highly concentrated. The study scope covered equipment acquisition, procurement processes, maintenance practices and associated costs, human resource capacity and financial decisions that affect sustainability and planning. The choice of this focus was based on the critical role that these hospitals play in Uganda’s healthcare delivery and their high dependance on government funding and donor-supported technologies/medical equipment.

The article employed a combination of secondary data review and key information insights. Documents and reports reviewed included the Ministry of health reports, WHO guidelines, National Medical Stores (NMS) procurement reports. Scholarly peer-reviewed articles were also searched for and read. These publications were on healthcare technology management and life-cycle cost analysis. Furthermore, policy and institutional analysis examined the Public Procurement and Disposal of Public Assets (PPDA) Act and several frameworks governing equipment management. All the data sources were carefully assessed for relevance and credibility to ensure valid findings. Expert consultations were drawn from biomedical engineers and hospital administrators to contextualize observed challenges in public hospitals.

For ethical considerations, no personal identifiers were used since the study relied primarily on secondary data and expert consultation. Institutional documents and publications from Web of Science and Google Scholar were cited according to academic standards. Expert opinions were anonymized to maintain confidentiality and respect organizational policies. However, the greatest limitation faced was restricted access to up-to-date maintenance cost data and inconsistencies in hospital reporting systems. Additionally, the reliance on secondary information limited the extent of quantitative verification. To overcome this, cross-referencing multiple credible data sources and validation of findings with expert perspectives were considered.

4 Results

4.1 Current state of diagnostic medical equipment in Ugandan public hospitals

Uganda's public health system operates within a decentralized framework that includes national referral hospitals (NRH), regional referral hospitals (RRH), general hospitals, and lower-level health facilities [18]. Each level is expected to provide progressively advanced diagnostic services. The study revealed that diagnostic medical equipment in Ugandan public hospitals is characterized by partial availability and limited functionality. A 2022 assessment by the Ministry of Health reported that while over 70% of regional hospitals had functioning ultrasound and X-ray units, only two public facilities, that is Mulago NRH and Mbarara RRH possessed operational MRI scanners. Most advanced diagnostic imaging equipment remains concentrated in urban centers, with the private sector and faith-based hospitals contributing significantly to the availability of CT and MRI services. A 2020 Hospital Infrastructure Insight Uganda report indicated that there were about 150 hospitals (both private and public) in the country, with about

38 providing tertiary healthcare. However, functional disparities persist within basic diagnostics. As a result, equipment downtime is frequent and directly affects service delivery, increasing patient waiting times. Many district hospitals operate outdated analog X-ray systems with limited image quality. A significant proportion of laboratory diagnostic equipment, such as chemistry and hematology analyzers, is donor-procured, leading to a mix of brands and models that complicates maintenance and standardization. The overall picture is one of partial coverage but uneven functionality, where the presence of equipment does not necessarily equate to service readiness [19].

4.1.1 Procurement Processes and Funding Mechanisms

The procurement of medical equipment in Uganda is guided by the Public Procurement and Disposal of Public Assets Act (PPDA) and sector-specific guidelines issued by the Ministry of Health. The key procurement agencies are National Medical Stores (NMS) and Joint Medical Stores (JMS) for public facilities and private not-for-profit facilities, respectively. While the regulatory framework emphasizes transparency and competition, the practical implementation of procurement for diagnostic equipment remains fragmented.

Funding sources include the central government, development partners, and donor-supported projects, with additional input from district and hospital budgets. Donor-funded procurements, while vital, often occur outside standardized national planning, leading to mismatched equipment and duplication across facilities. Moreover, procurement processes frequently prioritize initial acquisition cost over long-term sustainability, with limited attention given to life-cycle costs, spare parts, and maintenance contracts. The Ministry of Health has made progress by introducing the National Medical Equipment Guidelines (2024), which recommend the inclusion of Total Cost of Ownership (TCO) analysis and post-installation support in all procurement activities. However, enforcement remains a big challenge across all hospital levels.

4.1.2 Maintenance, Usage, and Operational Challenges

One of the most persistent issues in Uganda’s diagnostic infrastructure is the high rate of non-functional equipment. Research shows that between 30–40% of medical devices in public facilities may be out of service at any given time, largely due to a lack of spare parts, consumables, or technical expertise [19]. This results in equipment downtime that compromises service delivery and patient safety. Maintenance of diagnostic equipment is largely reactive rather than preventive. Most facilities lack scheduled maintenance plans or service contracts with suppliers. Regional biomedical workshops established in Gulu, Mbale, and Mbarara have helped improve repairs, but their reach remains limited. The absence of ring-fenced maintenance budgets means that equipment servicing competes with other pressing expenditure needs.

Another major challenge is the inconsistent supply of consumables. Radiology units frequently experience shortages of films, reagents, and printer cartridges, rendering functional machines unusable. In laboratory departments, stockouts of quality-control and calibration reagents disrupt analyzer operations and compromise data accuracy. Additionally, donated equipment, though valuable often arrives without adequate documentation, user manuals, or compatibility with local utilities. Some devices require stable electricity or specialized maintenance support, which is unavailable in rural hospitals. Without standardized procurement and user training, such donations sometimes become non-functional soon after installation. Operational inefficiencies also stem from limited user training. Nurses and clinicians often lack familiarity with device care, leading to misuse or neglect. For example, poor handling of ultrasound probes and inadequate cleaning practices reduce device lifespan and diagnostic accuracy.

4.1.3 Infrastructure and Human Resource Considerations

The availability of diagnostic equipment alone is insufficient without the infrastructure and human resources necessary for operation. Many district and regional hospitals in Uganda lack reliable power supply, favorable environmental conditions and appropriate space requirements for advanced medical diagnostic equipment. Frequent power fluctuations not only interrupt diagnostic procedures but also damage sensitive electronics. In some hospitals, radiology departments are housed in improvised spaces without adequate shielding, ventilation, or patient flow design, compromising safety and efficiency. Human resources present an equally critical constraint. The biomedical engineering workforce remains small relative to the number of facilities requiring support. As of 2023, Uganda had fewer than 300 well trained and qualified biomedical engineers and technicians serving over 6,000 health facilities. This shortage leads to long repair turnaround times and dependence on external contractors.

4.2 Opportunities and strategies for improved technology management in the healthcare sector

The findings of this study underscore the critical importance of adopting a life cycle cost (LCC) approach in managing diagnostic medical equipment within low-resource healthcare systems. The high rate of non-functional equipment reflects a systemic failure to integrate procurement, maintenance and overall financial planning into a unified framework. Procurement sets the foundation for all subsequent stages of equipment management. In Uganda, fragmented procurement processes and limited coordination between users, technical teams, and suppliers have often led to acquisition of unsuitable or poorly supported technologies. A shift towards evidence-based and standardized procurement is essential. Facilities should base purchasing decisions on verified user requirements, life-cycle costs, and compatibility with existing infrastructure. Introducing a Total Cost of Ownership (TCO) framework will ensure that budgeting covers not only acquisition but also installation, training, spare parts, and disposal.

4.2.1 Implementing preventive maintenance and life-cycle planning

Historically, equipment maintenance in Uganda has relied on reactive repair, addressing breakdowns only after they occur. This approach is costly and leads to prolonged downtime. A preventive maintenance culture should therefore be institutionalized within all healthcare levels. A structured maintenance framework can be organized in four categories. At the user-level care, clinical staff perform basic cleaning and operational checks. In-house maintenance should be conducted by facility biomedical technicians. Regional workshop support offering calibration and complex repairs and specialized or manufacturer service for high-end technologies. The MoH's regional biomedical workshops serve as key maintenance hubs. However, to sustain their impact, a dedicated maintenance budget line must be incorporated into annual health facility plans. Routine inspections, asset tagging, and monthly functionality reports should be mandatory. Developing equipment life-cycle plans including expected lifespan, replacement intervals, and decommissioning guidelines will also enhance long-term planning.

4.2.2 A tiered capacity building approach of training for biomedical personnel

Human resource capacity remains one of the most pressing challenges in Uganda's HTM system. Many facilities lack adequately trained biomedical engineers, and users often have limited understanding of equipment operation. A tiered capacity-building approach can address this challenge. At the basic level, nurses and clinicians should be trained on proper handling and routine care of devices. At the technical level, biomedical technicians require continuous professional development in maintenance, calibration, and troubleshooting. Partnerships between the MoH, training institutions, and the private sector actors can provide structured mentorship and certification programs.

Several institutions of higher education have made progress in training biomedical engineers and technologists. However, more emphasis is needed on practical exposure and regional mentorship, ensuring that skills gained are applicable within the local health system. Establishing a national registry of all the biomedical professionals in the country would also improve deployment, monitoring, and professional recognition. Blended learning combining short face-to-face sessions with digital learning modules offers a cost-effective method for continuous training. E-learning programs for medical engineers provided by the manufacturers of medical devices shows that hybrid approaches enhance retention and reduce travel costs yet keep the engineers with most up-to-date developments for their daily troubleshooting and repair works.

4.2.3 Leveraging technology and innovation

Modern innovations provide practical opportunities for transforming health technology management (HTM), a critical yet an underdeveloped component of the healthcare system in Uganda. Efficient management of medical equipment directly influences service quality, patient safety, and financial sustainability. Remote monitoring systems, supported by Internet-of-Things (IoT) technologies, enable real-time tracking of critical equipment. Data from these systems can alert technicians to early faults, reducing downtime [20]. Similarly, mobile maintenance applications could support biomedical teams in logging repair tickets, accessing spare-parts inventories, and generating maintenance reports from the field. Another promising area is equipment reconditioning and local refurbishment. Establishing refurbishment centers for common devices would reduce costs and enhance sustainability thus creating opportunities.

In order to achieve optimal outcomes in healthcare facilities, a holistic strategy beyond controlling individual procedures is necessary to integrate modern technology. The transition to data-based, automated, environmentally responsible practices in medical device inventory and maintenance management is no longer optional but is essential for ensuring high-quality, sustainable, future-ready health-care systems. The scope of HTM thus extends beyond simple asset management, but rather to a comprehensive strategy that integrates technology, policy and sustainability to improve health-care efficiency, patient safety and long-term system resilience. Understanding the medical device life cycle is fundamental to HTM, as it demonstrates the importance of an interconnected system in which procurement, maintenance, regulatory compliance, financial planning and sustainability are integrated rather than managed independently. Health-care technology is only as effective as its management [21]. Below is an illustration of the interconnection of the different components could be integrated into one solid framework, the HTM system.

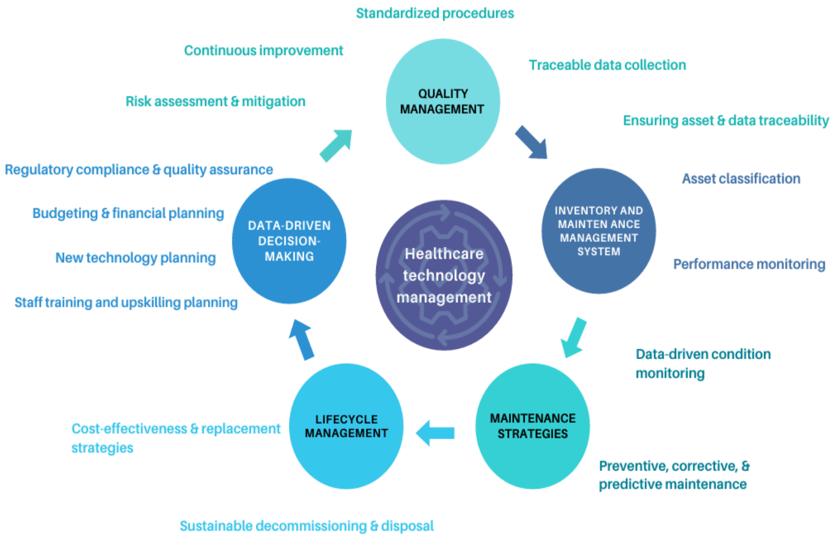

Figure 3
Showing the HTM model for effective equipment management.
Source: Inventory and maintenance management information system for medical devices WHO: Medical device technical series

Modifications to some of the component actors or interactions from this technological process, as well as the incorporation of other interactions or actors, might be carried out based on the knowledge of the improvement activities [22]. Effective technology management requires an enabling policy and financing environment. The establishment of a national HTM policy framework that clearly defines roles, standards, and reporting requirements would be a game-changer.

4.2.4 Policy and partnership recommendations

The promotion of public-private partnerships (PPPs) for training, maintenance, and spare parts supply is highly recommended. Encouragement and support of local innovation and manufacturing, particularly for low-complexity equipment, consumables, and accessories will play a big role. Lastly, the integration of equipment data into a national health information system to improve transparency and planning. Sustaining and scaling these partnerships will be vital for achieving national coverage. Additionally, developing equipment refurbishment centers could extend the lifespan of diagnostic devices and reduce dependence on imported machines. Private-sector partners such as Crown Healthcare (U) Ltd have demonstrated that local reconditioning of laboratory devices is feasible and cost-effective. Expanding these models under public-private partnerships would not only enhance equipment availability but also build local technical capacity.

Financial sustainability emerges as the central challenge in all the above. This is very significant in public hospitals that rely heavily on constrained government budget and donor funding. Even when capital investments are made, recurrent costs of maintenance, consumables, power, and human resource expense often outstrip available budgets. Public hospitals operate under constrained annual budgets. Capital acquisitions are frequently supported by one-off donor funding or special projects, but recurrent budgets rarely account fully for maintenance or consumables. The problem is that facilities receive equipment without reliable financial plans for its upkeep and operation. Central allocations, district budgets and donor projects coexist without harmonized planning. To address some of these burdens, there is an urgent need to allocate resources towards the proper maintenance of equipment. The disconnect between capital investment and recurrent funding creates a cycle in which equipment is procured but not operated sustainably.

Integrating diagnostic planning into broader health infrastructure investments such as power stabilization, digital record systems, and telemedicine will create a more resilient and interconnected diagnostic ecosystem. Uganda's public health system has made meaningful progress in expanding diagnostic capacity, yet significant challenges persist in ensuring equitable access to, functionality of, and sustainability of diagnostic equipment. The country's diagnostic landscape is characterized by an uneven distribution of advanced technologies, fragmented procurement, inadequate maintenance, and a shortage of skilled personnel. Addressing these challenges requires a holistic approach that links procurement reforms, maintenance planning, infrastructure investment, and human resource development. Policies should prioritize preventive maintenance, enforce total-cost-of-ownership frameworks in procurement, and ensure sustainable funding for biomedical engineering functions.

5 Discussion

The findings suggest that the challenge of diagnostic medical equipment in Ugandan public hospitals is not simply that machines are unavailable. A more serious problem is that many existing machines are not consistently functional. Some hospitals have basic equipment such as X-ray and ultrasound units, but these devices may be old, poorly maintained, or unusable due to missing consumables, spare parts, unreliable power supplies, or limited technical support. This means that equipment listed in a hospital inventory may not reflect the real diagnostic capacity of that facility. The uneven distribution of advanced technologies also remains a major concern. Equipment such as MRI and CT scanners is still concentrated mainly in urban and referral hospitals, leaving many district and rural patients with limited access to advanced diagnostic services. For these patients, diagnosis may involve long travel distances, additional costs, or referral to already congested higher-level hospitals. This shows that weak equipment management is not only a technical issue; it directly affects equity, affordability, and timely patient care.

Procurement and maintenance practices appear to be key contributors to the problem. Equipment is sometimes purchased or donated without enough planning for installation, user training, service contracts, consumables, spare parts, and future replacement. In addition, maintenance in many facilities remains reactive, with repairs only carried out after breakdowns occur. This increases downtime and makes service delivery unreliable. A preventive maintenance system, supported by proper records and dedicated budgets, would therefore be more suitable for sustaining diagnostic services. Human resource and infrastructure gaps also limit equipment performance. The shortage of biomedical engineers and technicians means that faults may take long to be addressed, while unstable electricity, inadequate space, poor ventilation, and weak safety provisions can shorten the lifespan of sensitive diagnostic equipment. These challenges show that medical equipment planning should not be separated from hospital infrastructure development and workforce planning.

A stronger Health Technology Management system in Uganda will be of great impact. Diagnostic equipment should be managed throughout its full life cycle, from needs assessment and procurement to installation, use, maintenance, replacement, and disposal. Although Uganda has made progress in expanding diagnostic capacity, future efforts should focus more on whether equipment is functional, sustainable, and accessible to the patients who need it most.

5.1 Limitations and Recommendations

This article was based mainly on secondary data, reports, and published literature. Because the condition of medical equipment can change from time to time, the information used may not give the exact current situation in every public hospital. Some facilities may have improved, while others may still be facing serious equipment challenges that were not fully captured in the available sources. There was also no direct physical assessment of diagnostic equipment in these hospitals, which further restricted and biased the results and discussion. For this reason, some regional differences and facility-specific issues may not have been fully identified. In addition, information on equipment downtime, repair costs, maintenance response time, and availability of spare parts was limited, especially because many facilities do not keep complete digital maintenance records. Another limitation is that the article focused mainly on diagnostic medical equipment. Although some of the issues discussed may also affect other hospital equipment, the findings should not be applied to all medical devices without further investigation.

Future work should involve field-based assessments in selected public hospitals across different regions of Uganda. This would help collect first-hand information on the actual condition of diagnostic equipment, including whether machines are functional, partially functional, or completely out of service. Studies should also examine equipment downtime in more detail. This should include how often machines break down, how long repairs take, the common causes of failure, and how downtime affects patient waiting time, referrals, and service delivery. Future research should include a detailed cost analysis of diagnostic equipment management. This could compare the cost of reactive maintenance with preventive maintenance and show whether planned servicing is more affordable and sustainable in the long term.

There is also need for future work to develop and test a digital equipment inventory system for public hospitals. Such a system could track equipment location, age, functionality, maintenance history, spare-part needs, and replacement timelines. Testing this system in a few hospitals before national scale-up would help identify practical challenges. Further research should assess the role of biomedical engineers and technicians in improving equipment performance. This could include studying staffing levels, skills gaps, training needs, repair response time, and how biomedical personnel can be better supported at facility and regional levels. Further exploration of the impact of infrastructure on diagnostic equipment functionality will be significant. Areas such as power stability, space requirements, ventilation, radiation safety, and environmental conditions should be examined to understand their impact on equipment lifespan and performance. An investigation on the potential of public-private partnerships in equipment maintenance, refurbishment, spare-part supply, and training will be greatly important. This would help determine which partnership models are practical, affordable, and sustainable for Uganda's public health system.

Conclusion

While Uganda has made progress in expanding diagnostic medical equipment in public hospitals, a significant gap remains in ensuring their functionality and long-term sustainability. Despite current challenges, there are opportunities to strengthen diagnostic technology management through innovation. The findings show that decision-making is often driven by initial acquisition costs rather than total life costs, which eventually render the medical equipment non-operational. Limitations in infrastructure, human resource capacity, and poor coordination among stakeholders also constrain the effective use of diagnostic technologies. Addressing these problems calls for a shift towards integrated Health Technology Management approaches that prioritize life-cycle cost analysis and sustainable financing. Future research should focus on quantitative life-cycle cost evaluations, the impact of predictive preventive maintenance strategies, and the scalability of digital equipment management systems, as well as on exploring context-specific frameworks and partnerships that can support sustainable diagnostic services in low-resource settings. In the long run, Uganda's diagnostic capacity will depend on the extent to which it institutionalizes technology management as a core component of healthcare planning. By aligning national strategies with best practices and leveraging digital innovation, Uganda can transform its diagnostic services into a robust and sustainable system that supports the country's health and development goals.

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