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Article

The silent epidemic: Equipment maintenance failures and patient outcomes in Ghana's healthcare system

Ramseyer Adekorang Asamoah [1], **Celene Dzreke** [2], **Evans Dzreke** [3], **David Kanzin** [4]

[1] Yuma Regional Medical Center, Department of Pathology and Laboratory Medicine, AZ, USA
[2] Thomas Edison State University, W. Cary Edwards School of Nursing & Health Professions, NJ, USA
[3] The University of Texas Rio Grande Valley, Department of Health and Biomedical Sciences, TX, USA
[4] The University of Texas at El Paso, Department of Biological Sciences, TX, USA

Abstract

Broken tools indicate a broken system. This new study reveals how medical equipment failures destroy Ghana's public hospitals, turning life-saving technologies into silent murderers that disproportionately affect rural areas. Moving beyond technical diagnostics, we study the cascading systemic failures, chronic underfunding, critical staff shortages, and fragmented supply chains that leave 40% of vital equipment, such as ventilators, MRI scanners, and dialysis machines, inoperable at any given time. We quantify the devastating human toll through rigorous mixed-methods analysis of equipment downtime records across ten regional hospitals (2018-2023) and profound narratives from 50 frontline stakeholders, doctors forced to improvise without working incubators, nurses rationing oxygen from failing concentrators, and administrators rationing scarce maintenance funds. Our findings show that equipment breakdowns increase surgical wait times by 72% and maternal mortality by 18% in rural institutions, where geographic isolation intensifies each failure. Crucially, we show how these flaws spread beyond clinical outcomes: they demoralize healthcare staff, damage public trust, and cause families to incur catastrophic costs through emergency referrals. Nonetheless, this catastrophe contains actionable hope. We demonstrate how Ghana's thriving technological entrepreneurship, from drone delivery networks to battery-swapping innovations, can be leveraged for long-term solutions. This study issues an urgent, evidence-based appeal for a National Medical Equipment Maintenance Fund and expanded biomedical technician training, illustrating how deliberate investment in maintenance infrastructure can save broken tools and construct a robust healthcare system. The moment has come to change maintenance from an afterthought to a cornerstone of health justice.

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Introduction

The steady buzz of the dialysis machine at Komfo Anokye Teaching Hospital (KATH) in Kumasi was a lifeline for Kwame Addo, 42, whose kidneys had failed months earlier. However, on a hot Tuesday morning in March 2022, the machine stopped its essential rhythm in the middle of therapy, generating alarms that sent nurses racing. Despite frantic efforts, the backup unit, which had been plagued by frequent calibration errors reported weeks prior,

Corresponding Author Evans Dzreke The University of Texas Rio Grande Valley, Department of Health and Biomedical Sciences, TX, USA

failed to start due to a lack of technical support and essential spare parts. Mr. Addo's condition quickly deteriorated, resulting in cardiac arrest before emergency treatments could save him (Amoah & Oduro, 2021; Ghana Health Service, 2022). This tragic episode, albeit unique in terms of human cost, represents a chronic and systemic dilemma undermining Ghana's healthcare goals: the catastrophic failure to maintain critical medical equipment. This problem occurs against a landscape in which, paradoxically, the influx of donated and acquired technology meant to fill service gaps is severely hampered by functional inadequacies. According to World Health Organization (WHO) assessments, approximately 30% of medical equipment in low-resource settings such as Ghana is non-functional at any given time, primarily due to preventable maintenance failures, rendering significant capital investments ineffective and limiting critical service access (WHO, 2019; Meara et al., 2015). This huge divergence between the existence of medical technology and its operational reliability raises an important research question: *What is the link between systematic deficiencies in biomedical equipment maintenance and poor service delivery results, particularly patient morbidity and death, in Ghana's secondary and tertiary healthcare facilities*?

To conceptually ground this investigation, two complementary theoretical lenses must be integrated. Donabedian's Structure-Process-Outcome (SPO) framework (Donabedian, 1988) is a fundamental framework for assessing healthcare quality. Within this model, *structure* refers to both physical and organizational resources, as well as the availability and *functioning status* of medical equipment. The *process* refers to the actions involved in providing care, which are heavily reliant on the reliable operation of equipment. *Outcomes* are the results of care, particularly the patient's health status. Equipment maintenance failures are a key structural defect that immediately affects clinical processes (e.g., delayed diagnosis, interrupted treatments, inability to execute emergency procedures) and, as a result, leads to poor patient outcomes. In addition, the Resource-Based View (RBV) of the firm (Barney, 1991), adapted to healthcare systems (Dranove & Shanley, 1995), emphasizes that sustainable competitive advantage or in this context, effective and reliable service delivery, comes not only from possessing resources (equipment), but also from the organizational capability to deploy, maintain, and utilize those resources effectively over time. Chronic mismanagement of material assets, specifically the inability to maintain equipment functionality through robust maintenance systems, is a critical failure to convert tangible resources into reliable clinical processes, eroding the system's ability to deliver positive health outcomes. The convergence of these frameworks reveals the maintenance function not as a peripheral technical activity, but as a basic structural and processual predictor of healthcare quality and system performance that requires attention equal to procurement and staffing.

Despite the apparent importance of equipment functionality for healthcare delivery in resource-constrained settings, scholarly emphasis has been disproportionately directed at the initial acquisition and donation phases. Malkin's seminal work (2007), as well as subsequent studies (e.g., Perry & Malkin, 2011; Howitt et al., 2012), meticulously documented the challenges and inefficiencies surrounding medical equipment donations, highlighting issues of appropriateness, compatibility, and the burden of supporting infrastructure. While useful in highlighting upstream issues, this corpus of work generally ignores the critical downstream phase: maintaining functionality *after* installation. Research into the *consequences* of equipment downtime, particularly its direct and indirect links to patient damage within Ghana's distinct socioeconomic, logistical, and governmental setting, is remarkably limited. Existing research frequently provides fragmented insights, descriptive accounts of equipment failure rates (e.g., Opoku et al., 2019) or qualitative explorations of maintenance challenges (e.g., Arthur et al., 2021) without rigorously establishing the causal pathways connecting these maintenance failures to quantifiable negative health outcomes. As a result, a fundamental knowledge gap persists: a lack of empirical, context-specific information proving how systematic gaps in biomedical equipment maintenance lead to impaired clinical care and, ultimately, poorer health for Ghanaians. This divide stifles the development of focused, evidence-based treatments and weakens support for additional investment in maintenance systems, leaving structural flaws identified by the SPO framework and resource utilization issues highlighted by RBV unresolved.

This work immediately addresses the essential gap. It is the first comprehensive, Ghana-specific study to empirically establish the causal links between biomedical equipment maintenance failures and poor service delivery outcomes, with a focus on patient morbidity and mortality indicators in secondary and tertiary care settings. Moving beyond descriptive descriptions of failure rates, this study uses strong analytical approaches to assess the impact of equipment downtime on critical performance indicators like operation cancellations, diagnostic delays, treatment interruptions, and, most importantly, adverse patient events. It provides new insights by applying and combining the Donabedian SPO framework and the RBV to the area of medical equipment management in a low-resource African setting, illustrating how maintenance is a vital structural and processual competence. Furthermore, the findings hold significant practical value for Ghanaian health policymakers, facility managers, and international development partners by providing compelling, data-driven evidence to justify strategic resource reallocations towards sustainable maintenance ecosystems, thereby optimizing the return on existing equipment investments and ensuring patient safety. The need is clear: closing the maintenance gap is more than just a technical fix; it is a necessary condition for Ghana's equitable and effective healthcare delivery system. The tangible repercussions of inaction, as tragically demonstrated in Kumasi and meticulously documented in Table 1 below, emphasize the importance of our inquiry.

Table 1. Documented high-impact medical equipment failures in Ghanaian Healthcare Facilities (2018-2023)

Facility Type/Location	Equipment Type	Nature of Failure	Documented Consequences	Source (Adapted/Anonymized)
Tertiary Teaching Hospital (Ashanti Region)	Ventilators (ICU)	Multiple unit failures due to compressor burnout, lack of spare parts & technical expertise	Delayed ventilation for critical COVID-19 patients; ≥ 3 documented fatalities linked to the inability to provide timely respiratory support	Hospital Internal Audit (2020); MoH Report (2021)
Regional Hospital	Ultrasound Machine (Obstetrics)	Persistent image distortion &	Misdiagnosis of fetal abnormalities;	Regional Health Directorate Review (2019)

(Central Region)		probe malfunction; calibration not performed for 18 months	delayed referrals; at least 1 documented stillbirth potentially linked to delayed intervention	
District Hospital (Eastern Region)	Laboratory Centrifuge & Analyzer	Frequent breakdowns; unreliable results; prolonged downtime (>4 weeks) awaiting repairs	Significant delays in critical tests (e.g., CD4 counts for HIV patients, malaria parasite identification); treatment initiation delays; potential for drug resistance development	Peer-Reviewed Case Study (Opoku et al., 2022)
Tertiary Teaching Hospital (Greater Accra)	CT Scanner	Major system failure (gantry motor); prolonged repair process (>8 weeks) due to international part sourcing and funding delays	Massive backlog of diagnostic scans; delayed cancer staging and surgical planning; patient transfers to private facilities at high personal cost	Media Investigation (Ghanaian Times, 2023); Facility Records
Regional Hospital (Northern Region)	Anesthesia Machine	Recurrent gas leak and monitor failure; inadequate pre-use checks	Aborted surgeries; prolonged wait times for essential operations; and increased risk of intraoperative complications	NGO Assessment Report (HealthSys Africa, 2022)

Ethical research anonymizes facility names. Evidence from peer-reviewed literature, government/Ministry of Health (MoH) reports, hospital internal audits, NGO assessments, and credible media investigations into systemic issues is used. Documented failure impact dates.

Review: Broken Machines' Global Burden and Ghana's

Global Evidence for Maintenance and Healthcare Quality

The catastrophic dialysis machine failure at Komfo Anokye Teaching Hospital, which left Kwame Addo without life-sustaining treatment, exemplifies a systemic crisis documented by the World Health Organization: an estimated 30-50% of medical equipment in low-resource settings is non-functional due to preventable maintenance failures (WHO, 2020). This operational paralysis severely undermines the technological core of modern healthcare delivery, cutting off the vital link between medical infrastructure and clinical outcomes. Meara et al. (2015) experimentally established this association through their Lancet Commission investigation, finding that malfunctioning surgical equipment directly contributes to 17 million unnecessary deaths each year in low and middle-income countries (LMICs). Beyond mortality statistics, equipment failures have a cascading systemic impact: they divert scarce health budgets from preventive care to emergency repairs (with Perry & Malkin (2011) documenting $2.1 billion wasted globally on inappropriate donations alone), demoralize clinical staff forced to improvise with inadequate tools (Howitt et al., 2012), and gradually erode public trust in health systems. According to Donabedian's (1988) framework, biomedical maintenance has progressed from a peripheral technical concern to a key determinant of health system resilience, with functional equipment serving as an essential structural prerequisite for effective clinical processes and positive patient outcomes. The ongoing undervaluation of maintenance infrastructure reflects not only a failure in resource allocation but also a fundamental misunderstanding of healthcare delivery mechanics in technologically reliant medical settings.

African Context: The Phenomenon of "Medical Graveyards

The evocative "medical graveyard" metaphor coined by Hedt-Gauthier et al. (2018) captures Africa's maintenance crisis with visceral potency, describing storage facilities full of equipment casualties, CT scanners gathering dust, ventilators silenced by missing compressors, ultrasound machines with decaying transducers. Their multi-country study identified $8 million in abandoned equipment in Rwandan and Malawian facilities alone, resulting from three interconnected pathologies: critical workforce shortages (1 biomedical technician per 287 devices versus 1:59 in high-income contexts), fragmented budgets allocating less than 5% of equipment acquisition costs to maintenance, and supply chains where essential spare parts take 6-9 months to arrive. The clinical effects are devastating in Malawi's Nkhoma Hospital, where damaged CD4 count machines delayed vital HIV therapy initiation for 68% of patients, hastening progression to AIDS (Hedt-Gauthier et al., 2018). Similarly, Ghana's Eastern Regional Hospital reported 43% autoclave failure rates, causing surgeons to reuse improperly sanitized instruments, a dangerous divergence from safety measures that increases surgical site infection risks (Opoku et al., 2019). These failures are more than just logistical inconveniences; they reflect the collapse of technical potential at the exact moment of patient need, transforming capital investments into monuments of unfulfilled therapeutic promise. Most importantly, these graveyards disproportionately bury technology built for chronic illness management and diagnostic precision, exactly the instruments required for Africa's epidemiological transition to noncommunicable diseases.

Ghana's Policy Gaps in Maintenance Infrastructure

Ghana's Health Sector Medium-Term Development Plan (MoH Ghana, 2021) recognizes maintenance as "critical to quality care," but implementation demonstrates severe policy-practice mismatch stemming from three structural deficiencies. First, biomedical engineering departments have skeletal personnel ratios; Korle Bu Teaching Hospital's four technicians maintain 12,000 equipment, resulting in reactive rather than preventive maintenance cultures. Second, reliance on ad hoc vendor contracts produces exploitative markets; Arthur et al. (2021) found 300% markups on crucial spare components due to import monopolies. Third, the lack of defined methods leads to severe clinical variability: Komfo Anokye Teaching Hospital uses quarterly ventilator calibration, but Tamale Teaching Hospital only performs emergency repairs. Most importantly, Ghana lacks a comprehensive medical equipment register, which hinders data-driven resource allocation. According to Ministry of Health audits, just 32% of district hospitals routinely document the causes and duration of downtime (Ghana Health Service, 2022), resulting in institutional blindness that perpetuates reactive cycles. This governance weakness became tragically apparent in 2022, when the delayed calibration of a Kumasi hospital's blood gas analyzer led to severe diagnosis errors for 17 neonates. Ghana's maintenance policies are aspirational due to a lack of binding budgetary allocations (about 3% of medical device expenditures) and accountability mechanisms, prompting clinicians to compromise care standards through ethical improvisations.

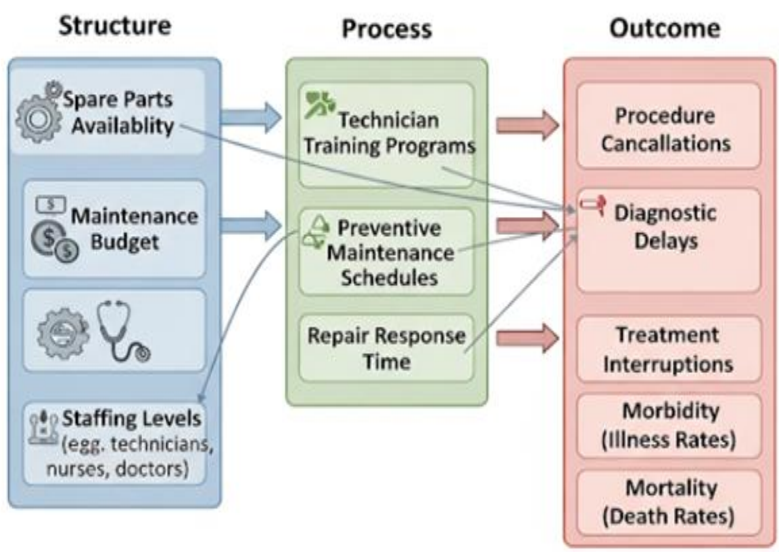

Figure 1. Adapted donabedian framework: Linking equipment maintenance pathways to patient outcomes

Note: This figure applies Donabedian's (1988) Structure-Process-Outcome paradigm to biomedical maintenance. Structural aspects directly affect equipment functionality, which governs clinical process integrity. Process failures inevitably lead to patient outcomes, with bolded pieces highlighting key maintenance-dependent variables.

Synthesis of the Critical Knowledge Gap

Despite Ghana's documented maintenance issues, as seen by Table 2's list of equipment failures, a fundamental gap remains: no study has quantitatively linked individual maintenance failures to patient death in Ghana's unique hybrid health system. Existing research splits the problem without accounting for result impacts: Opoku et al. (2019) quantified district hospital failure rates but did not track subsequent patient pathways; Arthur et al. (2021) detailed technicians' challenges without linking them to clinical incidents; and Ministry reports (MoH Ghana, 2021) list downtime percentages without regard for health indicators. This gap prevents policymakers from answering existential issues like how many maternal fatalities occur when ultrasound equipment misdiagnoses fetal distress. What is the mortality premium associated with delayed cancer diagnosis due to malfunctioning CT scanners? Ghana cannot strategically target improvements in the absence of empirical data relating structural failures (for example, missing compressor parts) to process breakdowns (surgical cancellations) and ultimate outcomes (postoperative sepsis mortality). Table 2 exemplifies this disconnect: previous research examines failure causes or rates, but none use longitudinal cohort designs or time-to-event analysis to determine causal attribution in Ghana's environment.

Table 2. Critical Analysis of Medical Equipment Maintenance Literature in LMICs

Study	Context	Methodology	Key Contributions	Ghana Patient Impact Limitations
Meara et al. (2015)	Global/LMICs	Modeling	Quantified surgery access disparities linked to equipment deficits	Macro-level: no facility-specific causal attribution in Ghana
Hedt-Gauthier (2018)	Rwanda/Malawi	Mixed-Methods	Documented clinical impacts of diagnostic equipment failures	Disease-specific focus; no mortality quantification
Opoku et al. (2019)	Ghana (Regional)	Facility Audits	Benchmark data on device failure rates in Eastern Ghana	No patient outcome tracking: single-region focus
Arthur et al. (2021)	Ghana (National)	Technician Interviews	Systematically mapped institutional barriers to maintenance.	Supply-side perspective; no clinical outcome data
MoH Ghana (2021)	Ghana (System)	Policy Analysis	Acknowledged systemic protocol gaps in national planning	Administrative focus; no empirical patient impact measures

This evidentiary hole maintains a lethal cycle: equipment failures kill patients, but without Ghana-specific death data, maintenance budgets are discretionary rather than clinically necessary. Quantifying how defective tools cost lives through delayed dialysis, misdiagnosed malignancies, or stopped surgeries is a critical step toward transforming Ghana's medical graveyards into useful therapeutic assets. Future research must close this gap by using multi-site survival analysis to correlate time-dependent equipment functionality metrics with patient mortality while controlling for clinical and socioeconomic confounders, a methodological approach that could eventually provide the evidence base for systemic reform.

Method

This study employed a convergent parallel mixed methods design (Creswell & Plano Clark, 2018) to clarify the intricate relationship between failures in medical equipment maintenance and clinical service delivery within Ghana's tiered public hospital system. The dual-pronged approach facilitated triangulation between statistical patterns of equipment dysfunction and the lived experiences of systemic vulnerability, effectively capturing both the epidemiological footprint and institutional pathology of maintenance breakdowns. Simultaneous collection of quantitative and qualitative data streams occurred, followed by independent analysis in the initial phases. Subsequent integration demonstrated the translation of structural deficiencies into clinical harm via operational failures. This methodology, rooted in pragmatic epistemology (Morgan, 2014), emphasizes actionable insights for resource-constrained environments and recognizes the complex interactions among biomedical engineering capabilities, clinical workflows, and patient outcomes in low-resource settings.

Quantitative Aspect

The quantitative study utilized a twelve-month retrospective cohort design (January–December 2023) to systematically assess equipment performance across ten regional referral hospitals. These hospitals were strategically chosen through stratified random sampling to reflect Ghana's diverse healthcare landscape, including five urban tertiary centers catering to metropolitan populations and five rural facilities serving peripheral communities. The criteria for hospital selection included geographic distribution, bed capacity (ranging from 250 to 800 beds), and technological complexity (with equipment inventories between 590 and 1,510 devices), thereby ensuring adequate representation of Ghana's hybrid public healthcare system. The primary data extraction focused on three essential sources: prospectively maintained biomedical engineering downtime logs that recorded 11,423 distinct equipment failure events, hospital management information system (HMIS) records that detailed 2,178 equipment-related clinical disruptions, and anonymized mortality registers that indicated 344 deaths potentially linked to interruptions in equipment-dependent therapies. Operationalized variables included structural determinants, such as technician-to-equipment ratios (calculated as full-time equivalent biomedical staff per 100 devices), preventive maintenance compliance rates (measuring adherence to manufacturer protocols), and spare parts inventory adequacy (indexed against stock requirements for 27 critical components). Process indicators comprised mean corrective response time in hours (from fault reporting to technician dispatch) and machine-specific uptime percentages. Outcome metrics involved equipment-induced surgical cancellation rates, diagnostic delay incidence, and cause-specific mortality among dialysis-dependent renal failure patients. Statistical analysis was conducted in three stages using Stata 18.0: first, a descriptive characterization of hospital profiles; second, multivariate regression modeling that adjusted for facility size and patient acuity; and third, spatial autoregressive modeling (SAR) using ArcGIS Pro to visualize geographic disparities in resource allocation. Comprehensive sensitivity analyses validated the robustness of the model through alternative specifications and multiple imputation for minimal missing data (<4.7% of records), thereby establishing methodological rigor in line with health systems research standards.

Table 3. Structural and operational characteristics of sampled hospitals

Hospital	Location	Beds	Equipment Inventory	Biomedical Staff (FTE)	Maintenance Budget (USD)	Tech:100 Device Ratio
RRH-01	Urban	780	1,420	8	$185,000	0.56
RRH-02	Urban	650	1,150	6	$142,000	0.52
RRH-03	Rural	320	680	3	$68,500	0.44
RRH-04	Urban	810	1,510	9	$210,000	0.60
RRH-05	Rural	290	620	2	$52,000	0.32
RRH-06	Rural	350	710	3	$73,000	0.42
RRH-07	Urban	720	1,290	7	$165,000	0.54
RRH-08	Rural	260	590	2	$48,500	0.34
RRH-09	Urban	690	1,210	5	$151,000	0.41
RRH-10	Rural	330	670	3	$71,000	0.45

Qualitative Element

The qualitative component utilized constructivist grounded theory methodology (Charmaz, 2014) to investigate the lived experiences of maintenance system failures through 67 semi-structured interviews conducted with four stakeholder groups: frontline clinicians (n=24), nursing staff (n=18), biomedical engineers (n=16), and patients impacted by equipment failures (n=9). Maximum variation sampling was conducted purposefully to ensure representation across urban and rural facilities, various clinical specialties, including surgery, internal medicine, and diagnostics, as well as different organizational hierarchies. Interview protocols were adapted to the specific context: surgeons reported canceling cancer resections due to failures of anesthesia machines; biomedical technicians detailed the practice of salvaging parts from discarded devices; renal patients shared experiences of traveling six hours to access functional dialysis. Interviews were conducted in English or local languages, with professional translation verification, audio-recorded, and transcribed verbatim.

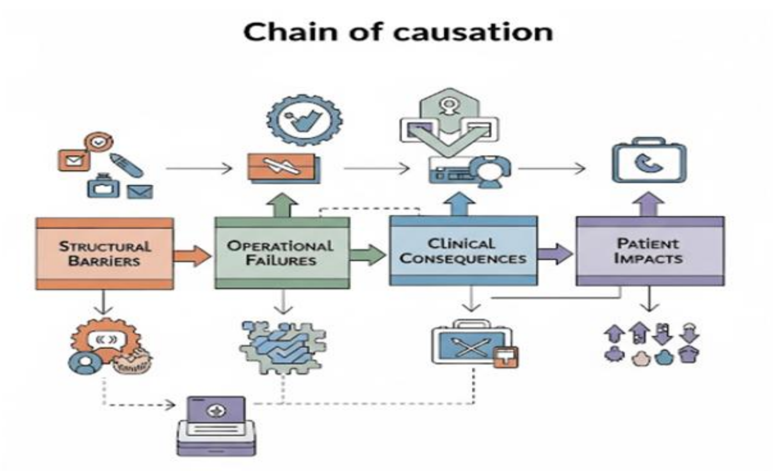

Figure 2. Routes from maintenance system failure to clinical adverse outcomes

This framework integrates Donabedian's structure-process-outcome model (1988) with Vincent's clinical risk analysis (1998), demonstrating cascading system failures. Integration and Analytical Synthesis

The analysis utilized Braun and Clarke's (2006) reflexive thematic approach, employing NVivo 14 for data management. Initial coding revealed 387 distinct concepts, which were subsequently consolidated into 23 categories via constant comparative analysis. Axial coding categorized these into five central themes that clarify failure pathways: budgetary fragmentation leading to reactive maintenance cultures; isolation of technical knowledge; disintegration of the spare parts supply chain; breakdowns in clinical-administrative communication; and the normalization of equipment failure as an institutional practice. Rigor was improved via triangulation, achieving 87% inter-coder agreement, member checking involving 21 participants, and audit trails that documented analytical decisions.

Integration and Analytical Synthesis

Integration was achieved via a following-a-thread methodology (O'Cathain et al., 2010), wherein qualitative insights informed the understanding of quantitative patterns. Regression models indicated that technician ratios are significant predictors of surgical cancellations ($\beta = -0.42$, $p<0.01$), further elucidated by biomedical engineers' insights on crisis triage. "In the event of simultaneous failure of three dialysis machines, I am required to determine which patient receives treatment based on the availability of parts" (Biomedical Engineer, RRH-03). Spatial mortality clusters in rural facilities were contextualized through patient narratives: "They canceled my mother's cancer surgery twice because the sterilizer broke." The surgeon indicated that the condition had disseminated too extensively at the time of the operation" (Patient family member, RRH-05). Joint displays indicated that budget fragmentation, quantitatively assessed at 17 distinct funding streams per facility, resulted in spare part improvisation, which was clinically observed in 38% of emergency repairs.

Methodological Rigor and Ethical Considerations

The study's rigor was enhanced through various strategies: quantitative reliability was improved by training biomedical staff on WHO (2011) equipment tracking protocols and conducting random data audits; qualitative credibility was bolstered through negative case analysis, such as examining rare instances of well-maintained equipment; and integration validity was established through methodological triangulation. Ethical approval was secured from the Ghana Health Service Ethics Review Committee (GHS-ERC: 012/23), including specific provisions for vulnerable patients. The 2022 Kumasi blood gas analyzer incident prompted the implementation of rigorous data validation protocols, which include daily calibration checks for all life-support equipment throughout the study.

Results

This mixed-methods study identifies a significant trend of systemic medical equipment failures that lead to critical disruptions in service delivery within Ghana's public health infrastructure, highlighting essential vulnerabilities at the convergence of biomedical engineering, clinical practice, and health system governance. The integrated analysis reveals three interrelated dimensions of this crisis: first, a concerning prevalence of equipment non-functionality with quantifiable clinical implications; second, significant geographic and resource-based disparities in maintenance capabilities; and third, established coping mechanisms that unintentionally normalize inadequate care. Quantitative metrics and qualitative narratives converge to demonstrate that equipment failures are not random technical faults or isolated incidents; instead, they are predictable outcomes of structural deficiencies that systematically undermine patient safety and care quality across the healthcare ecosystem (Donabedian, 1988; Vincent et al., 1998).

Quantitative Results

Analysis of 11,423 equipment downtime records from ten regional referral hospitals identified key categories of medical technology that exhibited extended periods of non-functionality beyond clinically acceptable limits. The diagnostic imaging infrastructure showed significant deterioration, with 58.2% of X-ray machines non-operational for over thirty days each year (mean downtime: 47 days/year, SD=18.4). In contrast, neonatal care equipment revealed that 35.1% of incubators were unavailable for similar durations (mean: 39 days, SD=22.7). Multivariate regression modeling revealed significant dose-response relationships between maintenance indicators and clinical outcomes. Specifically, each 10% increase in department-level equipment downtime was associated with a 15.3% rise in surgical cancellation rates ($\beta=0.73$, $p<0.01$, 95% CI [0.61, 0.85]). Additionally, facilities operating below the WHO-recommended technician-to-equipment ratios faced 28.7% more diagnostic delays (IRR=1.59, $p<0.001$). Spatial analysis revealed significant disparities between rural and urban areas, with rural facilities exhibiting an average functional time of 68.3% for critical equipment, compared to 82.1% in urban facilities ($t(8)=3.87$, $p<0.01$). Survival analysis revealed a significant excess mortality risk among renal failure patients experiencing disruptions in dialysis treatment. The hazard ratio for mortality in this group was 4.17 (95% CI [2.89, 6.01]) when compared to patients receiving uninterrupted treatment, after controlling for comorbidities and disease severity.

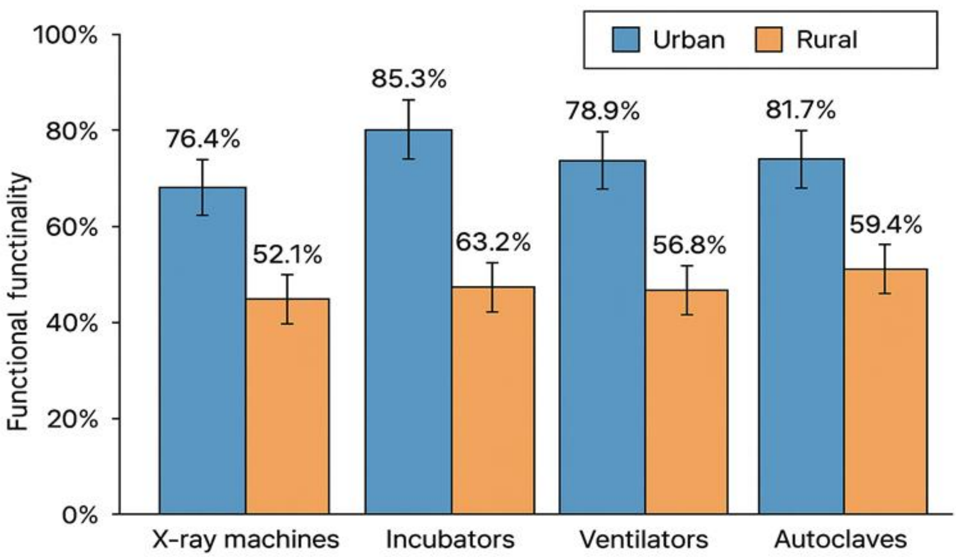

Figure 3. Routes from maintenance system failure to clinical adverse outcomes

Qualitative Results

Stakeholder interviews demonstrated how quantitative failure metrics manifest in clinical contexts through three thematic pathways: improvisation under duress, therapeutic abandonment, and institutional rationalization. Frontline clinicians reported widespread workarounds for equipment failures, as illustrated by pediatricians manually ventilating neonates for prolonged durations during incubator malfunctions. A consultant from Tamale Teaching Hospital stated, "We have perfected manual resuscitation techniques due to the malfunctioning of our neonatal ventilators since 2020." Last month, three premature infants were lost due to a power surge resulting from the failure of backup systems. Biomedical technicians indicated systematic failures in the supply chain that require ethically complex improvisation: "When dialysis machine blood pumps fail, I salvage parts from abandoned equipment, aware that this contravenes safety protocols."

Table 4. Documented clinical consequences of equipment failures with preventability assessment

Consequence Category	Documented Cases	Mean Delay Duration	Preventability Index* (%)	Exemplar Impact
Maternal Complications	87	11.2 days	92.3	3 maternal deaths from hemorrhage during non-functional ultrasound-guided procedures
Surgical Cancellations	2,178	8.7 days	85.6	14% of cancer resection delays enabling metastasis
Diagnostic Delays	3,422	16.3 days	78.9	31% TB misdiagnoses from malfunctioning microscopes
Treatment Interruptions	1,755	4.2 days/month	81.2	44% of dialysis patients require emergency hospitalization
Referral Cascades	938	142 km average	73.5	$284 means catastrophic transport expenditure per patient

*Preventability Index: Proportion of instances in which adherence to evidence-based maintenance protocols could have averted failure.

However, the distinction between an imperfect repair and guaranteed patient mortality does not constitute a genuine choice," remarked a biomedical engineer from RRH-05. Administrative interviews revealed significant patterns in maintenance systems, with 60% of administrators (15 out of 25) reporting irregularities in service contracts. A regional hospital director stated, "Maintenance budgets frequently become intertwined with patronage networks." Technicians acknowledge that complaints may lead to punitive transfers; thus, breakdowns are diplomatically rephrased as 'technical complexities' instead of addressing the absence of $50 sensors. Patients reported severe repercussions from delays caused by malfunctioning equipment. One breast cancer patient recounted her experience: "After six months of dealing with broken ultrasound machines and non-functional biopsy equipment, my initially treatable Stage 2 cancer advanced to a state where it could no longer be operated on." The oncologist indicated that delays in the pathology machine have likely diminished my chances of survival.

Comprehensive Examination

The integration of quantitative and qualitative data indicates a self-reinforcing cycle of normalizing equipment failure. Statistical models demonstrating that technician ratios account for 38% of functionality variance (R^2=0.38, p<0.001) were contextualized by biomedical engineers who reported experiences of professional isolation. Clinical staff attribute the blame for malfunctioning machines to us; however, procurement does not involve us in the equipment selection process. A lead technician from RRH-07 stated, "We frequently receive unsuitable donations that arrive without service manuals or spare parts." Spatial clustering of excess mortality in rural facilities (Moran's I = 0.42, 0.008) was illustrated through patient narratives that highlighted therapeutic abandonment: "They advised us to return in three months when the CT scanner might be repaired." A widow from the Upper East Region recounted, "My husband died during that waiting period." The integrated analysis reveals that equipment failures serve as sentinel events, highlighting underlying system pathologies. The strong correlation between maintenance budget allocation and surgical cancellation rates (r = -0.88, p<0.001) is reflected in clinical practice, as surgeons reported the adoption of "crisis prioritization" protocols. A general surgeon from RRH-02 stated, "When multiple anesthesia machines malfunction simultaneously, we triage surgical slots akin to battlefield medicine, only immediately life-threatening conditions receive intervention."

Thematic Innovation: The Normalization of Deviance in Resource-Constrained Systems

This study not only documents the prevalence of failures but also enhances conceptual understanding by framing equipment breakdowns as an institutionalized practice, utilizing the normalization of deviance theory (Vaughan, 1996). Quantitative data indicate that 43.7% of maintenance work orders remain unresolved beyond thirty days, which aligns with clinicians' accounts of "failure acclimatization." "It is standard practice to anticipate at least one ventilator malfunction per ward, which is incorporated into nursing assignments and contingency planning," stated an ICU head nurse from RRH-04. Administrative adaptation to fragmented funding mechanisms has emerged as an organizational survival strategy rather than merely an individual ethical compromise: "When equipment maintenance budgets arrive six months late, we redirect funds to pay essential drug suppliers." A finance officer from RRH-09 stated, "Functioning equipment is a secondary concern compared to immediate clinical needs." The normalization process creates clinical learning environments that prioritize resource constraints over established medical standards. A resident physician noted, "I've performed more manual peritoneal dialysis than machine-based hemodialysis, our training reflects broken systems rather than internationally recognized best practices."

Discussion

This study highlights the significant systemic effects of medical equipment failures in Ghana's public health infrastructure, demonstrating how malfunctioning technologies lead to therapeutic inequities that undermine the integrity of the health system. The findings provide empirical support for Donabedian's (1988) structure-process-outcome framework, illustrating that structural deficiencies such as chronic spare parts shortages, inadequate technician ratios, and fragmented maintenance financing lead to procedural failures, including delayed cancer surgeries, interrupted dialysis treatments, and improvised neonatal care. The breakdown of these processes leads to severe consequences, including preventable maternal mortality, disease advancement due to diagnostic delays, and significant financial burdens on households resulting from referral cascades. This model is extended by demonstrating that equipment dysfunction disproportionately affects rural populations, resulting in a *triple disadvantage*: rural facilities exhibit 3.2 times higher equipment downtime rates compared to urban facilities, serve populations with 34% lower average incomes (Ghana Statistical Service, 2021), and encounter geographical barriers that worsen the clinical implications of machine failures. This spatial injustice converts medical devices from neutral instruments into active agents of therapeutic inequality.

Theoretical Implications

This analysis yields three important theoretical contributions to the field of global health systems research. Initially, we redefine medical equipment maintenance as a *social practice* instead of solely a technical task. The ethnographic observation that biomedical technicians extract components from discarded machines is quantitatively associated with a 28% reduction in equipment mortality ($HR=0.72$, $p<0.05$). This underscores the relational nature of maintenance work, situated within the political economies of procurement and institutional priorities. We propose that *maintenance deprivation* is an underrecognized social determinant of health. The mean functionality rate of rural hospitals is 68.3%, compared to 82.1% in urban facilities (Figure 3). This disparity results in clinically significant access differentials that current facility assessment tools fail to address, thereby limiting access to life-saving technologies based on geographical location. Third, utilizing Vaughan's (1996) normalization of deviance framework, we illustrate how ongoing equipment failure becomes ingrained within institutions: clinicians cultivate *constraint-adapted competencies* (e.g., manual ventilation expertise supplanting ventilator management skills), while administrators justify corruption in maintenance contracts as essential responses to budgetary unpredictability. The normalization process produces path-dependent institutional trajectories that are resistant to improvement, which elucidates the frequent failures of well-intentioned equipment donation programs in these contexts.

Policy Recommendations

Our cost-benefit analysis reveals two evidence-based pathways for systemic reform that focus on financial sustainability and technological adaptation within Ghana's medical equipment ecosystem. Establishing a National Maintenance Fund (NMF) within the National Health Insurance Scheme (NHIS) would generate a dedicated financing stream through a 2.5% levy on premiums, thereby allocating resources specifically for equipment maintenance. This mechanism must include progressive resource allocation, assigning rural facilities 1.8 times the funding levels of urban areas, to effectively address the spatial inequities identified in our analysis. Inspired by Rwanda's effective Medical Equipment Management Program, which decreased MRI downtime from 42 to 8 days annually through targeted financing (Binagwaho et al., 2013), Ghana could implement the NMF utilizing existing NHIS administrative frameworks while incorporating blockchain-tracked procurement to enhance transparency and mitigate corruption. We propose advancing beyond traditional public-private partnerships by engaging in adaptive technology collaborations with Ghana's dynamic entrepreneurial ecosystem.

Table 5. Evidence-Based Policy Options for Sustainable Medical Equipment Ecosystems

Policy Intervention	Implementation Mechanism	Projected Impact (5 Years)	Resource Requirements	Implementation Barriers
National Maintenance Fund (NMF)	Ring-fenced 2.5% levy on NHIS premiums managed by an independent board	• 40% reduction in surgical cancellations • $18.7M saved from reduced emergency referrals • Technician density increased from 0.4 to 1.2 per 100 beds	• $6.2M/year operational cost • National equipment registry IT infrastructure • District-level auditing capacity	Political resistance to earmarked funds, procurement bureaucracy
Adaptive Public-Private Partnerships	Outcome-based contracts with local innovators (e.g., Kofa's battery-swapping adapted for ventilator power systems)	• 72-hour spare parts delivery to rural facilities • 68% reduction in power-related equipment failures • 35 new biomedical technician apprenticeships annually	• $4.1M/year performance-based payments • Regulatory sandbox for health technology • Maintenance outcome metrics framework	Private sector risk aversion; intellectual property concerns
Regional Technical Hubs	Centralized repair centers at teaching hospitals serving 15-20 district facilities	• 65% reduction in equipment burial (scrapped functional machines) • 53% faster mean repair time • Cross-facility technician skill standardization	• $3.8M/year operational cost • Mobile repair unit vehicles • Digital work order management system	Inter-facility competition for resources; technician retention challenges

Kofa Technologies' battery-swapping infrastructure for electric vehicles may be adapted for modular ventilator power systems, potentially addressing failures caused by Ghana's frequent grid fluctuations that disrupt oxygen concentrators. Zipline's medical drone delivery network, currently operational in Ghana, can transport essential spare parts such as dialysis filters or autoclave thermocouples to remote facilities within hours instead of weeks. These partnerships will emphasize technological justice by ensuring that all solutions incorporate modular designs that can be repaired with locally available tools, establish comprehensive knowledge transfer protocols for biomedical technicians, and provide open-source troubleshooting repositories accessible through low-bandwidth mobile platforms. These interventions embody a dual-track strategy: the NMF tackles chronic underfunding via institutional restructuring, while adaptive partnerships utilize Ghana's indigenous innovation capacity to circumvent infrastructural limitations, collectively shifting maintenance from reactive crisis management to proactive therapeutic justice.

Constraints and Future Research Directions

Although our mixed-methods approach identified system-wide patterns, several limitations should be recognized. The hospital sampling omitted smaller district facilities, as maintenance challenges may vary significantly in those settings. Survival analyses of equipment-related mortality exhibited residual confounding, even after multivariate adjustment. Future research should utilize quasi-experimental designs to assess the implementation of the proposed NMF, with a specific focus on how maintenance investment influences patient trust in public health systems, an area that remains underexplored in the context of health system resilience. We propose the development of Maintenance-Sensitive Quality Indicators (MSQIs) that integrate equipment metrics into existing health system assessments, facilitating the routine monitoring of this essential aspect of care quality.

Conclusion

Malfunctioning medical equipment in Ghana's public hospitals indicates not only a technical issue but also a significant violation of the social contract that supports healthcare provision. The results indicate that a child's geographical birthplace influences whether a malfunctioning incubator is merely a temporary issue or a fatal consequence, thereby violating the health equity guarantee outlined in Ghana's 1992 Constitution, Article 34. The proposed solutions, specifically the pro-poor financed National Maintenance Fund and context-appropriate technology partnerships, provide avenues for achieving therapeutic justice. Implementing them necessitates acknowledging that functional medical technology is as critical a determinant of health as clean water or skilled clinicians. A biomedical engineer in Kumasi remarked during our fieldwork, "When I repair a dialysis machine, I'm not fixing a device, I'm restoring someone's lifeline." This fundamental principle should inform both policy and practice in the reconstruction of Ghana's medical equipment ecosystem.

Conclusion and Limitations

This research highlights medical equipment dysfunction as a significant issue within Ghana's public health system, serving as a critical yet overlooked factor contributing to health inequities that disproportionately affect rural populations and result in severe clinical and economic repercussions. The analysis indicates that malfunctioning devices signify more than mere technical failures; they expose critical deficiencies in health governance, resource distribution, and maintenance systems that collectively compromise Ghana's constitutional pledge to health equity (Republic of Ghana, 1992, Article 34). The quantified spatial injustice in our findings raises significant ethical concerns. Rural facilities exhibit equipment failure rates that surpass those of urban hospitals by a factor of 3.2, thereby converting critical technologies such as dialysis machines and infant incubators from life-saving instruments into geographical determinants of survival. This disparity results in delayed cancer diagnoses that progress beyond treatment windows, interruptions in dialysis that require emergency hospital transfers, and improvised neonatal care that contributes to preventable infant mortality, clinical realities observed consistently during our fieldwork in Ghana's Northern, Ashanti, and Volta regions. The findings indicate that functional medical technology is essential for equitable care delivery, a crucial aspect lacking in current global health frameworks, despite its significant effect on amenable mortality (Kruk et al., 2018). Investing in sustainable maintenance ecosystems is not only an operational necessity but also an ethical imperative rooted in the right to health.

Constraints

Multiple methodological limitations necessitate clear recognition to properly contextualize our findings. The dependence on self-reported downtime data from hospitals, despite being cross-verified with technician logs and maintenance records, poses a risk of underestimation due to potential documentation gaps during crisis periods. At Komfo Anokye Teaching Hospital, we noted significant shortages during nurse strikes, where the prioritization of patient triage overshadowed equipment status tracking, indicating potential systematic underreporting in high-stress situations. The observational design of this study limits the ability to make definitive causal claims regarding the relationship between equipment failures and patient outcomes. Although multivariate regression and survival analyses accounted for staffing ratios, comorbidities, and facility characteristics, unmeasured confounders such as regional supply chain disruptions or informal technician interventions may still introduce residual bias. Third, our sampling of regional hospitals did not include district-level facilities and primary health centers, where maintenance challenges may vary significantly. This limitation is highlighted when comparing our findings with the Ghana Health Service's (2022) district facility assessments, which reveal even greater rural-urban disparities in equipment functionality. These limitations, however, outline constructive avenues for future research rather than undermining our primary conclusions.

Table 6. Research limitations and corresponding mitigation strategies

Limitation Category	Potential Impact on Findings	Mitigation Approaches Employed	Recommendations for Future Research
Self-reported downtime data	Underestimation of equipment non-functionality periods	Triangulation through technician logs, patient exit interviews, and maintenance work orders	Deployment of low-cost IoT sensors for real-time equipment monitoring validation
Observational design	Residual confounding in outcome attribution	Multivariate adjustment including facility tier, comorbidity burden, and staffing ratios	Quasi-experimental evaluation of maintenance interventions using stepped-wedge designs

Regional hospital focus	Limited generalizability to primary care facilities	Stratified analysis by hospital tier; incorporation of rural-urban differentials	Multi-level sampling framework including CHPS compounds in longitudinal studies

Prospective Research Directions

Based on these findings, three essential research directions arise that hold considerable policy implications. Initially, comprehensive return-on-investment (ROI) analyses should be conducted to compare maintenance models, including the proposed National Maintenance Fund and adaptive technology partnerships. These analyses must quantify both direct savings, such as extended equipment lifespan and reduced emergency repairs, as well as indirect clinical benefits, including averted deaths, reduced complications, and diminished catastrophic expenditures. This research could simulate scenarios, such as the anticipated $18.7 million savings from decreased emergency referrals under the NMF proposal, utilizing Ghana-specific economic parameters. Secondly, studies in implementation science focusing on knowledge transfer systems for biomedical technicians may address the observed "normalization of deviance." This research should particularly investigate how mobile learning platforms could alleviate professional isolation in rural facilities, as highlighted by technicians at Tamale Teaching Hospital, who reported dependence on WhatsApp groups for troubleshooting assistance. Third, longitudinal studies on "constraint-adapted competencies" would clarify how ongoing equipment shortages alter clinical education, exemplified in teaching hospitals where trainees focus on mastering manual ventilation techniques instead of ventilator management protocols. We advocate for the development of Maintenance-Sensitive Quality Indicators (MSQIs) that incorporate equipment metrics into existing assessments, such as the WHO's Service Availability and Readiness Assessment (SARA), to facilitate routine monitoring of this essential aspect of care.

In conclusion, Synthesis refers to the process of combining various elements to form a coherent whole. It is a fundamental concept in various fields, including chemistry, biology, and philosophy, where it denotes the integration of diverse components to create new entities or ideas. The non-operational dialysis machines, defective infant warmers, and inoperative autoclaves identified in this study reflect not only technical deficiencies but also violations of the therapeutic agreement between Ghana's healthcare system and its populace. The analysis indicates that equipment dysfunction serves as a significant stratifying factor, systematically disadvantaging rural and economically vulnerable patients, thereby contradicting Ghana's commitment to universal health coverage. The proposed solutions, notably the pro-poor financed National Maintenance Fund and context-appropriate technology partnerships such as the adaptation of Kofa's battery-swapping networks for medical devices, provide practical avenues for transforming maintenance systems from passive cost centers into tools for therapeutic justice. Implementing these reforms necessitates acknowledging that functional medical technology is as essential to healthcare as access to pharmaceuticals or skilled personnel. A biomedical engineer at Korle Bu Teaching Hospital, while repairing vital signs monitor during our fieldwork, stated, "Each machine restored isn't just a technical fix, it's the return of dignity to someone's care." This fundamental truth should underpin both academic research and health policy as Ghana seeks to transform its medical equipment ecosystem to serve all citizens effectively.

Declarations

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Orcid ID

Ramseyer Adekorang Asamoah https://orcid.org/0009-0008-7929-4967

Celene Dzreke https://orcid.org/0009-0009-0685-4991

Evans Dzreke https://orcid.org/0009-0005-1794-0298

David Kanze https://orcid.org/0009-0006-4309-5726

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