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Developing Sustainable Diagnostic Laboratory Infrastructure Models for Emerging and Resource Constrained Health Systems

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Abstract- Background: Diagnostic laboratories are foundational to effective health systems, yet many emerging and resource-constrained settings face persistent deficits in infrastructure, workforce capacity, quality assurance, and sustainability. These gaps undermine disease surveillance, timely diagnosis, antimicrobial stewardship, and public health decision-making. Objective: This study proposes a comprehensive, sustainable diagnostic laboratory infrastructure model tailored to emerging and resource-constrained health systems, integrating technical, financial, governance, and digital dimensions to enhance resilience, equity, and long-term performance. Methods: A conceptual synthesis approach was adopted, drawing on peer-reviewed literature, global health policy frameworks, and implementation experiences from low- and middle-income countries. Key domains were systematically analyzed, including facility design, equipment lifecycle management, human resources, supply chain optimization, quality management systems, financing mechanisms, and data integration. These domains were consolidated into an adaptive, modular framework aligned with universal health coverage and health system strengthening principles. Results: The proposed model emphasizes phased infrastructure development, prioritizing essential diagnostics, standardized laboratory tiers, and context-appropriate technology selection. Sustainability is reinforced through preventive maintenance strategies, pooled procurement, task-shifting and continuous professional development, and integration of laboratory information systems with national health data architectures. Innovative financing options, such as blended finance, public–private partnerships, and performance-based funding, are incorporated to reduce donor dependency. Governance components focus on regulatory harmonization, accreditation pathways, and accountability mechanisms to ensure quality, safety, and equity. Conclusion: Developing sustainable diagnostic laboratory infrastructure requires moving beyond fragmented investments toward integrated, systems-level models that balance technical robustness with financial and institutional feasibility. The framework presented provides policymakers, health planners, and development partners with a practical blueprint for strengthening diagnostic capacity in resource-constrained settings. By embedding sustainability, digital integration, and governance from the outset, the model supports improved health outcomes, pandemic preparedness, and progress toward resilient and equitable health systems. Implementation of this model is adaptable across disease priorities, including infectious diseases, noncommunicable conditions, and emergency response contexts, while remaining sensitive to local epidemiology, governance capacity, and socioeconomic constraints. Future research should empirically validate the framework through pilot deployments, cost-effectiveness analyses, and longitudinal assessments of diagnostic access, quality, and system resilience outcomes across diverse health sectors and financing environments globally in low resource settings.

Keywords: Diagnostic Laboratories; Health System Strengthening; Sustainability; Resource-Constrained Settings; Laboratory Infrastructure; Global Health Systems

I. INTRODUCTION

Diagnostic laboratories are a cornerstone of effective health systems, underpinning clinical decision-making, disease surveillance, public health preparedness, and health system resilience. Accurate and timely diagnostic services enable early detection of diseases, guide appropriate treatment, support antimicrobial stewardship, and inform population-level health interventions (Udechukwu, 2018). In both routine care and emergency contexts, laboratory systems play a decisive role in shaping health outcomes, influencing mortality, morbidity, and the efficient allocation of limited healthcare resources. As global health priorities increasingly emphasize prevention, preparedness, and universal health coverage, the strategic importance of diagnostic laboratory infrastructure has become more pronounced (Pouliakas & Theodossiou, 2013, Schulte, et al., 2015).

Despite this central role, many emerging and resource-constrained health systems continue to face significant and persistent laboratory infrastructure deficits. These challenges include inadequate physical facilities, unreliable power and water supply, obsolete or poorly maintained equipment, fragmented supply chains, limited access to quality reagents, and chronic shortages of trained laboratory professionals (Ahmed & Odejobi, 2018, Odejobi & Ahmed, 2018, Seyi-Lande, Arowogbadamu & Oziri, 2018). Weak quality management systems, inconsistent regulatory oversight, and limited integration of laboratory data into national health information systems further constrain diagnostic performance. As a result, delayed diagnoses, inaccurate test results, and inequitable access to essential diagnostics remain common, undermining both individual patient care and broader public health objectives (Hale, Borys & Adams, 2015, Peckham, et al., 2017).

Historically, laboratory investments in low- and middle-income settings have often been disease-specific, donor-driven, and implemented in a fragmented manner. While such approaches have yielded short-term gains, they frequently lack sustainability, scalability, and system-wide integration. Standalone laboratories or vertical programs may struggle to adapt to changing disease patterns, absorb technological advancements, or maintain services once external funding declines. These limitations highlight the need to reconceptualize laboratory infrastructure development as a long-term, system-level intervention rather than a series of isolated projects (Eeckelaert, et al., 2012, Reese, 2018).

Developing sustainable diagnostic laboratory infrastructure models offers a pathway to address these challenges by aligning technical capacity, human resources, financing, governance, and digital integration within a coherent framework. Systems-level models emphasize phased development, standardization, interoperability, and local capacity building, enabling laboratories to remain functional, adaptable, and responsive over time (Ahmed & Odejobi, 2018, Odejobi & Ahmed, 2018, Seyi-Lande, Arowogbadamu & Oziri, 2018). By embedding sustainability principles into laboratory planning and implementation, emerging and resource-constrained health systems can strengthen diagnostic capacity, improve equity of access, and enhance preparedness for both endemic diseases and future public health emergencies (Tompa, et al., 2016, Walters, et al., 2011).

2.1. Methodology

This study adopted a qualitative, framework-guided methodological approach to develop a sustainable diagnostic laboratory infrastructure model tailored to emerging and resource-constrained health systems. The methodology was designed to synthesize conceptual, institutional, and operational insights from established frameworks and empirical evidence, enabling the construction of a context-responsive and systems-level infrastructure model. A qualitative integrative synthesis method was selected as the most suitable approach, given the study's focus on conceptual model development rather than hypothesis testing or quantitative measurement.

The methodological foundation draws primarily on the conceptual framework for sustainable implementation in resource-constrained settings proposed by Fanta and Pretorius, which emphasizes systemic alignment across technological, organizational, environmental, and socio-economic dimensions. This framework informed the structural logic of the study, particularly the need to view diagnostic laboratory infrastructure as a socio-technical system rather than a collection of physical assets. To strengthen the human and institutional dimensions of the model, the comprehensive human resources for health system development framework by Fujita et al. was incorporated. This framework provided a lens for examining workforce availability, capacity building, governance, and resilience in fragile and constrained contexts. Empirical grounding was achieved through the qualitative findings of Boadu et al., which documented real-world implementation challenges

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associated with diagnostic services at the primary healthcare level in a resource-limited district. These challenges informed the operational realism of the proposed model.

The study began with a structured review and analytical reading of the three selected sources. Rather than conducting a broad systematic review, a purposive framework synthesis approach was employed, focusing on extracting constructs, principles, and causal relationships relevant to sustainability, diagnostic systems, and constrained health environments. Key themes were identified through iterative coding, including infrastructure readiness, workforce competence, supply chain reliability, governance and policy alignment, user trust, and contextual adaptability. These themes were continuously compared across the three sources to identify areas of convergence and divergence.

Following thematic extraction, a cross-framework mapping process was conducted to align conceptual elements from the sustainability framework with human resource system dimensions and field-level diagnostic implementation challenges. This mapping enabled the identification of core domains essential for sustainable diagnostic laboratory infrastructure, including physical infrastructure and technology, human resources, governance and financing, supply chains, quality assurance, digital integration, and community and health system interface. Particular attention was given to feedback loops, interdependencies, and failure points commonly observed in resource-constrained settings.

An abductive reasoning process was then applied to move iteratively between theory and empirical evidence. This allowed the study to refine assumptions and ensure that the emerging model was both theoretically robust and practically grounded. Contextual constraints such as limited funding, workforce shortages, infrastructural fragility, and governance variability were explicitly incorporated into the model design rather than treated as external limitations. This ensured that sustainability was conceptualized as adaptive capacity rather than static optimization.

To enhance methodological rigor, the model development process followed principles of analytical transparency and conceptual validity. The alignment of constructs across the three source frameworks served as a form of theoretical triangulation, reducing the risk of single-source bias. The final output of the methodology is a consolidated diagnostic laboratory infrastructure model that integrates systemic sustainability principles, human resource development pathways, and operational realities observed in primary healthcare settings.

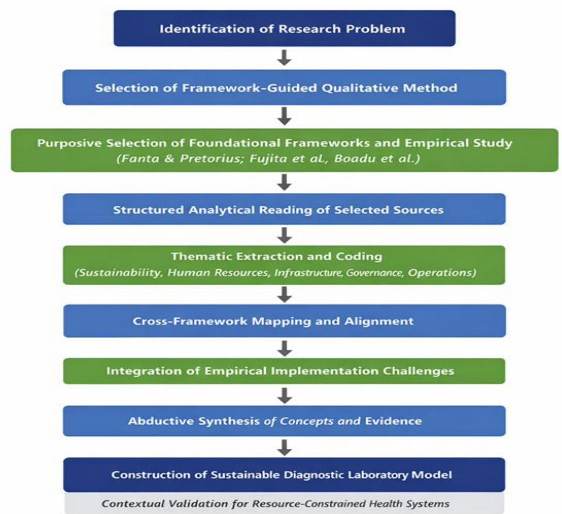

Figure 1: Flowchart of the study methodology

2.2. Conceptual and Theoretical Foundations of Sustainable Laboratory Infrastructure

Sustainable laboratory infrastructure is increasingly recognized as a foundational element of resilient health systems, particularly in emerging and resource-constrained contexts where diagnostic capacity directly influences health outcomes, surveillance effectiveness, and system preparedness. Conceptually, sustainability in laboratory infrastructure extends beyond physical facilities and equipment to encompass institutional capacity, governance, financing, human resources, and adaptive capability over time (Martinez-Martin, et al., 2018, Rees, 2016). A sustainable diagnostic laboratory system is therefore one that consistently delivers accurate, timely, and accessible diagnostic services while remaining technically functional, financially viable, environmentally responsible, and institutionally embedded within the broader health system (Aransi, et al., 2018, Nwafor, et al., 2018, Seyi-Lande, Arowogbadamu & Oziri, 2018).

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At the core of sustainability principles applied to laboratory infrastructure is the notion of long-term functionality under changing epidemiological, economic, and technological conditions. This aligns with the broader sustainable development paradigm, which emphasizes meeting present needs without compromising the ability of future systems to meet theirs (Larkins, et al., 2013, Wallerstein, Yen & Syme, 2011). In laboratory settings, this translates into infrastructure designs and operational models that account for life-cycle costs, maintenance requirements, workforce retention, and evolving diagnostic demands. Sustainability principles also emphasize equity, ensuring that diagnostic services are accessible across geographic, socioeconomic, and demographic boundaries, rather than concentrated in urban or tertiary facilities alone. Figure 2 shows development of sustainable technology presented by Fanta & Pretorius, 2018.

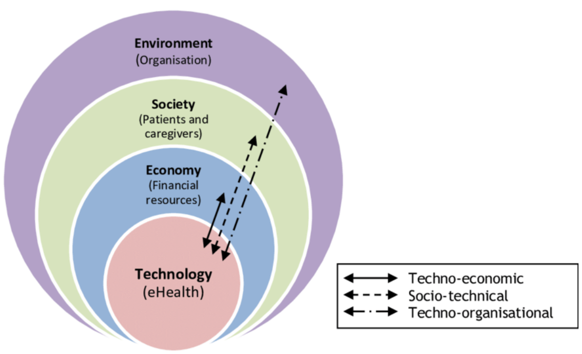

Figure 2: Development of sustainable technology (Fanta & Pretorius, 2018).

Health systems strengthening frameworks provide an essential theoretical lens for understanding how laboratory infrastructure contributes to overall system performance. The World Health Organization's health system building blocks framework, for example, identifies service delivery, health workforce, information systems, access to essential medicines and technologies, financing, and leadership and governance as interdependent components of a functioning health system. Diagnostic laboratories intersect with all these components simultaneously (Liang, et al., 2018, Lönnroth, et a., 2015). They are a core service delivery platform, depend on a skilled workforce, generate critical health information, require reliable access to consumables and technologies, demand sustainable financing, and operate within regulatory and governance structures. Conceptually, this positions laboratory infrastructure not as a peripheral technical service, but as a cross-cutting system enabler whose sustainability depends on balanced investments across multiple domains (Index, 2016).

Resilient diagnostic services are further underpinned by systems theory, which views health systems as complex adaptive systems rather than linear production processes. From this perspective, laboratories must be designed to absorb shocks, adapt to stressors, and continue functioning during disruptions such as disease outbreaks, supply chain failures, or funding fluctuations. Theoretical models of resilience emphasize redundancy, flexibility, learning, and feedback mechanisms (Gragnolati, Lindelöw & Couttolenc, 2013). Applied to laboratory infrastructure, this implies diversified supply chains, modular facility designs, scalable testing platforms, continuous quality improvement systems, and feedback loops that link laboratory data to clinical and public health decision-making. In resource-constrained settings, resilience also involves the ability to operate under infrastructural limitations such as intermittent power supply, limited cold chain capacity, and workforce shortages (Akinrinoye, et al., 2015, Gil-Ozoudeh, et al., 2018, Nwafor, et al., 2018, Seyi-Lande, Arowogbadamu & Oziri, 2018).

The concept of integrated service delivery further informs sustainable laboratory infrastructure models. Fragmentation has historically characterized diagnostic systems in many low-resource settings, with parallel laboratories established for specific diseases or donor programs. Theoretical approaches to integration argue that system efficiency and sustainability improve when services share infrastructure, workforce, data systems, and governance arrangements. Integrated laboratory networks, organized through tiered systems linked by referral and information flows, exemplify this principle (Hiller, et al., 2011, Knaul, et al., 2012). Such models draw on network theory, which highlights the value of coordination, standardization, and central oversight combined with decentralized service provision. In this framework, sustainability emerges from shared resources, harmonized standards, and collective learning across the network. Figure 3 shows

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figure of human resources for health system development: analytical framework the ‘‘house model’’ presented by Fujita, et al., 2011.

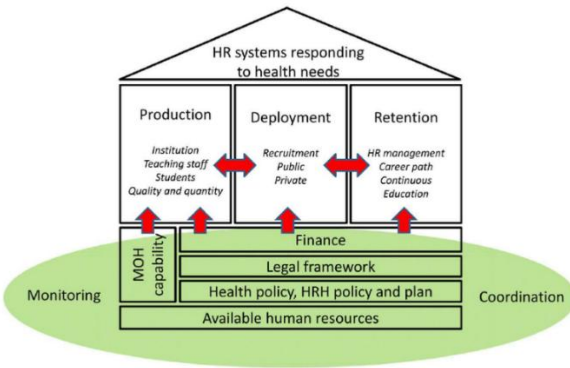

Figure 3: Human resources for health system development: analytical framework the ‘‘house model’’ (Fujita, et al., 2011).

Economic theories of public goods and market failure also underpin the case for sustainable laboratory infrastructure. Diagnostics generate significant positive externalities by enabling disease surveillance, outbreak control, and population-level risk reduction, benefits that extend beyond individual patients. In resource-constrained health systems, market-based provision alone is often insufficient to ensure equitable and reliable diagnostic access. Sustainable laboratory models therefore require public financing, pooled risk mechanisms, and regulatory oversight to correct market failures and ensure continuity of essential services (DiMase, et al., 2015, Hargreaves, et al., 2011). Cost-effectiveness and value-for-money principles further guide decisions on technology selection, test menus, and network design, emphasizing the importance of aligning investments with population health priorities.

Institutional and governance theories contribute additional insight into sustainability challenges. Weak institutional capacity, fragmented authority, and unclear accountability structures frequently undermine laboratory performance (Gil-Ozoudeh, et al., 2018, Nwafor, et al., 2018, Seyi-Lande, Arowogbadamu & Oziri, 2018). Theoretical models of good governance stress transparency, accountability, rule-based decision-making, and stakeholder participation as prerequisites for sustainable public services. Applied to laboratory infrastructure, this implies clear regulatory frameworks, accreditation systems, defined roles across national and subnational levels, and mechanisms for performance monitoring and corrective action (Afriyie, 2017, Moore, Wurzelbacher & Shockey, 2018). Sustainability is thus not only a technical issue but also an institutional one, dependent on the stability and legitimacy of governance arrangements.

Digital health and information systems theory further inform contemporary models of sustainable diagnostic infrastructure. Laboratories are major producers of health data, and their integration into national health information systems enhances both clinical care and public health intelligence. Theoretical models of interoperability and digital transformation emphasize standardized data architectures, secure data exchange, and user-centered system design (Takala, et al., 2014, Wachter & Yorio, 2014). In resource-constrained settings, sustainable digital integration requires technologies that are scalable, interoperable, and adaptable to local capacity, avoiding dependence on proprietary or donor-specific platforms that may not be maintained over time. Figure 4 shows the conceptual framework for investigating healthcare providers’ compliance with the test-before-treat guideline for malaria in a Ghanaian district presented by Boadu, et al., 2016.

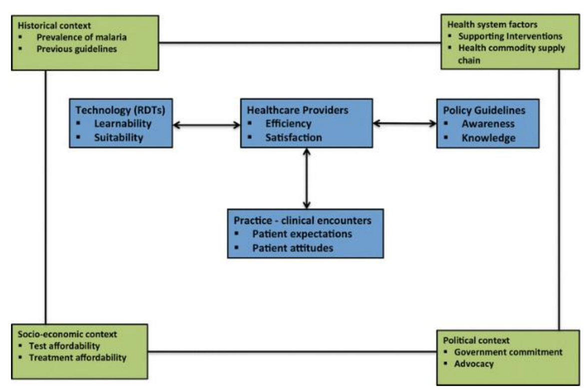

Figure 4: Conceptual framework for investigating healthcare providers’ compliance with the test-before-treat guideline for malaria in a Ghanaian district (Boadu, et al., 2016).

Finally, human capital theory underscores the centrality of the laboratory workforce to sustainability. Infrastructure and technology investments yield limited returns without skilled personnel to operate, maintain, and interpret diagnostic systems. Sustainable laboratory models therefore integrate continuous professional development, task-shifting strategies, and career pathways to retain expertise within the system. This aligns with broader theories of capacity building, which emphasize endogenous development, knowledge transfer, and institutional learning as drivers of long-term system performance (Jilcha & Kitaw, 2017, Longoni, et al., 2013).

Taken together, these conceptual and theoretical foundations demonstrate that sustainable diagnostic laboratory infrastructure is inherently multi-dimensional. It is shaped by sustainability principles, health systems strengthening frameworks, resilience theory, economic and governance models, digital integration concepts, and human capital development. In emerging and resource-constrained health systems, translating these theories into practice requires moving beyond fragmented, short-term interventions toward coherent, systems-level models that embed laboratories firmly within the broader architecture of health system development (Kim, Park & Park, 2016, Lerman, et al., 2012).

2.3. Current State of Diagnostic Laboratory Infrastructure in Resource-Constrained Health Systems

The current state of diagnostic laboratory infrastructure in resource-constrained health systems is characterized by persistent structural, technological, workforce, and operational challenges that collectively limit diagnostic capacity and undermine health system performance. Although diagnostic services are essential for effective clinical care, disease surveillance, and public health response, laboratories in many low- and middle-income settings continue to operate under conditions that constrain accuracy, timeliness, accessibility, and sustainability. These constraints are not isolated technical problems but reflect systemic weaknesses that shape how laboratories are planned, financed, managed, and integrated into broader health systems (Badri, Boudreau-Trudel & Souissi, 2018).

Structurally, many laboratories in resource-constrained settings operate in facilities that were not purpose-built for diagnostic services or have deteriorated due to inadequate maintenance and underinvestment. Physical infrastructure challenges include overcrowded laboratory spaces, poor ventilation, insufficient biosafety features, unreliable water supply, and intermittent electricity (Corral de Zubielqui, et al., 2015, Diraviam, et al., 2018). These conditions compromise biosafety, increase the risk of contamination, and limit the ability to implement standardized workflows. In rural and underserved areas, laboratories may be entirely absent or limited to basic microscopy services, forcing patients to travel long distances or rely on clinical diagnosis alone (Tsui, et al., 2015, Wiatrowski, 2013). Even in tertiary facilities, spatial constraints and aging buildings often restrict the installation of modern diagnostic equipment and limit scalability during disease outbreaks or surges in testing demand.

Technological challenges further constrain laboratory performance. Many facilities rely on outdated or inappropriate diagnostic equipment that is poorly matched to local disease profiles or operational realities. Equipment donations and donor-funded procurements, while well-intentioned, often result in fragmented technology landscapes with incompatible platforms, limited availability of consumables, and high maintenance requirements. Breakdowns are frequent due to lack of preventive maintenance, absence of service contracts, and shortages of trained biomedical engineers (Balcazar, et al., 2011, Zhao & Obonyo, 2018). Supply chain disruptions exacerbate these challenges, leading to stock-outs of reagents, calibrators, and spare parts, which in turn cause service interruptions and delays in diagnosis. Limited access to reliable cold chain infrastructure further restricts the use of advanced diagnostics, particularly in peripheral laboratories.

The digital dimension of laboratory technology remains underdeveloped in many resource-constrained systems. Laboratory information systems, where they exist, are often fragmented, paper-based, or limited to specific programs or facilities. Lack of interoperability with national health information systems impedes data sharing, surveillance, and evidence-based decision-making. As a result, laboratory data are underutilized for public health intelligence, outbreak detection, and monitoring of disease trends. Manual reporting processes increase the risk of errors, delays, and data loss, further weakening the contribution of laboratories to health system governance and planning (Sarker, et al., 2018, Woldie, et al., 2018).

Workforce constraints represent one of the most critical challenges affecting diagnostic laboratory infrastructure. Chronic shortages of trained laboratory professionals are common, particularly in rural and remote areas. Existing staff often face high workloads, limited opportunities for professional development, and inadequate remuneration, contributing to burnout, attrition, and migration to better-resourced sectors or countries. Training programs may be outdated or poorly aligned with evolving diagnostic technologies, leaving personnel ill-prepared to operate and maintain modern equipment (Bitran, 2014, Lund, Alfers & Santana, 2016). In some settings, task-shifting to non-laboratory personnel occurs out of necessity, raising concerns about quality assurance and patient safety when appropriate supervision and training are lacking.

Operational challenges compound structural, technological, and workforce limitations. Weak quality management systems are widespread, with inconsistent adherence to standard operating procedures, limited internal quality control, and minimal participation in external quality assessment schemes. Accreditation remains out of reach for many laboratories due to resource constraints, limited regulatory support, and lack of technical assistance. These gaps undermine confidence in test results among clinicians and patients, reducing the clinical utility of laboratory services and reinforcing reliance on empirical treatment (Nwameme, Tabong & Adongo, 2018, Vilcu, et al., 2016).

Financial and managerial constraints further affect laboratory operations. Laboratories in resource-constrained health systems often operate with fragmented and unpredictable funding streams, heavily dependent on donor support or disease-specific programs. This financing model limits flexibility, constrains long-term planning, and perpetuates verticalization of services. Cost recovery mechanisms, where they exist, may create barriers to access for low-income populations, undermining equity objectives. At the same time, limited financial autonomy at facility level restricts the ability of laboratory managers to procure essential supplies, invest in maintenance, or respond to emerging needs (Bardosh, et al., 2017, Zulu, et al., 2014).

Governance and coordination challenges also shape the current state of diagnostic laboratory infrastructure. Responsibilities for laboratory oversight may be dispersed across multiple agencies, leading to duplication, gaps, and inconsistent standards. Weak regulatory frameworks and enforcement mechanisms limit accountability for quality, safety, and performance. In decentralized health systems, subnational authorities may lack the technical capacity or resources to effectively manage laboratory services, resulting in wide variations in capacity and quality across regions (Badri, Boudreau-Trudel & Souissi, 2018, Kim, et al., 2016).

The cumulative effect of these structural, technological, workforce, and operational challenges is a diagnostic landscape marked by inequities, inefficiencies, and vulnerability to shocks. During public health emergencies, such as infectious disease outbreaks, these weaknesses become particularly evident, as laboratories struggle to scale up testing, ensure biosafety, and deliver timely results. The COVID-19 pandemic highlighted both the critical importance of diagnostic capacity and the consequences of longstanding underinvestment in laboratory systems across resource-constrained settings (Pacifico Silva, et al., 2018).

Understanding the current state of diagnostic laboratory infrastructure is essential for developing sustainable models that address root causes rather than symptoms. The challenges observed are interconnected and mutually reinforcing, requiring comprehensive, systems-level interventions rather than isolated technical fixes. Structural improvements must be aligned with appropriate technology selection, workforce development, operational strengthening, and governance reform. Only by addressing these dimensions holistically can emerging and resource-constrained health systems build laboratory infrastructure capable of supporting high-quality care, effective surveillance, and resilient health system performance over the long term (Main, et al., 2018).

2.4. Core Components of a Sustainable Diagnostic Laboratory Infrastructure Model

A sustainable diagnostic laboratory infrastructure model for emerging and resource-constrained health systems is built on a set of interdependent core components that collectively determine functionality, resilience, and long-term performance. These components extend beyond the physical presence of laboratory facilities to include the systems, processes, and human capacities required to deliver reliable diagnostic services over time. Facility design, equipment lifecycle management, human resources, supply chains, and quality management systems form the backbone of such a model, and their effective integration is essential for ensuring that laboratory services remain accessible, accurate, and adaptable in challenging contexts (Kuupiel, Bawontuo & Mashamba-Thompson, 2017).

Facility design is a foundational element of sustainable laboratory infrastructure, as it directly influences biosafety, workflow efficiency, scalability, and environmental performance. In resource-constrained settings, laboratories are often retrofitted into existing buildings not originally designed for diagnostic purposes, leading to inefficiencies and safety risks. A sustainable model emphasizes context-appropriate, purpose-driven design that accommodates current diagnostic needs while allowing for future expansion. This includes adequate space for sample reception, processing, storage, and waste management, as well as clearly defined clean and dirty zones to minimize contamination risks (Vogler, Paris & Panteli, 2018, Wirtz, et al., 2017). Design considerations must also account for local infrastructure constraints, incorporating natural ventilation where appropriate, energy-efficient lighting, and resilient water and power systems, including backup supplies. Modular and standardized designs can reduce construction costs, facilitate replication across regions, and enable phased development aligned with available resources (Brenner, et al., 2018, Van Eerd & Saunders, 2017).

Equipment lifecycle management is another critical component, addressing the full spectrum of technology selection, procurement, operation, maintenance, and eventual replacement. Sustainable laboratory models prioritize the selection of diagnostic equipment that is fit for purpose, aligned with disease burden, and compatible with local operating conditions. Overly complex or high-maintenance technologies may offer advanced capabilities but often prove unsustainable without reliable service support and consumables (Bam, et al., 2017, Nascimento, et al., 2017). Lifecycle management approaches emphasize preventive maintenance, availability of spare parts, service contracts, and training of local technicians to minimize downtime and extend equipment lifespan. Centralized procurement and standardization of platforms across laboratory networks can further enhance sustainability by simplifying maintenance, reducing costs, and improving supply chain reliability.

Human resources are central to the sustainability of diagnostic laboratory infrastructure, as skilled personnel are required to operate equipment, implement quality systems, and interpret results. A sustainable model recognizes laboratory professionals as strategic assets and prioritizes workforce planning, training, and retention. This includes aligning pre-service education with evolving diagnostic technologies, providing continuous professional development, and establishing clear career pathways to motivate and retain staff (Kwon, et al., 2018). In resource-constrained settings, task-shifting and role diversification may be necessary to address workforce shortages, but these strategies must be supported by appropriate supervision, competency assessment, and regulatory frameworks to safeguard quality and safety (Gronde, Uyl-de Groot & Pieters, 2017, Sayed, et al., 2018). Strengthening leadership and management capacity within laboratories is equally important, as effective managers are essential for coordinating operations, managing resources, and driving continuous improvement.

Reliable supply chains are a further cornerstone of sustainable laboratory infrastructure. Diagnostic services depend on the consistent availability of reagents, consumables, and spare parts, yet supply chain disruptions are common in resource-constrained health systems. A sustainable model emphasizes integrated supply chain management that links forecasting, procurement, inventory management, and distribution across laboratory networks. Accurate demand forecasting, informed by test volumes and epidemiological trends, reduces stock-outs and wastage. Pooled procurement and long-term supplier agreements can improve purchasing power and price stability, while decentralized distribution systems enhance responsiveness at facility level. Strengthening cold chain capacity and logistics infrastructure is particularly important for preserving the integrity of temperature-sensitive reagents and samples (Meyer, et al., 2017).

Quality management systems underpin the reliability and credibility of diagnostic services and are integral to sustainable laboratory infrastructure. Without consistent quality assurance, investments in facilities, equipment, and workforce yield limited benefits. A sustainable model embeds quality management as a routine operational function rather than an external compliance requirement. This includes the development and implementation of standard operating procedures, internal quality control processes, and participation in external quality assessment schemes. Progressive accreditation pathways, adapted to local contexts, provide structured mechanisms for continuous improvement and accountability. Importantly, quality management systems should be supported by leadership commitment, staff engagement, and a culture of learning that encourages reporting and correction of errors rather than punitive responses (Mackey & Nayyar, 2017, Mohammadi, et al., 2018).

The integration of these core components is what distinguishes sustainable diagnostic laboratory infrastructure models from fragmented or short-term interventions. Facility design must align with equipment requirements and workflow patterns; equipment choices must reflect workforce competencies and supply chain realities; human resource strategies must support quality management objectives; and supply chain systems must be responsive to both routine operations and surge demands. In resource-constrained settings, trade-offs are often necessary, but sustainability depends on making informed choices that balance immediate needs with long-term system performance (Bam, et al., 2017).

Moreover, these core components must be embedded within broader health system structures to achieve sustainability. Laboratories do not operate in isolation, and their effectiveness depends on linkages with clinical services, public health programs, financing mechanisms, and governance frameworks. Sustainable models therefore emphasize integration within tiered laboratory networks, supported by referral systems and information flows that optimize resource use and expand access. By strengthening the core components of facility design, equipment lifecycle management, human resources, supply chains, and quality management systems in a coordinated manner, emerging and resource-constrained health systems can build diagnostic laboratory infrastructure that is resilient, equitable, and capable of supporting health priorities over the long term (Jacobsen, et al., 2016, Polater & Demirdogen, 2018).

2.5. Digital Integration and Data Governance in Diagnostic Laboratory Systems

Digital integration and robust data governance are increasingly central to the sustainability and effectiveness of diagnostic laboratory systems, particularly in emerging and resource-constrained health systems where efficient use of limited resources is critical. As laboratories generate vast volumes of clinical and public health data, the way these data are captured, managed, shared, and protected directly influences diagnostic efficiency, surveillance capacity, and evidence-based decision-making. Sustainable diagnostic laboratory infrastructure models therefore require digital systems that are not only technologically functional but also institutionally embedded, interoperable, secure, and aligned with national health priorities (Min, 2016, Paul & Venkateswaran, 2018).

Laboratory information systems form the backbone of digital integration in diagnostic services. At a fundamental level, these systems support the registration of samples, tracking of workflows, reporting of results, and storage of historical records. In resource-constrained settings, many laboratories still rely on paper-based processes or fragmented digital tools limited to specific tests or programs. Such approaches increase turnaround times, introduce transcription errors, and constrain the ability of laboratories to scale services during periods of

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increased demand (Marda, 2018). Implementing laboratory information systems that are appropriately tailored to local capacity can significantly improve operational efficiency by automating routine processes, reducing duplication, and enabling real-time visibility of laboratory activities. Importantly, sustainability depends on selecting systems that are affordable, user-friendly, and maintainable within existing technical and human resource constraints.

Interoperability is a critical dimension of digital integration that extends the value of laboratory information systems beyond individual facilities. Diagnostic laboratories operate within complex health ecosystems that include clinical services, public health agencies, supply chain systems, and national health information platforms. Interoperable systems enable laboratory data to flow seamlessly across these interfaces, supporting continuity of care, referral tracking, and population-level analysis. In resource-constrained health systems, lack of interoperability often results from the proliferation of donor-specific platforms, proprietary software, and inconsistent data standards. Sustainable laboratory infrastructure models prioritize the adoption of open standards and interoperable architectures that allow diverse systems to communicate while preserving local autonomy. This approach enhances resilience by reducing dependence on single vendors and facilitating system upgrades as technologies evolve (Hodge, et al., 2017).

Effective data governance is essential to ensuring that digital integration strengthens rather than undermines trust, accountability, and system performance. Governance frameworks define who owns laboratory data, who can access them, how they can be used, and how responsibilities are distributed across institutions. In many emerging health systems, data governance arrangements are weak or poorly enforced, leading to fragmented ownership, unclear accountability, and inconsistent data quality. Sustainable diagnostic laboratory models embed clear governance structures that align laboratory data management with national health information policies, legal frameworks, and ethical standards. This includes defining roles for laboratories, ministries of health, and other stakeholders in data stewardship, oversight, and decision-making (Ismail, Karusala & Kumar, 2018).

Data security and privacy are particularly important considerations in the digital transformation of laboratory systems. Diagnostic data often include sensitive personal and clinical information, and breaches can have serious consequences for individuals and institutions alike. In resource-constrained settings, cybersecurity risks are heightened by limited technical capacity, outdated infrastructure, and insufficient regulatory enforcement. Sustainable digital integration therefore requires proportionate but effective security measures, including access controls, encryption, audit trails, and regular system updates (Asi & Williams, 2018, Miah, Hasan & Gammack, 2017). Training laboratory personnel in data protection practices is equally important, as human error remains a significant source of security vulnerabilities. By integrating data security into system design and daily operations, laboratory systems can protect patient confidentiality while maintaining operational efficiency.

The analytical potential of laboratory data represents one of the most powerful yet underutilized benefits of digital integration. When aggregated and analyzed effectively, laboratory data provide critical insights into disease patterns, diagnostic demand, antimicrobial resistance, and health system performance. In resource-constrained health systems, timely access to such information can inform targeted interventions, optimize resource allocation, and strengthen outbreak preparedness (Leath, et al., 2018). Digital laboratory systems enable automated data aggregation and visualization, supporting routine reporting as well as advanced analytics. However, realizing this potential requires not only technical tools but also institutional capacity to interpret and act on data. Sustainable models therefore emphasize building analytical skills within laboratories and public health institutions, fostering a culture of data-driven decision-making.

Digital integration also enhances surveillance functions by linking laboratory data with epidemiological and clinical information. Laboratories are often the first point at which emerging health threats are detected, and real-time data transmission can significantly reduce response times. In fragmented systems, delays in reporting and limited data sharing undermine surveillance effectiveness. Integrated laboratory information systems, supported by interoperable platforms, enable rapid notification of priority conditions and support coordinated responses across levels of the health system. This function became particularly evident during recent public health emergencies, highlighting the importance of digital readiness as a component of laboratory sustainability (Goel, et al., 2017).

Despite these benefits, digital integration in resource-constrained settings faces practical challenges that must be addressed within sustainable infrastructure models. These include unreliable electricity and internet connectivity, limited technical support, resistance to change among users, and the ongoing costs of system maintenance. Sustainable approaches recognize these constraints and promote phased implementation, hybrid paper–digital workflows where necessary, and local capacity building. Emphasis is placed on selecting technologies that can operate offline, synchronize data when connectivity is available, and be supported by existing information technology structures (Lee, et al., 2015, Srivastava & Shainesh, 2015).

Ultimately, digital integration and data governance are not standalone technical solutions but integral components of sustainable diagnostic laboratory infrastructure. Their value lies in enhancing efficiency, strengthening surveillance, and enabling informed decision-making across the health system. By embedding laboratory information systems within interoperable, secure, and well-governed digital ecosystems, emerging and resource-constrained health systems can maximize the impact of diagnostic services while safeguarding trust and sustainability. As diagnostic demand continues to grow and health systems confront increasingly complex challenges, digitally integrated and well-governed laboratory systems will be essential to resilient, equitable, and effective healthcare delivery.

2.6. Financing, Governance, and Policy Alignment for Sustainability

Financing, governance, and policy alignment are central determinants of the sustainability of diagnostic laboratory infrastructure in emerging and resource-constrained health systems. While technical capacity and human resources are essential, laboratories ultimately depend on stable financing, coherent governance arrangements, and supportive policy environments to function effectively over time. Weaknesses in any of these areas can undermine investments in facilities, equipment, and workforce development, resulting in fragmented services, declining quality, and limited public health impact. Sustainable diagnostic laboratory infrastructure models therefore require deliberate strategies that integrate financial mechanisms, institutional governance, and policy alignment within a unified framework (Huang, et al., 2017, Lim, et al., 2016).

Financing mechanisms for diagnostic laboratories in resource-constrained settings have historically been characterized by fragmentation and volatility. Many laboratory systems rely heavily on donor funding, often tied to disease-specific programs or short-term project cycles. While such funding has expanded diagnostic access for priority conditions, it frequently fails to support cross-cutting system needs such as maintenance, workforce retention, quality management, and data integration (Metcalf, et al., 2015). Sustainable financing models emphasize diversification of funding sources and the integration of laboratory services into national health financing strategies. This includes allocating dedicated budget lines for laboratory services within public health expenditures, incorporating essential diagnostics into health insurance benefit packages, and leveraging pooled funding mechanisms to reduce dependence on external donors.

Public–private partnerships represent an increasingly important financing and implementation option for sustainable laboratory infrastructure. In resource-constrained settings, the private sector often possesses technical expertise, operational efficiency, and access to capital that can complement public sector capacity. Well-designed partnerships can support laboratory construction, equipment provision, maintenance services, and diagnostic network expansion. However, sustainability depends on clear contractual arrangements that align private incentives with public health objectives (Portnoy, et al., 2015). Without appropriate governance, public–private partnerships risk increasing costs, exacerbating inequities, or prioritizing profit over quality and access. Sustainable models therefore emphasize transparent procurement processes, performance-based contracts, and regulatory oversight to ensure that partnerships deliver long-term value and support equitable access to diagnostic services.

Governance frameworks play a critical role in coordinating the diverse actors involved in laboratory systems and ensuring accountability for performance. In many emerging health systems, governance responsibilities for laboratories are fragmented across multiple ministries, agencies, and levels of government. This fragmentation can lead to inconsistent standards, duplication of effort, and gaps in oversight. Sustainable diagnostic laboratory infrastructure models promote clear institutional roles and coordination mechanisms that align national policy objectives with subnational implementation. Central stewardship functions, such as standard setting, accreditation oversight, and strategic planning, can coexist with decentralized service delivery when governance arrangements are well defined and supported by adequate capacity (Bradley, et al., 2017, Lee, et al., 2016).

Regulatory frameworks are a key component of governance, providing the legal and normative foundation for quality, safety, and ethical practice in laboratory services. In resource-constrained settings, regulatory systems are often underdeveloped or unevenly enforced, limiting their effectiveness. Sustainable models emphasize strengthening regulatory capacity to cover laboratory licensing, personnel certification, equipment standards, and biosafety requirements. Importantly, regulatory frameworks must be proportionate and context-sensitive, avoiding overly burdensome requirements that could discourage service provision in underserved areas. Harmonization of regulations across public and private laboratories further supports integration and standardization within national laboratory networks (Beran, et al., 2015, De Souza, et al., 2016).

Accreditation pathways offer a structured approach to quality improvement and accountability in diagnostic laboratory systems. International accreditation standards provide valuable benchmarks, but full accreditation may be unrealistic for many laboratories in resource-constrained settings due to cost and capacity constraints. Sustainable models therefore support stepwise or tiered accreditation approaches that enable laboratories to progress incrementally toward higher standards. Such pathways reinforce a culture of continuous improvement while recognizing local realities. Integration of accreditation requirements into national policies and financing mechanisms further strengthens sustainability by linking quality performance to funding and recognition (Assefa, et al., 2017, Cleaveland, et al., 2017).

Institutional accountability is closely linked to both governance and financing, shaping how laboratory systems respond to performance challenges and stakeholder expectations. Accountability mechanisms include routine performance monitoring, transparent reporting, audits, and community oversight. In many resource-constrained settings, weak accountability contributes to inefficiencies, misuse of resources, and declining trust in public institutions. Sustainable diagnostic laboratory infrastructure models emphasize accountability at multiple levels, from facility managers responsible for day-to-day operations to national authorities overseeing system performance (Wang & Rosemberg, 2018). Digital reporting systems and public dashboards can enhance transparency and enable evidence-based oversight, while supportive supervision and feedback mechanisms promote learning rather than punitive responses.

Policy alignment across sectors and levels of government is essential to sustaining laboratory infrastructure investments. Laboratories intersect with policies related to health, education, science and technology, finance, and infrastructure development. Misalignment among these policies can create barriers to workforce training, technology adoption, and long-term financing. Sustainable models advocate for integrated policy frameworks that recognize diagnostic services as a core component of health system strengthening and public health security. Alignment with national development plans and universal health coverage strategies further elevates the priority of laboratory infrastructure and supports sustained investment.

Ultimately, financing, governance, and policy alignment are mutually reinforcing elements of

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sustainable diagnostic laboratory infrastructure. Stable and diversified financing enables long-term planning and investment; effective governance ensures coordination, quality, and accountability; and aligned policies create an enabling environment for innovation and integration. In emerging and resource-constrained health systems, building sustainable laboratory infrastructure requires moving beyond isolated projects toward systemic reforms that embed laboratories within national health priorities and institutional structures. By strengthening these foundational elements, countries can ensure that diagnostic laboratory systems continue to support clinical care, public health surveillance, and health system resilience over the long term.

2.7. Implementation Strategies and Contextual Adaptation

Implementing sustainable diagnostic laboratory infrastructure models in emerging and resource-constrained health systems requires deliberate strategies that recognize contextual diversity, institutional capacity, and resource limitations. Even well-designed models can fail if implementation does not account for local realities, competing priorities, and system complexity. Effective implementation therefore depends on phased approaches, targeted capacity building, inclusive stakeholder engagement, proactive risk mitigation, and continuous adaptation to local epidemiological and socioeconomic conditions. These elements collectively enable laboratory systems to evolve incrementally while maintaining functionality and relevance over time (Contreras & Vehi, 2018, Dankwa-Mullan, et al., 2019).

Phased implementation is a practical and strategic approach for introducing sustainable laboratory infrastructure in resource-constrained settings. Rather than attempting comprehensive system transformation in a single step, phased approaches prioritize essential services and build complexity over time. Initial phases often focus on establishing or strengthening basic diagnostic capacity at primary and secondary levels, ensuring reliable infrastructure, essential equipment, and core workforce competencies. Subsequent phases can expand test menus, introduce advanced technologies, and enhance digital integration as capacity and resources grow (Car, et al., 2017, Novak, et al., 2013). Phasing allows health systems to align investments with available funding, absorb lessons from early stages, and reduce the risk of system overload. Importantly, phased implementation supports scalability and flexibility, enabling laboratories to respond to changing disease patterns and public health priorities.

Capacity building is central to sustainable implementation, as laboratory infrastructure is only as effective as the people and institutions that manage it. Capacity building extends beyond technical training to include organizational development, leadership, and management competencies. In many resource-constrained health systems, laboratory managers are promoted based on technical expertise without formal training in administration, budgeting, or quality management. Strengthening managerial capacity enables more effective resource use, staff supervision, and strategic planning (Bennett & Hauser, 2013, Udlis, 2011). At the system level, capacity building also involves strengthening institutions responsible for regulation, accreditation, supply chain management, and data governance. Sustainable implementation emphasizes local ownership by investing in endogenous capacity rather than relying on external technical assistance indefinitely.

Stakeholder engagement is another critical component of effective implementation. Diagnostic laboratory infrastructure intersects with a wide range of stakeholders, including government agencies, healthcare providers, laboratory professionals, donors, private sector partners, and communities. Early and continuous engagement helps align expectations, build consensus, and mobilize resources. In resource-constrained settings, stakeholder engagement is particularly important for addressing issues of equity and access, ensuring that infrastructure investments respond to the needs of underserved populations. Engaging frontline laboratory staff and clinicians in planning and implementation fosters buy-in and facilitates the adoption of new workflows, technologies, and quality systems. Community engagement also plays a role in building trust in diagnostic services, encouraging appropriate utilization, and supporting public health interventions (Stokes, et al., 2016).

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Risk mitigation is an essential consideration in implementing sustainable laboratory infrastructure models. Resource-constrained health systems face a range of risks, including funding shortfalls, supply chain disruptions, workforce attrition, political instability, and public health emergencies. Proactive risk assessment and mitigation strategies help ensure continuity of services and protect investments. This includes diversifying funding sources, establishing buffer stocks of critical supplies, standardizing equipment to reduce maintenance complexity, and developing contingency plans for surge capacity during outbreaks (Ahmed, 2017). Risk mitigation also involves building redundancy into laboratory networks, such as referral mechanisms and shared services, to prevent single points of failure. Monitoring and evaluation systems play a key role in identifying emerging risks and enabling timely corrective action (Tresp, et al., 2016).

Adaptation to local epidemiological contexts is fundamental to the relevance and sustainability of diagnostic laboratory infrastructure. Disease burden, transmission patterns, and health priorities vary widely across regions and over time. Sustainable models emphasize data-driven planning that aligns diagnostic capacity with prevailing and anticipated epidemiological needs. This may involve prioritizing infectious disease diagnostics in some settings, while focusing on noncommunicable disease testing in others. Flexibility in test menus and technology platforms enables laboratories to adapt as disease profiles evolve. Integration of laboratory data into surveillance systems further supports responsive adaptation by providing timely insights into emerging trends and outbreaks (Henke & Jacques Bughin, 2016, Holden, et al., 2016).

Socioeconomic context also shapes implementation strategies and sustainability outcomes. Factors such as poverty levels, geographic accessibility, education, and cultural norms influence both demand for diagnostic services and the feasibility of different implementation approaches. In low-income or rural communities, affordability and physical access may be major barriers, necessitating decentralized laboratory services or mobile testing units. User fees, while sometimes necessary for cost recovery, must be carefully designed to avoid excluding vulnerable populations. Sustainable implementation strategies therefore consider equity impacts and incorporate mechanisms such as subsidies, insurance coverage, or targeted support for underserved groups (Aitken & Gorokhovich, 2012, Daniel, et al., 2018).

Continuous learning and adaptation are essential features of successful implementation in dynamic and resource-constrained environments. Sustainable laboratory infrastructure models are not static blueprints but evolving frameworks that require regular review and adjustment. Implementation strategies should incorporate feedback loops that capture lessons from practice, including successes and failures, and translate them into policy and operational improvements. Pilot projects and demonstration sites can provide valuable evidence to inform scaling decisions, while peer learning networks facilitate knowledge exchange across regions and institutions (Browne, et al., 2012, Wallerstein, et al., 2017).

Ultimately, implementation strategies and contextual adaptation determine whether sustainable diagnostic laboratory infrastructure models translate from concept to impact. By adopting phased approaches, investing in capacity building, engaging stakeholders, mitigating risks, and tailoring interventions to local epidemiological and socioeconomic realities, emerging and resource-constrained health systems can build laboratory services that are resilient, equitable, and responsive. These strategies enable laboratories to support not only current health needs but also future challenges, strengthening the foundation of health systems and contributing to long-term public health and development goals (Abdulraheem, Olapipo & Amodu, 2012, Dzau, et al., 2017).

2.8. Conclusion and Policy Implications

Developing sustainable diagnostic laboratory infrastructure models for emerging and resource-constrained health systems requires a fundamental shift from fragmented, short-term investments toward integrated, systems-oriented approaches that recognize laboratories as core pillars of health system performance. Across the analysis, it is evident that diagnostic laboratories influence clinical care, public health surveillance, health security, and system resilience in profound and interdependent ways. Structural adequacy, appropriate technology, skilled human resources, reliable supply chains, digital integration, effective governance, and sustainable financing are not independent variables but mutually reinforcing components of a functional and resilient diagnostic ecosystem. Sustainability emerges when these elements are deliberately aligned and embedded within national health strategies rather than treated as isolated technical interventions.

For policymakers and health planners, the central implication is the need to elevate diagnostic laboratory infrastructure as a strategic public health investment rather than a peripheral service input. National health plans, universal health coverage frameworks, and health security strategies should explicitly incorporate laboratory systems as foundational enablers of prevention, preparedness, and equitable care. Policy decisions must prioritize long-term functionality, life-cycle costing, and institutional capacity over short-term expansion targets. This requires dedicated and predictable financing for laboratory services, integration of essential diagnostics into health benefit packages, and reduced reliance on disease-specific or donor-driven funding models that fragment systems and undermine sustainability.

Governance and regulatory reforms are equally critical. Policymakers should strengthen institutional stewardship of laboratory systems by clarifying roles, harmonizing standards across public and private sectors, and supporting progressive accreditation pathways that promote continuous quality improvement. Regulatory frameworks must balance rigor with feasibility, ensuring safety and quality while remaining responsive to local capacity constraints. Health planners should also prioritize digital integration and data governance, recognizing laboratory data as a strategic asset for surveillance, planning, and decision-making. Investments in interoperable laboratory information systems and data protection frameworks are essential to maximize the public health value of diagnostics.

At the operational level, health planners are encouraged to adopt phased implementation strategies that align diagnostic capacity with epidemiological priorities and available resources. Workforce development should be treated as a long-term investment, emphasizing continuous professional development, leadership training, and retention strategies to build endogenous capacity. Strengthening supply chain systems, standardizing equipment platforms, and embedding quality management into routine practice will further enhance system resilience and efficiency. Importantly, stakeholder engagement, including frontline health workers, private sector partners, and communities, should be institutionalized to ensure ownership, trust, and responsiveness.

Future research and practice should focus on generating empirical evidence to guide policy and investment decisions. Comparative studies assessing the cost-effectiveness, equity impacts, and resilience outcomes of different laboratory infrastructure models are particularly needed in low- and middle-income contexts. Implementation research can provide insights into how context-specific adaptations influence sustainability and performance over time. Additionally, the development of standardized indicators and benchmarking tools for laboratory system maturity would support monitoring, accountability, and cross-country learning.

In conclusion, sustainable diagnostic laboratory infrastructure is both a technical and institutional challenge that sits at the heart of health system strengthening. By adopting integrated, context-sensitive, and forward-looking models, emerging and resource-constrained health systems can build diagnostic services that support high-quality care, robust surveillance, and long-term public health resilience.

REFERENCES

[1] Abdulraheem, B. I., Olapipo, A. R., & Amodu, M. O. (2012). Primary health care services in Nigeria: Critical issues and strategies for enhancing the use by the rural communities. Journal of public health and epidemiology, 4(1), 5-13.

[2] Afriyie, D. (2017). *Leveraging Predictive People Analytics To Optimize Workforce Mobility, Talent Retention, And Regulatory Compliance In Global Enterprises*.

[3] Ahmed, K. (2017). The impact of multichannel engagement tools on the quality of care provided by a health care professional. Revista

de Administração de Roraima-RARR, 7(1), 81-98.

[4] Ahmed, K. S., & Odejobi, O. D. (2018). Conceptual framework for scalable and secure cloud architectures for enterprise messaging. *IRE Journals, 2*(1), 1–15.

[5] Ahmed, K. S., & Odejobi, O. D. (2018). Resource allocation model for energy-efficient virtual machine placement in data centers. *IRE Journals, 2*(3), 1–10.

[6] Aitken, M., & Gorokhovich, L. (2012). Advancing the responsible use of medicines: applying levers for change. Available at SSRN 2222541.

[7] Aransi, A. N., Nwafor, M. I., Uduokhai, D. O., & Gil-Ozoudeh, I. D. S. (2018). Comparative study of traditional and contemporary architectural morphologies in Nigerian settlements. *IRE Journals, 1*(7), 138–152.

[8] Asi, Y. M., & Williams, C. (2018). The role of digital health in making progress toward Sustainable Development Goal (SDG) 3 in conflict-affected populations. International journal of medical informatics, 114, 114-120.

[9] Assefa, Y., Hill, P. S., Ulikpan, A., & Williams, O. D. (2017). Access to medicines and hepatitis C in Africa: can tiered pricing and voluntary licencing assure universal access, health equity and fairness?. *Globalization and health*, *13*(1), 73.

[10] Badri, A., Boudreau-Trudel, B., & Souissi, A. S. (2018). Occupational health and safety in the industry 4.0 era: A cause for major concern?. *Safety science*, *109*, 403-411.

[11] Balcazar, H., Lee Rosenthal, E., Nell Brownstein, J., Rush, C. H., Matos, S., & Hernandez, L. (2011). Community health workers can be a public health force for change in the United States: three actions for a new paradigm. *American journal of public health*, *101*(12), 2199-2203.

[12] Bam, L., McLaren, Z. M., Coetzee, E., & Von Leipzig, K. H. (2017). Reducing stock-outs of essential tuberculosis medicines: a system dynamics modelling approach to supply chain management. Health Policy and Planning, 32(8), 1127-1134.

[13] Bardosh, K. L., Ryan, S. J., Ebi, K., Welburn, S., & Singer, B. (2017). Addressing vulnerability, building resilience: community-based adaptation to vector-borne diseases in the context of global change. *Infectious diseases of poverty*, *6*(1), 166.

[14] Bennett, C. C., & Hauser, K. (2013). Artificial intelligence framework for simulating clinical decision-making: A Markov decision process approach. Artificial intelligence in medicine, 57(1), 9-19.

[15] Beran, D., Zar, H. J., Perrin, C., Menezes, A. M., & Burney, P. (2015). Burden of asthma and chronic obstructive pulmonary disease and access to essential medicines in low-income and middle-income countries. *The Lancet Respiratory Medicine*, *3*(2), 159-170.

[16] Bitran, R. (2014). *Universal health coverage and the challenge of informal employment: lessons from developing countries* (pp. 1-86). World Bank, Washington, DC.

[17] Boadu, N. Y., Amuasi, J., Ansong, D., Einsiedel, E., Menon, D., & Yanow, S. K. (2016). Challenges with implementing malaria rapid diagnostic tests at primary care facilities in a Ghanaian district: a qualitative study. *Malaria journal*, *15*(1), 126.

[18] Bradley, B. D., Jung, T., Tandon-Verma, A., Khoury, B., Chan, T. C., & Cheng, Y. L. (2017). Operations research in global health: a scoping review with a focus on the themes of health equity and impact. Health research policy and systems, 15(1), 32.

[19] Brenner, M., Cramer, J., Cohen, S., & Balakrishnan, K. (2018). Leveraging quality improvement and patient safety initiatives to enhance value and patient-centered care in otolaryngology. Current Otorhinolaryngology Reports, 6(3), 231-238.

[20] Browne, A. J., Varcoe, C. M., Wong, S. T., Smye, V. L., Lavoie, J., Littlejohn, D., ... & Lennox, S. (2012). Closing the health equity gap: evidence-based strategies for primary health care organizations. International journal for equity in health, 11(1), 59.

[21] Car, J., Tan, W. S., Huang, Z., Sloot, P., & Franklin, B. D. (2017). eHealth in the future of medications management: personalisation, monitoring and adherence. BMC medicine, 15(1), 73.

[22] Cleaveland, S., Sharp, J., Abela-Ridder, B., Allan, K. J., Buza, J., Crump, J. A., ... & Halliday, J. E. B. (2017). One Health contributions towards more effective and equitable approaches to health in low-and middle-income countries. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *372*(1725), 20160168.

[23] Contreras, I., & Vehi, J. (2018). Artificial intelligence for diabetes management and decision support: literature review. Journal of medical Internet research, 20(5), e10775.

[24] Corral de Zubielqui, G., Jones, J., Seet, P. S., & Lindsay, N. (2015). Knowledge transfer between actors in the innovation system: a study of higher education institutions (HEIS) and SMES. Journal of Business & Industrial Marketing, 30(3/4), 436-458.

[25] Daniel, H., Bornstein, S. S., Kane, G. C., & Health and Public Policy Committee of the American College of Physicians*. (2018). Addressing social determinants to improve patient care and promote health equity: an American College of Physicians position paper. Annals of internal medicine, 168(8), 577-578.

[26] De Souza, J. A., Hunt, B., Asirwa, F. C., Adebamowo, C., & Lopes, G. (2016). Global health equity: cancer care outcome disparities in high-, middle-, and low-income countries. *Journal of Clinical Oncology*, *34*(1), 6-13.

[27] DiMase, D., Collier, Z. A., Heffner, K., & Linkov, I. (2015). Systems engineering framework for cyber physical security and resilience. *Environment Systems and Decisions*, *35*(2), 291-300.

[28] Diraviam, S. P., Sullivan, P. G., Sestito, J. A., Nepps, M. E., Clapp, J. T., & Fleisher, L. A. (2018). Physician engagement in malpractice risk reduction: a UPHS case study. The Joint Commission Journal on Quality and Patient Safety, 44(10), 605-612.

[29] Durán, J. M., Miranda, J. D., & Patiño, P. M. (2018, November). Implementation of safety management systems and health at work (case study in a telecommunications company). In *Journal of Physics: Conference Series* (Vol. 1126, No. 1, p. 012059). IOP Publishing.

[30] Dzau, V. J., McClellan, M. B., McGinnis, J. M., Burke, S. P., Coye, M. J., Diaz, A., ... & Zerhouni, E. (2017). Vital directions for health and health care: priorities from a National Academy of Medicine initiative. Jama, 317(14), 1461-1470.

[31] Eeckelaert, L., Dhondt, S., Oeij, P., Pot, F. D., Nicolescu, G. I., Webster, J., & Elsler, D. (2012). *Review of workplace innovation and its relation with occupational safety and health*. Bilbao: European Agency for Safety and Health at Work.

[32] Fanta, G. B., & Pretorius, L. (2018). A conceptual framework for sustainable eHealth implementation in resource-constrained settings. *South African Journal of Industrial Engineering*, *29*(3), 132-147.

[33] Figure 2 shows the main entities involved Health Insurance System presented by Bologa, Bologa & Florea, 2013.

[34] Fujita, N., Zwi, A. B., Nagai, M., & Akashi, H. (2011). A comprehensive framework for human resources for health system development in fragile and post-conflict states. *PLoS Medicine*, *8*(12), e1001146.

[35] Gil-Ozoudeh, I. D. S., Aransi, A. N., Nwafor, M. I., & Uduokhai, D. O. (2018). Socioeconomic determinants influencing the affordability and sustainability of urban housing in Nigeria. *IRE Journals, 2*(3), 164–169.

[36] Gil-Ozoudeh, I. D. S., Nwafor, M. I., Uduokhai, D. O., & Aransi, A. N. (2018). Impact of climatic variables on the optimization of building envelope design in humid regions. *IRE Journals, 1*(10), 322–335.

[37] Goel, N. A., Alam, A. A., Eggert, E. M., & Acharya, S. (2017, July). Design and development of a customizable telemedicine platform for improving access to healthcare for underserved populations. In 2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (pp. 2658-2661). IEEE.

[38] Gragnolati, M., Lindelöw, M., & Couttolenc, B. (2013). *Twenty years of health system reform in Brazil: an assessment of the Sistema Único de Saúde*. World Bank Publications.

[39] Gronde, T. V. D., Uyl-de Groot, C. A., & Pieters, T. (2017). Addressing the challenge of high-priced prescription drugs in the era of precision medicine: a systematic review of drug life cycles, therapeutic drug markets and regulatory frameworks. PloS one, 12(8), e0182613.

[40] Hale, A., Borys, D., & Adams, M. (2015). Safety regulation: The lessons of workplace safety rule management for managing the regulatory burden. *Safety science*, *71*, 112-122.

[41] Hargreaves, J. R., Boccia, D., Evans, C. A., Adato, M., Petticrew, M., & Porter, J. D. (2011). The social determinants of tuberculosis: from evidence to action. *American journal of public health*, *101*(4), 654-662.

[42] Henke, N., & Jacques Bughin, L. (2016). The age of analytics: Competing in a data-driven world.

[43] Hiller, J., McMullen, M. S., Chumney, W. M., & Baumer, D. L. (2011). Privacy and security in the implementation of health information technology (electronic health records): US and EU compared. *BUJ Sci. & Tech. L.*, *17*, 1.

[44] Hodge, H., Carson, D., Carson, D., Newman, L., & Garrett, J. (2017). Using Internet technologies in rural communities to access services: The views of older people and service providers. Journal of Rural Studies, 54, 469-478.

[45] Holden, K., Akintobi, T., Hopkins, J., Belton, A., McGregor, B., Blanks, S., & Wrenn, G. (2016). Community engaged leadership to advance health equity and build healthier communities. Social Sciences (Basel, Switzerland), 5(1), 2.

[46] Huang, H. C., Singh, B., Morton, D. P., Johnson, G. P., Clements, B., & Meyers, L. A. (2017). Equalizing access to pandemic influenza vaccines through optimal allocation to public health distribution points. PloS one, 12(8), e0182720.

[47] Index, G. I. (2016). Report. URL: https://www. globalinnovationindex. org/analysis-indicator (дата обращения: 29.09. 2021).–Текст: электронный.

[48] Ismail, A., Karusala, N., & Kumar, N. (2018). Bridging disconnected knowledges for community health. Proceedings of the ACM on Human-Computer Interaction, 2(CSCW), 1-27.

[49] Jacobsen, K. H., Aguirre, A. A., Bailey, C. L., Baranova, A. V., Crooks, A. T., Croitoru, A., ... & Agouris, P. (2016). Lessons from the Ebola outbreak: action items for emerging infectious disease preparedness and response. EcoHealth, 13(1), 200-212.

[50] Jilcha, K., & Kitaw, D. (2017). Industrial occupational safety and health innovation for sustainable development. *Engineering science and technology, an international journal*, *20*(1), 372-380.

[51] Kim, K., Choi, J. S., Choi, E., Nieman, C. L., Joo, J. H., Lin, F. R., ... & Han, H. R. (2016). Effects of community-based health worker interventions to improve chronic disease management and care among vulnerable populations: a systematic review. *American journal of public health*, *106*(4), e3-e28.

[52] Kim, Y., Park, J., & Park, M. (2016). Creating a culture of prevention in occupational safety and health practice. *Safety and health at work*, *7*(2), 89-96.

[53] Knaul, F. M., González-Pier, E., Gómez-Dantés, O., García-Junco, D., Arreola-Ornelas, H., Barraza-Lloréns, M., ... & Frenk, J. (2012). The quest for universal health coverage: achieving social protection for all in Mexico. *The Lancet*, *380*(9849), 1259-1279.

[54] Kuupiel, D., Bawontuo, V., & Mashamba-Thompson, T. P. (2017). Improving the accessibility and efficiency of point-of-care diagnostics services in low-and middle-income countries: lean and agile supply chain management. Diagnostics, 7(4), 58.

[55] Kwon, S. C., Tandon, S. D., Islam, N., Riley, L., & Trinh-Shevrin, C. (2018). Applying a community-based participatory research framework to patient and family engagement in the development of patient-centered outcomes research and practice. Translational behavioral medicine, 8(5), 683-691.

[56] Larkins, S. L., Preston, R., Matte, M. C., Lindemann, I. C., Samson, R., Tandinco, F. D., ... & on behalf of the Training for Health Equity Network (THEnet). (2013). Measuring social accountability in health professional education:

development and international pilot testing of an evaluation framework. Medical Teacher, 35(1), 32-45.

[57] Leath, B. A., Dunn, L. W., Alsobrook, A., & Darden, M. L. (2018). Enhancing rural population health care access and outcomes through the telehealth EcoSystem™ model. Online journal of public health informatics, 10(2), e218.

[58] Lee, B. Y., Connor, D. L., Wateska, A. R., Norman, B. A., Rajgopal, J., Cakouros, B. E., ... & Brown, S. T. (2015). Landscaping the structures of GAVI country vaccine supply chains and testing the effects of radical redesign. Vaccine, 33(36), 4451-4458.

[59] Lee, B. Y., Haidari, L. A., Prosser, W., Connor, D. L., Bechtel, R., Dipuve, A., ... & Brown, S. T. (2016). Re-designing the Mozambique vaccine supply chain to improve access to vaccines. Vaccine, 34(41), 4998-5004.

[60] Lerman, S. E., Eskin, E., Flower, D. J., George, E. C., Gerson, B., Hartenbaum, N., ... & Moore-Ede, M. (2012). Fatigue risk management in the workplace. *Journal of occupational and environmental medicine*, *54*(2), 231-258.

[61] Liang, F., Das, V., Kostyuk, N., & Hussain, M. M. (2018). Constructing a data-driven society: China's social credit system as a state surveillance infrastructure. *Policy & Internet*, *10*(4), 415-453.

[62] Lim, J., Claypool, E., Norman, B. A., & Rajgopal, J. (2016). Coverage models to determine outreach vaccination center locations in low and middle income countries. Operations research for health care, 9, 40-48.

[63] Longoni, A., Pagell, M., Johnston, D., & Veltri, A. (2013). When does lean hurt?–an exploration of lean practices and worker health and safety outcomes. *International Journal of Production Research*, *51*(11), 3300-3320.

[64] Lönnroth, K., Migliori, G. B., Abubakar, I., D'Ambrosio, L., De Vries, G., Diel, R., ... & Raviglione, M. C. (2015). Towards tuberculosis elimination: an action framework for low-incidence countries. *European Respiratory Journal*, *45*(4), 928-952.

[65] Lund, F., Alfers, L., & Santana, V. (2016). Towards an inclusive occupational health and safety for informal workers. *New Solutions: A Journal of Environmental and Occupational Health Policy*, *26*(2), 190-207.

[66] Mackey, T. K., & Nayyar, G. (2017). A review of existing and emerging digital technologies to combat the global trade in fake medicines. Expert opinion on drug safety, 16(5), 587-602.

[67] Main, E. K., Dhurjati, R., Cape, V., Vasher, J., Abreo, A., Chang, S. C., & Gould, J. B. (2018). Improving maternal safety at scale with the mentor model of collaborative improvement. The Joint Commission Journal on Quality and Patient Safety, 44(5), 250-259.

[68] Marda, V. (2018). Artificial intelligence policy in India: a framework for engaging the limits of data-driven decision-making. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 376(2133), 20180087.

[69] Martinez-Martin, N., Insel, T. R., Dagum, P., Greely, H. T., & Cho, M. K. (2018). Data mining for health: staking out the ethical territory of digital phenotyping. *NPJ digital medicine*, *1*(1), 68.

[70] Metcalf, C. J. E., Tatem, A., Bjornstad, O. N., Lessler, J., O'reilly, K., Takahashi, S., ... & Grenfell, B. T. (2015). Transport networks and inequities in vaccination: remoteness shapes measles vaccine coverage and prospects for elimination across Africa. Epidemiology & Infection, 143(7), 1457-1466.

[71] Meyer, J. C., Schellack, N., Stokes, J., Lancaster, R., Zeeman, H., Defty, D., ... & Steel, G. (2017). Ongoing initiatives to improve the quality and efficiency of medicine use within the public healthcare system in South Africa; a preliminary study. Frontiers in pharmacology, 8, 751.

[72] Miah, S. J., Hasan, J., & Gammack, J. G. (2017). On-cloud healthcare clinic: an e-health consultancy approach for remote communities in a developing country. Telematics and Informatics, 34(1), 311-322.

[73] Min, H. (2016). Global business analytics models: Concepts and applications in

predictive, healthcare, supply chain, and finance analytics.

[74] Mohammadi, I., Wu, H., Turkcan, A., Toscos, T., & Doebbeling, B. N. (2018). Data analytics and modeling for appointment no-show in community health centers. Journal of primary care & community health, 9, 2150132718811692.

[75] Moore, L. L., Wurzelbacher, S. J., & Shockey, T. M. (2018). Workers' compensation insurer risk control systems: Opportunities for public health collaborations. *Journal of safety research*, *66*, 141-150.

[76] Nascimento, R. C. R. M. D., Álvares, J., Guerra Junior, A. A., Gomes, I. C., Costa, E. A., Leite, S. N., ... & Acurcio, F. D. A. (2017). Availability of essential medicines in primary health care of the Brazilian Unified Health System. Revista de saude publica, 51, 10s.

[77] Novak, M., Costantini, L., Schneider, S., & Beanlands, H. (2013, March). Approaches to self-management in chronic illness. In Seminars in dialysis (Vol. 26, No. 2, pp. 188-194). Oxford, UK: Blackwell Publishing Ltd.

[78] Nwafor, M. I., Giloid, S., Uduokhai, D. O., & Aransi, A. N. (2018). Socioeconomic determinants influencing the affordability and sustainability of urban housing in Nigeria. *Iconic Research and Engineering Journals, 2*(3), 154–169.

[79] Nwafor, M. I., Uduokhai, D. O., Giloid, S., & Aransi, A. N. (2018). Comparative study of traditional and contemporary architectural morphologies in Nigerian settlements. *Iconic Research and Engineering Journals, 1*(7), 138–152.

[80] Nwafor, M. I., Uduokhai, D. O., Giloid, S., & Aransi, A. N. (2018). Impact of climatic variables on the optimization of building envelope design in humid regions. *Iconic Research and Engineering Journals, 1*(10), 322–335.

[81] Nwameme, A. U., Tabong, P. T. N., & Adongo, P. B. (2018). Implementing community-based health planning and services in impoverished urban communities: health workers' perspective. *BMC health services research*, *18*(1), 186.

[82] Odejobi, O. D., & Ahmed, K. S. (2018). Performance evaluation model for multi-tenant Microsoft 365 deployments under high concurrency. *IRE Journals, 1*(11), 92–107.

[83] Odejobi, O. D., & Ahmed, K. S. (2018). Statistical model for estimating daily solar radiation for renewable energy planning. *IRE Journals, 2*(5), 1–12.

[84] Pacifico Silva, H., Lehoux, P., Miller, F. A., & Denis, J. L. (2018). Introducing responsible innovation in health: a policy-oriented framework. Health research policy and systems, 16(1), 90.

[85] Paul, S., & Venkateswaran, J. (2018). Inventory management strategies for mitigating unfolding epidemics. IISE Transactions on Healthcare Systems Engineering, 8(3), 167-180.

[86] Peckham, T. K., Baker, M. G., Camp, J. E., Kaufman, J. D., & Seixas, N. S. (2017). Creating a future for occupational health. *Annals of Work Exposures and Health*, *61*(1), 3-15.

[87] Polater, A., & Demirdogen, O. (2018). An investigation of healthcare supply chain management and patient responsiveness: An application on public hospitals. International journal of pharmaceutical and healthcare marketing, 12(3), 325-347.

[88] Portnoy, A., Ozawa, S., Grewal, S., Norman, B. A., Rajgopal, J., Gorham, K. M., ... & Lee, B. Y. (2015). Costs of vaccine programs across 94 low-and middle-income countries. Vaccine, 33, A99-A108.

[89] Pouliakas, K., & Theodossiou, I. (2013). The economics of health and safety at work: an interdiciplinary review of the theory and policy. *Journal of Economic Surveys*, *27*(1), 167-208.

[90] Rees, J. (2016). *Reforming the workplace: A study of self-regulation in occupational safety*. University of Pennsylvania Press.

[91] Reese, C. D. (2018). *Occupational health and safety management: a practical approach*. CRC press.

[92] Sarker, A. R., Sultana, M., Ahmed, S., Mahumud, R. A., Morton, A., & Khan, J. A. (2018). Clients' experience and satisfaction of utilizing healthcare services in a community

based health insurance program in Bangladesh. *International journal of environmental research and public health*, *15*(8), 1637.

[93] Sayed, S., Cherniak, W., Lawler, M., Tan, S. Y., El Sadr, W., Wolf, N., ... & Fleming, K. A. (2018). Improving pathology and laboratory medicine in low-income and middle-income countries: roadmap to solutions. The Lancet, 391(10133), 1939-1952.

[94] Schulte, P. A., Guerin, R. J., Schill, A. L., Bhattacharya, A., Cunningham, T. R., Pandalai, S. P., ... & Stephenson, C. M. (2015). Considerations for incorporating "well-being" in public policy for workers and workplaces. *American journal of public health*, *105*(8), e31-e44.

[95] Seyi-Lande, O. B., Arowogbadamu, A. A. G., & Oziri, S. T. (2018). A comprehensive framework for high-value analytical integration to optimize network resource allocation and strategic growth. *Iconic Research and Engineering Journals*, *1*(11), 76-91.

[96] Seyi-Lande, O. B., Arowogbadamu, A. A.-G., & Oziri, S. T. (2018). A comprehensive framework for high-value analytical integration to optimize network resource allocation and strategic growth. Iconic Research and Engineering Journals, 1(11), 76–91.

[97] Seyi-Lande, O. B., Oziri, S. T., & Arowogbadamu, A. A. G. (2018). Leveraging business intelligence as a catalyst for strategic decision-making in emerging telecommunications markets. *Iconic Research and Engineering Journals*, *2*(3), 92-105.

[98] Seyi-Lande, O. B., Oziri, S. T., & Arowogbadamu, A. A.-G. (2018). Leveraging business intelligence as a catalyst for strategic decision-making in emerging telecommunications markets. Iconic Research and Engineering Journals, 2(3), 92–105.

[99] Srivastava, S. C., & Shainesh, G. (2015). Bridging the service divide through digitally enabled service innovations. Mis Quarterly, 39(1), 245-268.

[100] Takala, J., Hämäläinen, P., Saarela, K. L., Yun, L. Y., Manickam, K., Jin, T. W., ... & Lin, G. S. (2014). Global estimates of the burden of injury and illness at work in 2012. *Journal of occupational and environmental hygiene*, *11*(5), 326-337.

[101] Tompa, E., Kalcevich, C., Foley, M., McLeod, C., Hogg-Johnson, S., Cullen, K., ... & Irvin, E. (2016). A systematic literature review of the effectiveness of occupational health and safety regulatory enforcement. *American journal of industrial medicine*, *59*(11), 919-933.

[102] Tresp, V., Overhage, J. M., Bundschus, M., Rabizadeh, S., Fasching, P. A., & Yu, S. (2016). Going digital: a survey on digitalization and large-scale data analytics in healthcare. Proceedings of the IEEE, 104(11), 2180-2206.

[103] Tsui, K. L., Chen, N., Zhou, Q., Hai, Y., & Wang, W. (2015). Prognostics and health management: A review on data driven approaches. *Mathematical Problems in Engineering*, *2015*(1), 793161.

[104] Udechukwu, L. M. (2018). *Beyond accuracy: Redefining data quality metrics for ethical AI in the wake of algorithmic bias*. *International Journal of Artificial Intelligence and Data Science (IJADS), 1*(3), 1–22.

[105] Udlis, K. A. (2011). Self-management in chronic illness: concept and dimensional analysis. Journal of Nursing and Healthcare of Chronic illness, 3(2), 130-139.

[106] Van Eerd, D., & Saunders, R. (2017). Integrated knowledge transfer and exchange: An organizational approach for stakeholder engagement and communications. Scholarly and Research Communication, 8(1).

[107] Verra, S. E., Benzerga, A., Jiao, B., & Ruggeri, K. (2018). Health promotion at work: A comparison of policy and practice across Europe. *Safety and Health at Work*, *10*(1), 21-29.

[108] Vilcu, I., Probst, L., Dorjsuren, B., & Mathauer, I. (2016). Subsidized health insurance coverage of people in the informal sector and vulnerable population groups: trends in institutional design in Asia. *International Journal for Equity in Health*, *15*(1), 165.

[109] Vogler, S., Paris, V., & Panteli, D. (2018). Ensuring access to medicines: How to redesign pricing, reimbursement and

procurement? (p. 30272895). Copenhagen: World Health Organization, Regional Office for Europe.

[110] Wachter, J. K., & Yorio, P. L. (2014). A system of safety management practices and worker engagement for reducing and preventing accidents: An empirical and theoretical investigation. *Accident Analysis & Prevention*, *68*, 117-130.

[111] Wallerstein, N. B., Yen, I. H., & Syme, S. L. (2011). Integration of social epidemiology and community-engaged interventions to improve health equity. American journal of public health, 101(5), 822-830.

[112] Wallerstein, N., Duran, B., Oetzel, J. G., & Minkler, M. (Eds.). (2017). Community-based participatory research for health: Advancing social and health equity. John Wiley & Sons.

[113] Walters, D., Johnstone, R., Frick, K., Quinlan, M., Baril-Gingras, G., & Thébaud-Mony, A. (2011). Regulating workplace risks: a comparative study of inspection regimes in times of change. In *Regulating Workplace Risks*. Edward Elgar Publishing.

[114] Wang, H., & Rosemberg, N. (2018). Universal health coverage in low-income countries: Tanzania's efforts to overcome barriers to equitable health service access.

[115] Wiatrowski, W. J. (2013). Using workplace safety and health data for injury prevention. *Monthly Lab. Rev.*, *136*, 1.

[116] Wirtz, V. J., Hogerzeil, H. V., Gray, A. L., Bigdeli, M., de Joncheere, C. P., Ewen, M. A., ... & Reich, M. R. (2017). Essential medicines for universal health coverage. The Lancet, 389(10067), 403-476.

[117] Woldie, M., Feyissa, G. T., Admasu, B., Hassen, K., Mitchell, K., Mayhew, S., ... & Balabanova, D. (2018). Community health volunteers could help improve access to and use of essential health services by communities in LMICs: an umbrella review. *Health policy and planning*, *33*(10), 1128-1143.

[118] Zhao, J., & Obonyo, E. (2018, May). Towards a data-driven approach to injury prevention in construction. In *Workshop of the European Group for Intelligent Computing in Engineering* (pp. 385-411). Cham: Springer International Publishing.

[119] Zulu, J. M., Kinsman, J., Michelo, C., & Hurtig, A. K. (2014). Integrating national community-based health worker programmes into health systems: a systematic review identifying lessons learned from low-and middle-income countries. *BMC public health*, *14*(1), 987.