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Design and Implementation of an Electronic Health Records (EHR) Analytics System for Improved Patient Care and Decision-Making in Zambia

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ABSTRACT

Many health facilities in Zambia and other developing countries continue to face challenges in effectively managing patient records. While platforms like Smart Care have improved record-keeping and data sharing, they lack advanced analytics tools to support timely, data-driven decision-making. This study presents the design and implementation of a web-based Electronic Health Records (EHR) Analytics System that enhances conventional record management with real-time and predictive analytics. Developed using PHP, JavaScript, and MySQL, the system incorporates a Python-based analytics module to generate actionable insights, including disease trends, patient history summaries, and resource forecasts. Core features include patient registration, consultation tracking, laboratory and pharmacy modules, billing, and interactive dashboards, all secured through encryption and role-based access control. By integrating comprehensive data management with real-time analysis, the system enables healthcare providers to respond more quickly and accurately to patient needs, particularly in low-resource settings where SmartCare's analytics capabilities are limited. The system is designed to be flexible, scalable, and user-friendly, offering a practical solution for improving healthcare delivery in Zambia and similar contexts.

1. Introduction

Healthcare information management remains a persistent challenge in many developing countries, where health facilities often depend on paper-based records or fragmented digital systems that hinder efficiency, data accuracy, and continuity of care (Adhikari et al., 2019). Weak health information systems have been linked to delayed clinical decisions, duplication of services, increased medical errors, and poor monitoring of population health trends, particularly in low- and middle-income countries (LMICs) (Braa et al., 2017). As healthcare demands increase due to population growth and the dual burden of communicable and non-communicable diseases, the need for reliable and intelligent data systems has become more critical than ever (World Bank, 2022).

Electronic Health Record (EHR) systems have been widely promoted as a solution to these challenges because they enable structured data capture, secure storage, and improved accessibility of patient information across care settings (Cohen et al., 2025). Evidence from high-income countries suggests that EHR adoption improves care coordination, reduces administrative workload, and enhances patient safety through better documentation and information sharing (Menachemi & Collum, 2011). Furthermore, EHR systems provide a foundation for advanced data analytics, which can support clinical decision-making and health system planning when effectively implemented (Shortliffe & Cimino, 2021).

Despite these advantages, the implementation of EHR systems in developing countries has produced mixed outcomes. Studies indicate that many systems focus primarily on digitizing paper records without fully leveraging the analytical potential of the data they collect (Fraser et al., 2018). Challenges such as limited infrastructure, unreliable connectivity, insufficient funding, and lack of trained personnel often restrict the functionality and sustainability of digital health systems in resource-constrained settings (Agarwal et al., 2016). As a result, healthcare data is frequently underutilized, limiting its value for improving patient outcomes and system performance (Heeks, 2018).

In Zambia, the introduction of the SmartCare system marked a significant step toward strengthening national health information management. SmartCare has improved patient record accessibility, continuity of care, and reporting across thousands of healthcare facilities nationwide (SMART Zambia Institute, 2024). The system has been particularly valuable in supporting HIV, maternal health, and primary care services by enabling standardized data capture and longitudinal patient tracking (Mutale et al., 2013). However, evaluations of SmartCare indicate that its functionality is largely limited to transactional record-keeping and retrospective reporting (Kaumba, 2023).

The absence of integrated real-time and predictive analytics within national EHR platforms limits the ability of healthcare providers and managers to anticipate demand, detect emerging disease patterns, and allocate resources effectively (Lipton et al., 2019). Without analytical tools, decision-making remains reactive rather than proactive, increasing the risk of service delays, overcrowding, and inefficient use of scarce medical resources (Arsenault et al., 2017). This limitation is particularly problematic

in health systems facing high patient volumes and constrained budgets, as is common in sub-Saharan Africa (WHO Regional Office for Africa, 2023).

Healthcare analytics has emerged as a critical enabler of data-driven decision-making by transforming raw clinical data into meaningful insights (Raghupathi & Raghupathi, 2014). Techniques such as real-time dashboards, predictive modeling, and machine learning have been shown to support early disease detection, risk stratification, and operational optimization when integrated with EHR systems (Rajkomar et al., 2018). These approaches enable healthcare organizations to move beyond descriptive reporting toward anticipatory and preventive care models (Basile et al., 2025).

However, most analytics-enabled EHR solutions have been developed and validated in high-income settings, limiting their applicability in low-resource environments (Sahay et al., 2020). Context-specific factors such as infrastructure limitations, workforce capacity, and workflow constraints must be carefully considered to ensure that analytics systems are practical, scalable, and sustainable in developing countries (Chib et al., 2015). There is therefore a clear need for locally appropriate EHR analytics solutions that align with the realities of healthcare delivery in LMICs.

This paper addresses this gap by presenting the design and development of an Electronic Health Records Analytics System tailored to the Zambian healthcare context. The proposed system integrates real-time and predictive analytics into routine electronic record-keeping to support clinical decision-making, resource planning, and operational efficiency (Smith et al., 2022). By enabling healthcare workers and managers to extract actionable insights from existing patient data, the system seeks to enhance patient care, strengthen health system responsiveness, and support evidence-based healthcare management in resource-constrained settings (OECD, 2022).

2. Literature Review

Electronic Health Records (EHRs) have become a cornerstone of modern healthcare systems by enabling structured data capture, improved information accessibility, and enhanced continuity of care. Empirical evidence from developed healthcare systems demonstrates that EHR adoption reduces documentation errors, improves patient safety, and enhances coordination among healthcare providers (Menachemi & Collum, 2011). Additionally, EHR systems have been shown to support health system efficiency by reducing duplication of services and improving administrative workflows (Cohen et al., 2025).

In sub-Saharan Africa, the adoption of EHR systems has progressed more slowly due to infrastructural limitations, inconsistent electricity supply, and constrained health system financing. Studies indicate that many digital health initiatives in the region focus primarily on replacing paper-based records without fully exploiting the secondary use of data for decision-making and planning (Braa et al., 2017). As a result, EHR systems in low- and middle-income countries often function as data repositories rather than intelligent decision-support platforms (Heeks, 2018).

The application of data analytics in healthcare has gained increasing attention due to its ability to transform large volumes of clinical data into actionable insights. Healthcare analytics techniques, including predictive modeling, trend analysis, and machine learning, have been successfully applied to support disease surveillance, patient risk stratification, and operational optimization (Raghupathi & Raghupathi, 2014). These approaches enable healthcare systems to shift from reactive to proactive models of care, improving outcomes while optimizing limited resources (Arsenault et al., 2017).

Despite the proven benefits of analytics-enabled healthcare systems, their integration into EHR platforms in low-resource settings remains limited. Research suggests that barriers such as inadequate technical expertise, lack of interoperable systems, and limited organizational readiness hinder the effective use of analytics in developing countries (Agarwal et al., 2016). Furthermore, analytics solutions developed for high-income contexts often fail to align with local workflows and constraints when deployed in resource-constrained environments (Sahay et al., 2020).

In Zambia, existing studies on digital health systems have largely focused on evaluating implementation challenges, user adoption, and infrastructure readiness rather than the analytical use of health data (Mutale et al., 2013). This creates a critical gap in the literature regarding the design and implementation of EHR systems that integrate real-time and predictive analytics tailored to local healthcare needs. Addressing this gap requires context-aware solutions that leverage existing EHR platforms while enhancing their analytical capabilities to support clinical and managerial decision-making.

This study contributes to the literature by proposing and developing an analytics-enabled EHR system designed specifically for the Zambian healthcare context. By integrating decision-support tools, real-time dashboards, and predictive analytics into routine electronic record-keeping, the study responds to the documented limitations of existing systems and advances the discourse on data-driven healthcare delivery in low-resource settings.

3. Methodology

3.1 Research Design

A mixed-methods approach was employed, integrating surveys, interviews, and observational studies to systematically examine existing record management practices and determine the functional and operational requirements of the proposed system. This methodology facilitated a comprehensive understanding of current workflows, user challenges, and system expectations. Subsequently, a descriptive-analytical design was implemented to evaluate the system's performance post-deployment, enabling a thorough assessment of its efficiency, effectiveness, and overall impact on record management processes.

3.2 System Architecture

The system is designed using a three-tier architecture, as illustrated in Figure 1.

The Presentation Layer utilizes Bootstrap 5 and JavaScript to provide a responsive and user-friendly interface, ensuring seamless interaction across devices. The Application Layer incorporates PHP-based business logic and modular components, facilitating

efficient processing of user requests and system functionalities. The Data Layer is implemented using a MySQL relational database, featuring indexed tables and foreign key constraints to ensure data integrity, consistency, and optimized query performance. This architectural design promotes scalability, maintainability, and separation of concerns within the system.

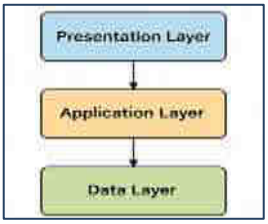

Figure 1

3.3 Modular Design

The system is structured around six core modules, each addressing specific functional areas of the Electronic Health Records system (Figure 2). The Patient Registration module is responsible for creating and maintaining patient records, including personal information and medical history, ensuring that accurate data is available for all subsequent processes. The Consultation Management module facilitates the scheduling, recording, and tracking of patient consultations with healthcare providers, supporting efficient clinical workflows. The Laboratory Results module manages the input, storage, and retrieval of diagnostic test results, providing clinicians with timely and reliable information for decision-making. The Pharmacy and Inventory module oversees medication dispensing, stock levels, and inventory tracking, contributing to effective resource management within the healthcare facility. The Billing and Finance module handles patient billing, payment records, and financial reporting, supporting administrative operations and accountability. Finally, the Analytics Dashboard module provides real-time and predictive analytics, enabling administrators and healthcare professionals to monitor system performance, patient care metrics, and overall operational efficiency.

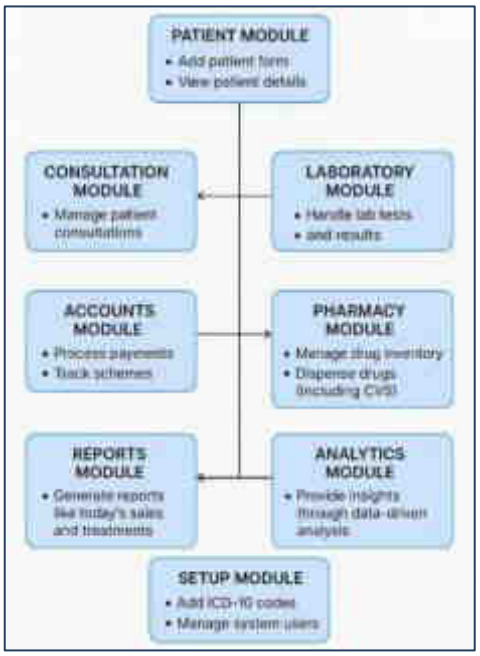

Figure 2

3.4 Analytics Integration

The system incorporates advanced analytics to support data-driven decision-making within healthcare operations. Real-time visualization of key metrics is provided through Chart.js, allowing users to quickly interpret patient data and system performance. For predictive insights, Python scripts are employed to model trends and forecast potential outcomes, enabling proactive healthcare management. Additionally, SQL queries are used for detailed trend analysis and reporting, facilitating the extraction of meaningful information from the database to guide administrative and clinical decisions. This integration of visualization, predictive modeling, and analytical reporting ensures that the system not only stores data but also transforms it into actionable intelligence for healthcare providers.

3.5 Security Measures

To ensure the confidentiality, integrity, and availability of patient data, the system incorporates multiple security measures. Role-Based Access Control (RBAC) is implemented to restrict system access based on user roles, ensuring that users can only access functionalities and data relevant to their responsibilities. Authentication and session management are secured through encryption techniques, protecting user credentials and preventing unauthorized access. Additionally, the system utilizes prepared SQL

statements to safeguard against SQL injection attacks, maintaining the integrity of the database. Collectively, these security measures provide a robust framework for protecting sensitive health information and supporting compliance with data protection standards.

4. Results

4.1 Baseline Assessment

A baseline assessment of record management practices was conducted using surveys, interviews, and observations across multiple healthcare facilities. The survey of 120 healthcare professionals revealed that 65% of rural clinics still relied on paper-based systems, while 70% expressed dissatisfaction with existing digital tools due to limited functionality and poor usability. Despite these challenges, 90% of respondents supported the need for integrated analytics to improve decision-making.

Interviews and observations highlighted inefficiencies such as delays in retrieving patient records, inconsistent data reporting, and duplication of tasks. Clinics with partial digital systems reported better accessibility, but the absence of real-time analytics limited overall effectiveness. These findings underscore the need for a robust Electronic Health Records system that integrates efficient data management with real-time and predictive analytics to enhance healthcare delivery.

4.4.2 System Testing and Validation

The implemented system underwent comprehensive testing to ensure its functionality, usability, security, and performance. Functional testing confirmed that all modules operated as intended, with accurate data capture and retrieval. During User Acceptance Testing (UAT), 85% of users reported that the interface was intuitive and significantly reduced administrative workload. Security testing demonstrated that Role-Based Access Control (RBAC) effectively restricted unauthorized access and that prepared SQL statements successfully prevented SQL injection attacks. Performance testing indicated that the system could support up to 50 concurrent users while maintaining response times under two seconds. The key findings from these evaluations are summarized in Table 1, providing a concise overview of the system's operational effectiveness and reliability.

Test Type	Key Findings
Functional Testing	All modules operated as intended; data captured and retrieved accurately.
User Acceptance Testing (UAT)	85% of users found the interface intuitive; reduced administrative workload.
Security Testing	RBAC effectively restricted unauthorized access; SQL injection attempts blocked.
Performance Testing	Handled 50 concurrent users with response times under 2 seconds.

Table 1

4.3 Analytics Outputs

The analytics module of the system provided actionable insights to support clinical and administrative decision-making (Figure 3). Disease trends were visualized in real time, enabling healthcare providers to monitor the prevalence of common diagnoses and identify emerging patterns. Patient load analysis offered department-wise consultation patterns, assisting in resource allocation and workflow optimization. Drug stock forecasting employed predictive analytics to support inventory management, ensuring adequate medication availability while reducing wastage. Additionally, the system generated billing reports, providing automated financial summaries to facilitate efficient administrative operations. Collectively, these analytics outputs transformed raw data into meaningful information, enhancing both patient care and operational efficiency.

Figure 3

4.4 System Interface and Implementation Results

This section presents screenshots of the implemented Electronic Health Records (EHR) Analytics System to demonstrate how the system operates in practice. The screenshots provide visual evidence of the system's functionality, usability, and integration of analytics within routine healthcare processes.

Figure 4

Figure 4 shows the system login interface, which requires users to authenticate before accessing the system. Role-Based Access Control (RBAC) is applied to ensure that users can only access features relevant to their roles, such as administrators, clinicians, laboratory staff, or pharmacy personnel. This security measure helps protect sensitive patient information and prevents unauthorized access.

Figure 5

Figure 5 illustrates the patient registration module, where patient demographic details and medical history are captured and stored in the database. This module forms the foundation of the EHR system, as all other clinical and administrative processes depend on accurate patient data. The interface is designed to be simple and user-friendly, allowing healthcare workers to enter information quickly and accurately.

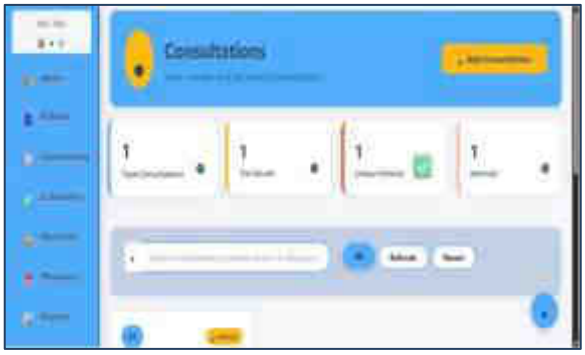

Figure 6

Figure 6 presents the consultation management interface, which enables clinicians to record patient visits, diagnoses, and treatment plans. This module supports continuity of care by allowing healthcare providers to easily review previous consultations and patient history during follow-up visits.

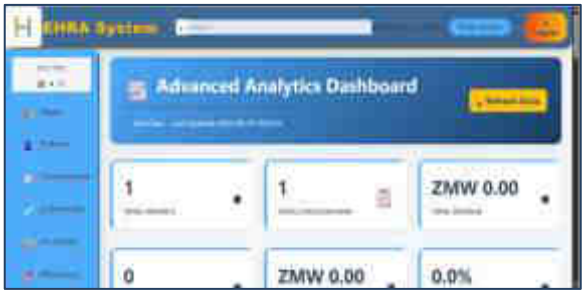

Figure 7

Figure 7 shows the analytics dashboard, which provides real-time visualization of key health indicators, including disease trends and patient load statistics. The dashboard transforms raw clinical data into meaningful insights that support timely decision-making by healthcare professionals and administrators.

Figure 8

Figure 8 displays the drug stock forecasting and inventory monitoring screen. This feature uses historical data to predict future drug demand, helping facilities to plan procurement effectively and reduce stock-outs or wastage.
Overall, the system interface screenshots confirm that the proposed EHR Analytics System was fully implemented and is capable of supporting clinical operations, administrative tasks, and data-driven decision-making in healthcare facilities.

5. Discussion

The implementation of the EHR Analytics System successfully addressed critical limitations observed in existing platforms, such as SmartCare, particularly the lack of integrated analytics and user-friendly design. By providing real-time dashboards and predictive analytics, the system enables healthcare professionals to shift from reactive to proactive care delivery. This increased visibility supports timely identification of disease trends, facilitates efficient resource allocation, and enhances patient management. In addition, the system's intuitive interface and modular design reduce administrative workload and streamline clinical workflows, illustrating how a well-integrated EHR can improve both operational efficiency and the quality of healthcare services. These results highlight the potential of analytics-driven digital health solutions to strengthen healthcare delivery, particularly in resource-limited settings, and demonstrate that combining usability with advanced data insights is essential for effective EHR adoption.

5.1 Usability and Adoption

The system's Bootstrap-based interface was well-received by healthcare professionals, who highlighted its simplicity and ease of use. This intuitive design significantly reduced the learning curve, particularly for staff with limited experience in information and communication technology (ICT). As a result, users were able to navigate the system efficiently, complete tasks with minimal guidance, and adopt the EHR Analytics System more readily into their daily workflows. The positive usability outcomes indicate that combining a responsive, user-friendly interface with functional robustness is critical for successful EHR adoption, especially in resource-limited healthcare settings.

5.2 Decision Support

The system's analytics features, including disease trend monitoring and drug stock forecasting, were identified by users as the most valuable components. These functionalities provide actionable insights that support evidence-based planning, enabling healthcare professionals to anticipate patient needs, allocate resources efficiently, and respond proactively to emerging health trends. By transforming raw data into meaningful information, the analytics module enhances decision-making at both clinical and administrative levels, demonstrating the critical role of integrated data intelligence in improving healthcare delivery and operational management.

5.3 Scalability and Sustainability

The adoption of open-source technologies, including PHP, MySQL, and Python, ensures that the system can be deployed at low cost while remaining adaptable to low-resource healthcare settings. Furthermore, the modular architecture provides flexibility for future enhancements, such as integration with mobile platforms or interoperability with national health databases. This design approach supports long-term scalability and sustainability, allowing the system to evolve in response to changing healthcare needs and technological advancements, while maintaining affordability and accessibility for a wide range of healthcare facilities.

5.4 Comparison with Existing Systems

The EHR Analytics System demonstrates several advantages over existing platforms. Unlike SmartCare, which primarily focuses on data entry, this system incorporates analytics at its core, enabling real-time insights and predictive decision support. Compared to OpenMRS, the system is lighter, simpler, and easier to deploy, making it well-suited for facilities with limited ICT infrastructure. In contrast to commercial solutions such as Epic and Cerner, the system is cost-effective and specifically tailored to the needs of resource-limited healthcare environments. These comparisons highlight the system's balance between functionality, usability, and affordability, emphasizing its suitability for improving healthcare delivery in contexts where both resources and technical capacity are constrained.

6. Conclusion

This study demonstrates the feasibility and positive impact of integrating analytics into Electronic Health Record systems in low-resource healthcare settings. The developed system not only enhances data management but also empowers healthcare providers with actionable insights, facilitating more informed and timely decision-making. By bridging the gap between data collection and utilization, the system contributes to efforts to modernize healthcare infrastructure in Zambia and similar contexts.
Future work should focus on expanding the system's capabilities and reach. Key areas for development include cloud-based scaling to enable nationwide deployment, mobile application integration to support on-the-go access, interoperability with national health information systems, and the incorporation of advanced machine learning models to enhance clinical prediction and decision support. These enhancements have the potential to further improve healthcare delivery, operational efficiency, and patient outcomes in resource-limited environments.

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