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# Framework Model for Sustainability Reliability Assessment of Clinical Laboratory Equipment in Indonesian Vertical Hospitals: Contributing to SDG 3

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**ABSTRACT**

***Objective:*** *This study aims to develop a holistic framework for assessing the reliability of clinical laboratory equipment in vertical hospitals in Indonesia. Clinical laboratories play a strategic role in supporting National Health Insurance and in achieving the Sustainable Development Goals (SDGs) across economic, social, and environmental dimensions. Reliable maintenance systems are crucial for ensuring equipment reliability, maintainability, availability, and safety.* ***Method:*** *A comprehensive literature review of international journals was conducted to identify existing models and methodologies for reliability assessment. The proposed framework integrates reliability engineering, sustainability principles, and VUCA (volatility, uncertainty, complexity, ambiguity) concepts. The model consists of sub-assessment sections covering pre-analytical, analytical, and post-analytical stages, as well as equipment reliability, logistics and warehousing, and continuous equipment monitoring.* ***Results:*** *The framework provides a structured approach for identifying factors that influence the reliability of laboratory equipment, enabling effective assessment and problem-solving in clinical laboratories. It facilitates continuous evaluation, supports maintenance planning, and aligns with safety and quality standards.* ***Novelty:*** *Integrating reliability, sustainability, and VUCA concepts into a single, holistic framework for clinical laboratory equipment in Indonesian vertical hospitals. The proposed framework provides practical guidance for hospital policymakers and managers to ensure accurate testing results, optimize equipment performance, enhance patient safety, and support sustainable healthcare operations. By strengthening the reliability of diagnostic services and improving the quality and accessibility of healthcare delivery, this framework contributes to achieving SDG 3 (Good Health and Well-Being).*

## INTRODUCTION

Current healthcare practice requires diagnosis based on data from clinical laboratories (Nayupe et al., 2023). Medical equipment is a critical asset that contributes greatly to the effectiveness and quality improvement of healthcare services (Wang et al., 2021; Zamzam et al., 2021). A comprehensive evaluation and effective monitoring of the entire operational cycle of medical equipment asset maintenance can improve equipment reliability, availability, and safety (Abd Rahman et al., 2023; Taskan et al., 2022). Asset and facility management is a key element in ensuring the continuity of operations of both primary and support health services (Zio, 2018). The delivery of health services and the fundamental right of the public to safety will be significantly affected if effective management is not implemented (Cesarotti & Silvio, 2006; Wekesa et al., 2021). Medical equipment used to support various services in the healthcare sector requires maintenance to ensure the assets are properly cared for throughout their life cycle. The life cycle of medical equipment is like that of machinery in general, which has a limited service life and will wear out after a certain period.

The quality of clinical laboratories needs to be supported by reliable maintenance (Shohet & Lavy, 2004), with consideration of reliability, maintainability, availability, and safety (Abd

Rahman et al., 2023; Hernández et al., 2020). Reliability is an important parameter in determining quality, with reliability instruments defined as the ability to be measured and the repeatability of the results (Barker et al., 2022). The reliability system, as a parameter, needs to be considered from the outset of concept preparation. The clinical laboratory service is an integral part of health services needed to establish a diagnosis, so clinical laboratories need to be organized effectively to support efforts to improve public health. Implementation of clinical laboratories must meet the criteria for organization, quality, safety, recording, and reporting (Erasmus & Ondoa, 2023; Hu & Huang, 2014; Kelsey et al., 2021).

Software, algorithms, and digital applications are increasingly used in clinical laboratory equipment. One of which is used to improve the quality and effectiveness of sample examination and laboratory information systems that support fast reporting with accurate results (Khayal, 2019). Thus, a model (Ondoa et al., 2020) is needed that can provide reliable estimates of clinical laboratory equipment, so as to prevent diagnostic failures and can be implemented in a nationwide network of hospital laboratories that provide extensive and economical services (Chan & Wang, 2022; Lin et al., 2017). Reliability assessment models can be used across various conditions and facility types (Santos et al., 2023). Clinical laboratories make important contributions across economic, social, and environmental (sustainability) dimensions (Crespo-Gonzalez et al., 2020; Harris et al., 2017).

In addition, the reliability and sustainability of clinical laboratory services are closely linked to achieving Sustainable Development Goal (SDG) 3: Good Health and Well-Being. Reliable laboratory equipment supports accurate and timely diagnosis, enhances patient safety, improves the quality of healthcare services, and contributes to equitable access to effective treatment. Therefore, strengthening the reliability assessment of clinical laboratory equipment is not only essential from technical and operational perspectives but also a strategic effort to support sustainable healthcare systems and the achievement of SDG 3 targets.

The Vertical Hospital Clinical Laboratory is an integrated clinical laboratory located in an independently managed hospital. It is responsible to the Director General of Health Services of the Ministry of Health of the Republic of Indonesia. There are currently 37 Vertical Hospitals in Indonesia, with 4 under construction in Surabaya, Makassar, Papua, and the Capital of the Nusantara (IKN). The Ministry of Health determines Vertical Hospital policy and is not influenced by local government or the private sector. With such a strategic position, the model produced from the research results will have a major impact on society and science. This paper aims to obtain a reliability assessment model framework for sustainable clinical laboratory equipment in vertical hospitals in Indonesia (Piadeh et al., 2018).

## RESEARCH METHOD

A literature review was conducted to examine both qualitative and quantitative empirical studies on the reliability and maintenance of clinical laboratory equipment. The review targeted international journals using several keywords, including reliability, reliability assessment, clinical laboratory equipment, sustainable healthcare, and maintenance of clinical laboratories (Abd Rahman et al., 2023; Nayupe et al., 2023; Wang et al., 2021; Zamzam et al., 2021). Articles were retrieved from reputable academic databases, including PubMed, Elsevier ScienceDirect, Emerald, and MDPI (Lin et al., 2017; Piadeh et al., 2018).

The search was limited to publications between 2019 and 2024 to ensure up-to-date insights. A total of 57 papers were identified and categorized by journal and publisher, as

summarized in Table 1. Metadata analysis was conducted to examine topics and themes within each paper, and the interconnections among studies were visualized using Connected Papers (https://www.connectedpaper.com) and VosViewer software (Crespo-Gonzalez et al., 2020; Santos et al., 2023; Smit, 2021; Subekti et al., 2021).

The resulting network graph revealed that most healthcare research focuses on service management, with relatively few studies directly addressing the reliability of clinical laboratory equipment (Alshahrani et al., 2020; Harris et al., 2017). This analysis supports the need for a structured framework to assess the reliability and sustainability of clinical laboratory equipment in vertical hospitals in Indonesia. Position and count of reviewed journals can see in Table 1.

**Table 1.** Position and count of reviewed journals

| Position of journal review | Count |
|---|---|
| Reliability Engineering & System Safety | 13 |
| African Journal of Laboratory Medicine | 5 |
| Practical Laboratory Medicine | 4 |
| Clinics in Laboratory Medicine | 2 |
| Front. Public Health | 2 |
| Health Policy | 2 |
| Systems | 2 |
| Applied Sciences | 1 |
| BMC Health Services Research | 1 |
| Computers & Industrial Engineering | 1 |
| Desalination | 1 |
| Digital Biomarkers | 1 |
| Energy Reports | 1 |
| European Journal of Operational Research | 1 |
| Futures | 1 |
| International Journal Organization Analysis (IJOA) | 1 |
| Informatics in Medicine Unlocked | 1 |

## RESULTS AND DISCUSSION

### *Results*

#### *Reliability assessment concept*

Reliability assessment must be designed by thoroughly considering multiple factors (Chia et al., 2023; Kowitt et al., 2020; Nayupe et al., 2023; Tanasiichuk et al., 2023; Zhao et al., 2023). Clinical laboratory equipment is a critical asset that contributes significantly to healthcare effectiveness and quality improvement (Abd Rahman et al., 2023; Santoso & Nurfitriana, 2022; Wang et al., 2021). Failure Mode and Effect Analysis (FMEA) is widely used to evaluate potential failure modes in complex systems, with Health-FMEA being applied for medical equipment reliability assessment (Chia et al., 2023; El-Awady, 2023; Pietrantuono et al., 2020). Modified FMEA ensures the quality of reliability assessment in medical equipment (Nayupe et al., 2023; Zio, 2018).

Facility service quality assessment can be conducted with models such as business excellence models, degradation performance models, and surrogate models (Barker et al., 2022; Piadeh et al., 2018). Improving degradation data models is critical for accurately estimating reliability and predicting failures, especially for highly reliable products with

minimal failure records (Zhao et al., 2023).

***Paper review related to reliability assessment and clinical laboratories***

Metadata analysis of 57 journals was conducted to examine previous studies based on title, author, year, journal, keywords, methodology, objectives, and results (Crespo-Gonzalez et al., 2020; Mannocci et al., 2019; Santos et al., 2023). Keywords such as clinical laboratory, healthcare, reliability, reliability assessment, and sustainability were used to categorize and summarize research findings. Papers from 2015 to 2023 were included for their relevance in providing indicators of sustainable laboratory equipment reliability (Loebl & Knowles, 2021; Sari et al., 2015; Slot et al., 2020).

Clinical laboratory quality encompasses personnel, equipment, methods, and reagents, and it must ensure accuracy, safety, and reliability of results (Gong et al., 2020; Harris et al., 2017; Nayupe et al., 2023). Table 2 provides a detailed summary of reviewed papers, which serves as the basis for compiling the reliability assessment framework for sustainable clinical laboratory equipment in hospitals.

**Table 2**. List of paper reviews related with the topic

| No. | Author's name, Year, Journal | Main Objective of paper | Object and Total Citations |
|---|---|---|---|
| 1 | Erasmus and Ondoa, 2023, AJLM | The need for digital technology and Artificial intelligence in improving the quality of clinical laboratories | Clinical Laboratory (3) |
| 2 | Tanasiichuk et al., 2023, AJLM | Success factors in running hospital laboratory management | Hospital Laboratory (4) |
| 3 | Chia et al., 2023, Ann Med Sur | Use of Health FMEA in healthcare equipment maintenance | Health Equipment (1) |
| 4 | Nayupe et al., 2023, AJLM | Implementation of Health Clinic Laboratory Health Equipment in Malawi | Health Laboratory (2) |
| 5 | Gámiz et al., 2023, Rel Eng Sys Saf | Create a stochastic model based on the Markov process that can illustrate the development of the system over time and estimate some dependence functions on the actual state of the system. | Industrial Equipment (3) |
| 6 | El-Awady, 2023, Glo Jou Qua Saf | Use of Health FMEA in the maintenance of patient health equipment | Patient Safety Tools (6) |
| 7 | Zhao et al., 2023, Rel Eng Sys Saf | Establish a comprehensive framework for assessing heterogeneous failure dependencies and developing maintenance optimization models using Markov processes for multi-component systems. | Multi-Component Industrial Facility (15) |
| 8 | Rust et al., 2023, Jor Trans Supp Cha | Use of Causal Loop Diagrams (CLD) in the transport system in South Africa | Transport Equipment (2) |
| 9 | Rastogi et al., 2022, Prac Lab Medi | Assess and compare the overall equipment performance (OEE) of four hematology analyzers in southern India. | Clinical Laboratory (5) |

| No. | Author's name, Year, Journal | Main Objective of paper | Object and Total Citations |
|---|---|---|---|
| 10 | Dshalalow and White, 2022, Math | Examines the fluctuating behaviour of mixed reliability systems involving natural wear and tear as well as shocks, which occur at specific events. The authors use a combination of analytical and numerical methods to investigate system reliability and failure behaviour patterns. | Framework: System (4) |
| 11 | Zamzam et al., 2021, Front Public Health | This research describes the proposed prioritization assessment and predictive system for medical equipment maintenance to improve healthcare reliability and availability. | Healthcare Equipment System (27) |

## *Discussion*

### *Framework model*

The development of a reliability assessment model begins with theoretical studies, including system thinking and the Rich Picture methodology, that describe the clinical laboratory sample examination process from start to reporting (Chia et al., 2023; Tanasiichuk et al., 2023). Considerations of Foresight, VUCA, and sustainability are critical for determining the indicators for reliability assessment, aligning with the regulations and operational targets of clinical laboratories in vertical hospitals (Brown, 2020; Crespo-Gonzalez et al., 2020; Piadeh et al., 2018). Approaches applied include Reliability Engineering, Health FMEA, Maintenance strategies, Overall Equipment Effectiveness (OEE), reliability calculation of supporting equipment, and logistics/warehousing assessment (Afifi et al., 2019; El-Awady, 2023; Khera et al., 2022; Sari et al., 2015; Zhao et al., 2023). These approaches provide a thorough research stage, contributing to the optimization of clinical laboratory operations, hospital performance, and government oversight.

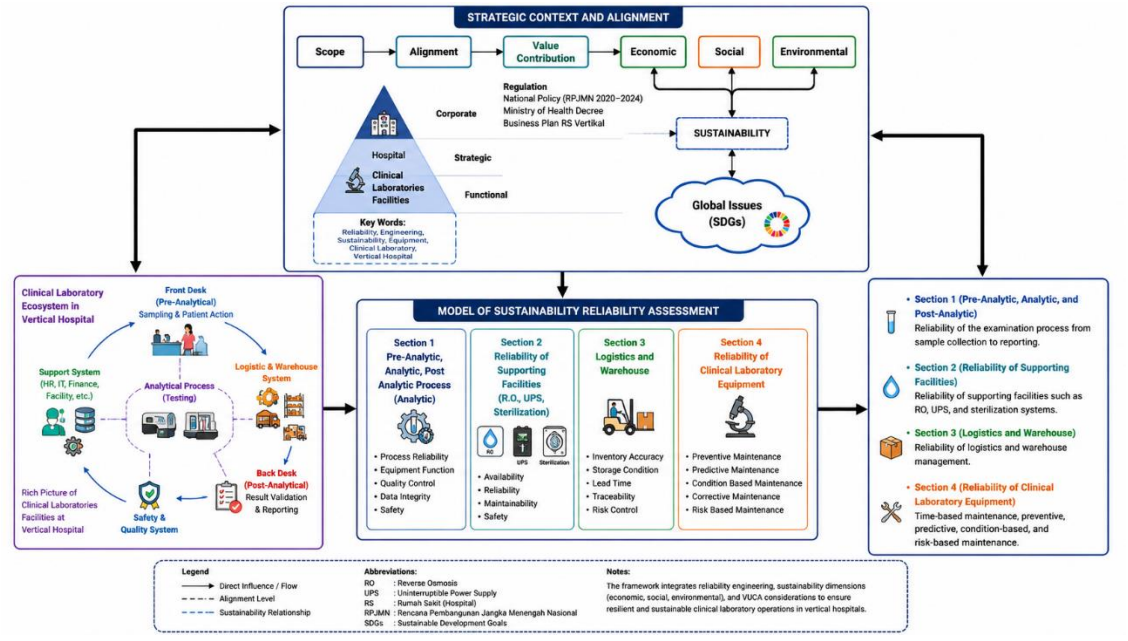


**Figure 1**. Framework models sustainability reliability assessment for clinical laboratories equipment of vertical hospital in Indonesia

The resulting framework is illustrated in Figure 1, which provides a comprehensive visual model of sustainability and reliability assessment for clinical laboratory equipment in vertical hospitals in Indonesia. The framework highlights the integration of maintenance practices, reliability calculations, Health FMEA, and sustainability indicators across all stages of laboratory operation. It demonstrates how these measures collectively ensure reliable performance, accurate examination results, and operational efficiency. This figure visually depicts the workflow from sample processing to reliability evaluation, integrating economic, social, and environmental sustainability aspects, as well as maintenance and supporting equipment evaluation. The framework guides hospital management and policymakers in implementing structured reliability assessments, ensuring quality, safety, and sustainable healthcare service delivery. The framework has practical implications, including ensuring reliable equipment performance, accurate examination results, economic benefits, expanded access to healthcare services, and enhanced independence in clinical laboratory management. By implementing this model, vertical hospitals can systematically assess, monitor, and improve the reliability of their clinical laboratory assets, which contributes to overall public health improvement.

From an SDG perspective, the proposed framework contributes to achieving SDG 3 (Good Health and Well-Being) by enhancing the reliability of diagnostic services in healthcare facilities. Reliable clinical laboratory equipment enables timely and accurate diagnoses, supports patient safety, minimizes diagnostic errors, and enhances the quality and continuity of healthcare services. In the context of Indonesian vertical hospitals, implementing this framework may help healthcare providers and policymakers promote more resilient, efficient, and sustainable healthcare systems, thereby supporting the broader agenda of ensuring healthy lives and promoting well-being for all at all ages.

## CONCLUSION

**Fundamental Finding:** Reliability assessment in clinical laboratory equipment is crucial for strategic healthcare management. This study emphasizes the importance of considering health service quality, safety, sustainability, and logistical efficiency. Although reliability research is well developed, few studies apply a holistic approach that integrates maintenance, sustainability, foresight, and VUCA to clinical laboratory equipment. **Implication:** A holistic reliability assessment framework can help hospitals ensure reliable equipment performance, accurate test results, and sustainable laboratory operations. It provides practical guidance for hospital administrators to optimize maintenance, resource allocation, and strategic planning while strengthening patient safety and the quality of diagnostic services. By supporting reliable and sustainable healthcare delivery, the proposed framework contributes to achieving SDG 3 (Good Health and Well-Being), particularly by promoting access to safe, effective, and high-quality healthcare services. **Limitation:** The study is conceptual and based on a literature review. Practical implementation may vary due to hospital type, equipment diversity, staff expertise, and operational conditions. **Future Research:** Future studies should validate the framework in various hospital settings and integrate quantitative monitoring, predictive maintenance, and sustainability metrics to enhance its effectiveness.

## AUTHOR CONTRIBUTIONS

**Amal Witonohadi** contributed to the conceptualization of the study, research design, project supervision, validation of research findings, and critical review of the manuscript. **Parwadi Moengin** contributed to methodology development, data collection, data analysis, and manuscript revision. **Emelia Sari** contributed to literature review, data processing, visualization, and administrative support. **Rianti Dewi Sulamet-Ariobimo** contributed to software support, technical implementation, interpretation of results, and manuscript editing.

## CONFLICT OF INTEREST STATEMENT

The authors confirm that they have no financial, personal, or professional relationships that could have influenced the design, conduct, results, or conclusions of this study.

## STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors affirm that no artificial intelligence tools, automated content generation software, or digital writing aids were used at any stage of the research, analysis, or manuscript preparation. All work, including data analysis, interpretation of findings, and manuscript writing, was carried out solely by the authors, who take full responsibility for the originality, accuracy, and integrity of the reported content.

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