e-HAMS: A UNIFIED MODEL-BASED INTEGRATED HEALTHCARE SERVICES MANAGEMENT SYSTEM FOR LOW-AND-MIDDLE INCOME ECONOMIES

[1] Fagbola Temitayo Matthew, [3] Egbetola Funmilola Ikeolu, [3,4,5] Emuoyibofarhe Justice, [2] Olaniyan Olatayo Moses, [3] Oloyede Ayodele, [3] Akinpelu James

[1] Department of Computer Science, Federal University, Oye-Ekiti, Nigeria
[2] Department of Computer Engineering, Federal University, Oye-Ekiti, Nigeria
[3] Department of Computer Science and Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
[4] Centre for Excellence in Mobile e-Services, University of Zululand, South Africa
[5] Hasso Plattner Institute, University of Potsdam, Germany

Corresponding Author: Fagbola Temitayo, temitayo.fagbola@fuoye.edu.ng

ABSTRACT: The emerging proliferation of fragmented healthcare applications has accounted for an overwhelming high cost of maintaining healthcare services and facilities, clinical data security and privacy concerns, decentralized data redundancy leading to snail-speed of improvement in healthcare services' delivery efficiency and more often than not, a total shutdown of health facilities. Due to lack of communication among these decentralized and often similar health applications, their relative characteristics and advantages are either misaligned and/or duplicated in most cases. Hence, needs be that robust and integrated healthcare services management applications, that can collaboratively deliver consolidated healthcare objectives and facilitate huge cost savings, seamless clinical information workflow, optimum access and sharing of centralized clinical data, highly-efficient quality of service (QoS) and real-time accountability, be developed especially for the healthcare systems in low-and-middle-income economies. In this paper, an integrated web-based electronic HealthcAre Management System (e-HAMS) for low-and-middle income economies was developed. e-HAMs is a composite mobile-compliant system with a collaborative framework that accommodates electronic patients' health record, electronic cash flow audit, electronic personnel record management, electronic pharmacy services and the electronic healthcare services payment management systems. Prior to its development, a users' needs assessment was conducted and the possibility that e-HAMS would offer some cost-savings benefit was also modelled. The collaborative model when evaluated based on Closed World Assumption (CWA) reveals that cost-savings benefit is huge. An underlying architecture for the integrated development plan was also developed. Unified modeling language and *V*-shaped software development model were employed to co-design and orient the development of e-HAMS. Interactive graphical user interfaces were developed to implement e-HAMS' designs in a visual studio integrated development environment using C# language. The system database was developed using a SQL server application. At the testing stage, a qualitative users' assessment of e-HAMS was conducted to evaluate the performance of the developed e-HAMS system. Results obtained reveal that cost savings benefit of e-HAMS is rated at 96%, reliability (92%), availability (90%), privacy (90%), security (89%), quality assurance (86%), user interface design (82%), ease of use (78%) and user friendliness (76%) in that order. Thus, e-HAMS is best suited for low-and-middle income economies to realize improved Quality of healthcare services delivery and facilitated efficiency of operations while offering timely generation of informed decisions.

KEYWORDS: Unified modeling design, co-design, cost, integrated healthcare services management system, pharmacy, audit, patient, low and middle income countries.

1 INTRODUCTION

The growing ubiquity of Information and Communication Technology (ICT) (mobile phones, internet, 3G/4G network, low-cost cloud servers, personal digital assistants, tablets and so on) has brought about transformational changes in the traditional approaches to healthcare service delivery and management especially in developing economies ([L+17]; [A+14]; [FI11]). This power of technology is increasingly being harnessed to revolutionize and improve the quality of healthcare services especially for public health surveillance, remote monitoring, diagnostic treatment, health education and awareness ([L+17]; [Y+13]). Today, there exists a huge number of electronic / mobile (e/m)-Health applications and systems ranging from e-pharmacy, e-prescription ([O+13]), telemonitoring ([F+13]; [Y+13]), public health information ([WHO11]) to diseases surveillance ([L+16]) among others, offering the healthcare services some efficiencies and administrative facelifts. [L+14] and

[A+14] identified some impacts of technology intervention in healthcare services delivery in the context of developing economies to include increased availability of often inaccessible quality healthcare services and cost savings.

However, despite the increasing ICT-in-health innovations, major reasons for the poor quality outcome of technology investments and intervention in healthcare service delivery include but are not limited to the existence of several fragmented systems and applications with no or little probability of interoperability within a particular healthcare facility leading to high cost duplication of ICT intervention efforts, rising clinical data security and privacy concerns ([Dee13]; [AS12]; [Shi12]; [RK12]; [AAR10]); lack of functional technology-in-health innovation management policy ([VR17]) and where it exists, a weak implementation of such policies ([L+17]), disparities in health reports obtained from non-uniform health applications, lack of organized and well-coordinated information systems at all facilities in which healthcare is delivered ([VR17]; [L+17]) despite the increasing investment in ICT-in-health systems.

As stated by Adenuga, Kekwaletswe and Coleman ([AKC15]), healthcare systems are being confronted with incessant proliferation of new systems (hardware, software) and applications (proprietary healthcare software solutions). For instance, remote e-Health monitoring system (EHMS), CAALYX, Cyber-Physical Healthcare System with Service Oriented Architecture (CPHSSOA) and Service Oriented and Cloud-Based eHealth System (SOCBeS) developed by Omar *et al*. ([OTB06]), Rocha *et al*. ([R+13]), Rao *et al*. ([R+12]) and Benharref *et al*. ([BS14]) respectively all serve the same purpose of tracking and monitoring patients towards early detection and prevention of chronic diseases. This establishes assertion of duplication of electronic intervention effort and wrong channeling of limited funds that could have served more critical, high benefit and relevant healthcare management purposes. Each of these applications has its own peculiar technological standards, hardware and software requirements which on acquisition might require that a new infrastructural set-up and/or facilities be put in place ([KMS17]). Obviously, this is an insurmountable challenge to low- and middle-income economies in Africa due to the high cost associated with the acquisition and maintenance of these decentralized healthcare services' intervention applications. Another similar problem is that, most existing healthcare applications are developed without prior planning or taking into consideration, scalability, portability, support for centralized access to available records and effective communication needs with other applications in the facilities in which they are deployed ([KMS17]; [WU09]). More often than not, how the healthcare stakeholders and managers in developing economies should respond appropriately to this rising trend of fragmented, similar and decentralized healthcare systems and technologies remains an open problem.

Recently, enterprise integration, a new and emerging field in computing, attempts to devise scalable architectures and technologies to allow for interaction between enterprise entities and integration of systems currently in use with some emerging ones without further investments in acquiring new set of software and hardware ([AKC15]; [ZT12]). Basically the levels of integration vary from physical, application and business to enterprise modeling ([K+05]). Physical integration involves the interconnection of devices, machines and networks; similarly, application integration consolidates software applications and database management systems. Integration of all underlying logical entities and learning models for managing, controlling and monitoring business processes is achieved through the business integration procedures while the use of consistent modeling framework can allow for enterprise model integration ([M+13]; [Sho97]). The goal of integration is to methodologically ensure generic enterprise-wide decision making, cost-savings, increased availability and accessibility of technologies and systems ([Dru12]).

More specifically, integration of healthcare management systems will allow for a more effective and efficient services' rendering via a number of constituent complementary health applications rather than a series of disjointed systems ([KMS17]; [AK12]; [CK10]). More so, it can be viewed as a critical measure towards the realization of reduced chances of medical errors and contradicting set of clinical information, emanating via decentralized e/m-health technologies from different manufacturers while offering a more reliable means to access and share information among public health systems ([Pep17]). In the same vein, Lange and Mendling ([LM11]) also stressed that developing integrated healthcare systems will promote correction and standardization of disparate technologies for interoperability and data communication towards a more reliable and safe exchange of public health data, with the possibility that, prior testing of integrated systems from different manufacturers be conducted for compliance with standards before final deployment and use. WHO ([WHO08]) emphasized the need to improve the health system through the promotion of health services integration in low and middle income countries for the targeted millennium development goals to be met. This is in a bid on one hand to

provide huge cost savings and on the other hand to improve administrative effectiveness, efficiency and quality of service delivery. Furthermore, empirical evidences showing the development of such integrated systems for healthcare services' management in low- and middle-income countries are very limited ([WHO17]; [WHO08]). More often than not, most referred integrated systems exist in form of policies rather than in their actual implementations ([AKC15]).

Integration of healthcare services and management applications is critically a big challenge to low- and middle-income countries in Africa; on one hand, due to paucity of funds needed to conduct the process as a result of global economic recession ([Mar14]; [Mus10]), business cost associated with the merging of such systems, staff training, security patches and periodic updates, maintenance, license and service charges ([KMS17]; [HF09[) and on the other hand, due to limited technical know-how, availability, quality assurance and migration strategies to be adopted (that is, a resolve on approaches for generic harmonization of backend data, metadata (format, size, type) structures and generic front-end design for anticipated compatibility among the applications to be integrated) ([Mar14]; [WWV14]; [FOB12]; [MS08]). To enjoy comprehensive and collaborative healthcare services delivery in resource limited settings, the need to develop integrated healthcare information systems, based on a common set of technological standards that support exclusive data exchange and information sharing is imminent ([VR17]; [Jen13]).

Therefore, in this paper, an integrated web-based and mobile-compliant healthcare management system for low-and-middle income economies tagged Electronic HealthcAre Management System (e-HAMS) is developed. e-HAMS is a collaborative healthcare system comprising of five (5) health applications which are electronic patients' health record management system (e-HRMS), electronic cash flow audit system (e-CFAudit), electronic personnel record management system (e-PRMS), electronic pharmacy services management system (e-PSMS) and the electronic healthcare services payment capturing system (e-HPCS). e-HRMS is responsible for an up-to-date management of patients' health records and history across regional health facilities; on the other hand, e-CFAudit is a financial tracer for tracking inflow and outflow of financial transactions at each health facility in real time; furthermore, e-PRMS is responsible for safe keeping and update of health workers' data (employment history and biodata information); e-PSMS is designed to manage pharmacy services (drug in stock, drug sales, drug prescription and administration all with its associated activity timestamp) and finally the e-HPCS is developed to capture all payments made to healthcare facilities for accessing healthcare services. The rest of this paper is organized as follows: Section 2 presents the conceptual underpinnings and related works. Section 3 details the materials and method used to orient the development of e-HAMS including the e-HAMS cost savings model and Needs assessment, architectural development plan and development phases of e-HAMS. Section 4 presents the results and discussion. Finally, Section 5 presents the conclusion and future research works.

2. CONCEPTUAL UNDERPINNINGS AND RELATED WORKS

According to the annual report of 2016 released by the Department of Defense ([DoD16]), on integrated information systems, DoD Legacy Healthcare Systems (LHS) (comprising of the Armed Forces Health Longitudinal Technology Application (AHLTA), Composite Health Care System (CHCS) and the components of the Theater Medical Information Program-Joint (TMIP-J) software) are currently being replaced with an Off-The-Shelf (OTS) Electronic Health Record (EHR) System which is an integrated, sustainable, scalable, interoperable, flexible and modernized EHR system offering exclusive features of all the DoD's LHS. The proposed OTS EHR system is such a collaborative healthcare system that consists of an integrated inpatient/outpatient Best of Suite (BoS) solution and Best of Breed (BoB) product(s). BoS exhibits a design architecture characterized with common user interfaces, common business rules, common workflows, unrestricted and prompt access to and sharing of a pool of common (centralized) data. It also aims to offer support towards end-to-end healthcare services. On the other hand, BoB is designed to provide exclusive access to authoritative and unrestricted sources of healthcare clinical data which in turn can be harnessed for public health surveillance, disease epidemic prediction and management (DoD, 2016). BoB anticipates to interpretably enhance the quality of care, public health safety, healthcare management services and decision making. However, the proposed OTS EHR system is expected to consolidate several disparate DoD legacy healthcare systems and facilitate accessibility to common knowledge pool.

In a recent development, bodies of medical experts and healthcare scientists like the Japan Industrial Association of Radiological Systems, Radiological Society of North America (RSNA), Health Level 7 (HL7), American Association of Physicists in Medicine (AAPM), Health Information and Communication Standards Board (HELICS),

Healthcare Information and Management Systems Society (HIMSS) and American Society for Radiation Oncology (ASTRO), with members from Germany, France, Netherlands, United Kingdom, USA, Switzerland, Spain, Canada, Belgium, Sweden, New Zealand and Japan, have been meeting to collaborate towards developing integrated healthcare systems' architecture based on common standard for sharing, managing and integrating electronic healthcare information and applications more reliably and efficiently in a cost-effective manner ([Pep17]; [Ysh11]). To this end, integrated healthcare standards are now being developed for managing, storing, printing and transfer of clinical information. For example, Digital Imaging and Communications in Medicine (DICOM), an integrated healthcare imaging standard, was developed by Integrated Healthcare Enterprise – Radiation Oncology (IHE-RO) to streamline workflow and interoperability of medical imaging systems ([Pep17]). IHE cycle is presented in Figure 1. This technology enables seamless integration of and cooperation among medical imaging systems including servers, printers, scanners, workstations and network hardware from multiple manufacturers, which in turn has been reported to have increased effectiveness and efficiency of treatment planning and management in healthcare services delivery.

Grandia ([Gra17]) while juxtaposing the past, present and future of information systems in what is referred to as "A Fortuitous Byproduct of Healthcare IT Implementation" stressed that clinical and healthcare management services require that new health technologies with integrated capabilities for multiple roles be prioritized over existing EMRs and other clinical healthcare management applications. The need to integrate multiple applications (clinical, financial, patient health records management) was strongly emphasized as a means to realize improved performance of healthcare systems and enormous cost savings in modern but resource-constrained clinical settings. Larry opined that most currently existing health management applications should have been developed to support integrated and scalable architecture that is characterized by a comprehensive common data warehouse for healthcare fully-operational performance expectations to be met.

Jensen ([Jen13]) developed a large scale community-based project termed "Standardized pull of patient data" (SUP) which provides a pragmatic solution that allows exclusive access to healthcare data generated by several fragmented set of electronic patient record (EPR) systems within hospitals in Denmark. SUP allows patient notes, diagnoses, requisitions, contacts, prescriptions, drug administration, clinical procedures, test results and personal information to be integrated and access under a common architecture. Built upon the principle of "flexible standards" required for sustainable systems' development, the integrated SUP has been in use by citizens and majority of hospitals across Denmark with characterized flexibility and scalability through its modular design strategies. The concepts of "change flexibility" and "use flexibility" were adopted to allow for the ability to change standards through modularization and to determine the extent to which varying tasks and activities can be simultaneously supported by a standard, respectively. In Figure 2, the block diagram of the SUP solution is presented.

The SUP portal unifies the process of registering patients' data on Patient Administrative Systems (PAS), EPR and other e-Health management systems in place using a MedCom XML standard to a SUP online database server. With the patient's civil registry number, healthcare professionals can search the common data pool to view the patient information through a web browser and secure internet access. Two pilot hospitals having three different EPR systems from three vendors were chosen to test SUP solution based on performance measures including but not limited to interoperability, accessibility of data, usability, efficiency, maintenance and security issues. SUP solution was conclusively reported to have make significant contributions to a large extent in solving information sharing and data access problems among EPR systems and other similar healthcare information systems in Denmark. However, Jensen ([Jen13]) advocated the need for more efforts and researches to be directed towards building a common architecture, framework and technological standard that would enhance interoperability and information sharing among different healthcare services management systems beyond spatio-temporal boundaries.

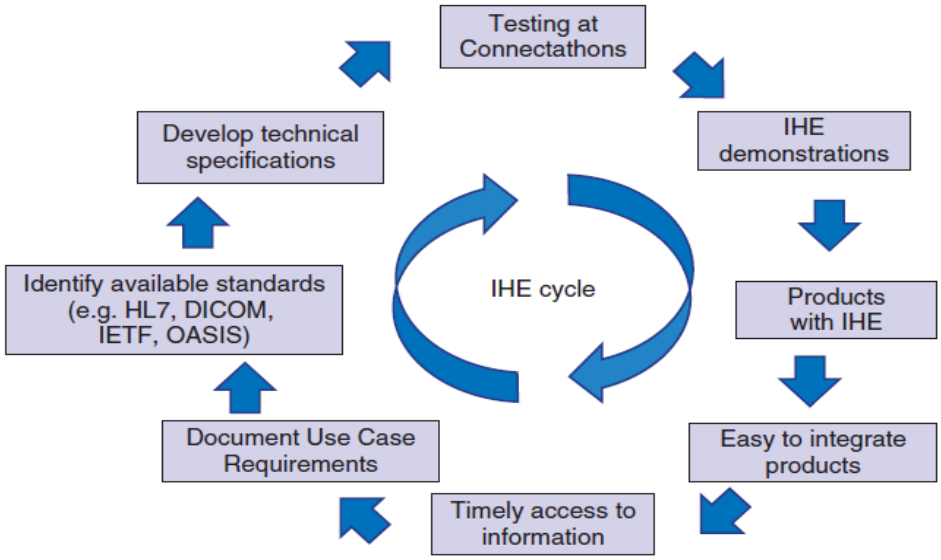

Figure 1: IHE cycle ([Pep17])

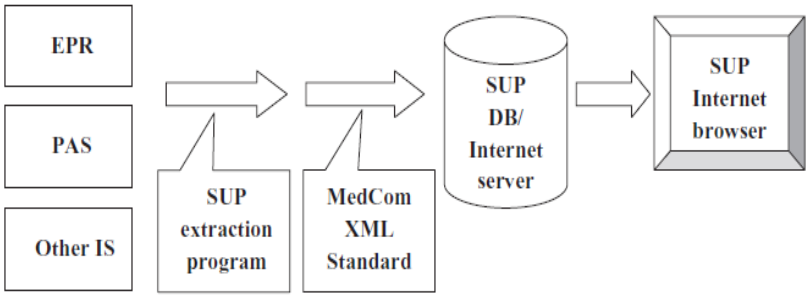

Figure 2: The Block Diagram of the Standardized Pull of Patient Data Solution ([Jen13])

HEALTHCAREfirst ([Hea17]) developed a composite integrated Electronic Medical Records (EMR) software solution consisting of four healthcare information systems which are operational and tactical systems, clinical and administrative systems, subject and task-based systems and financial systems. These systems provide simple means of classifying information; conducting administrative level management of patient details; offering EMR management and platform to track revenue and manage billing submissions, respectively. TriZetto ([Tri08]) developed an Integrated Healthcare Management (IHM) architecture to pioneer the development of the next generation of healthcare management technologies. It was claimed that IHM is fundamental to transforming, enhancing and converging the healthcare systems' capabilities into a unified system offering increased effectiveness of treatments, high cost of care savings and improved efficiencies of healthcare services. TriZetto's IHM converges the core benefit of administration, care management and constituent engagement technology competencies towards the realization of automated flexible business process in a bid to support diverse plan designs and integration with third-party solutions; support for increased collaboration and enhanced communication as well as fostering improved interactions and provision of relevant information among healthcare providers and stakeholders.

TriZetto's IHM-based solutions include the Facets, QNXT, CareAdvance Enterprise (CAE) and TriZetto NetworX Suite. Facets and QNXT are scalable, comprehensive, flexible and enterprise-wide core administration solutions. These set of solutions has seen the convergence of the healthcare management systems, information and processes. On one hand, Facets integrates healthcare business requirements (claims processing, risk fund accounting/capitation, claims re-pricing, referral management, premium billing, hospital and medical pre-authorization, electronic data interchange and customer service); and on the other hand, QNXT, a service oriented architecture-based open platform offers a thin client web-based user interface utilizing web services (Simple Object Access Protocol (SOAP), Extended Markup Language (XML) and .NET) to manage healthcare services like case management, provider network management and so on.

Furthermore, CAE is a web-based interactive and collaborative platform for advanced management of healthcare services, disease epidemic monitoring and public health surveillance. It is developed to ensure prompt maintenance of personal health and

wellness; reduced administrative costs of communicating with health stakeholders; timely interventions by healthcare providers; creation and maintenance of personalized online health records and disease surveillance campaigns. TriZetto NetworX suite is an integrated set of software applications offering total automation of all aspects of advanced network management, real-time modeling, timely and accurate projection of financial implications of healthcare management contracts during negotiation. Summarily, on one hand, only very limited works exist on integrated healthcare management system none of these works are tailored for use in low-and-middle income economies; and on the other hand, none of these works are tailored for use in resource-limited low-and –middle income economies.

3 MATERIALS AND METHOD

In this section, the needs assessment, architectural development plan and the development life cycle of e-HAMS are presented.

a. e-HAMS' Needs Assessment

The needs assessment for e-HAMS was carried out as follows:

i. *e-HAMS cost-savings modeling*

Costs associated with e-HAMS was modeled to establish a theoretical basis to embark on its development should such model offer some positive cost savings benefit.
Let P = personnel cost, M = maintenance cost, I = installation (acquisition) cost, T = Training cost, U = cost of periodic updates, S = license subscription cost.
In a closed world assumption, that is, a logical assumption that no other incurable costs exist other than those that currently exist ([YC11]), Cost (C) for each application is estimated as:

$$C = (I + P + M + U + S) \quad (1)$$

Total cost of incurring *n* Integrated Health Management Applications (IHMA),

$$\boldsymbol{C_{total(n)}} = \sum_{i=1}^{n} Cost\ (I_i + T_i + P_i + M_i + U_i + S_i) \quad (2)$$

Since e-HAMS is a composite system containing 5 IHMA, e-HAMS Cost Savings Value,

$$CSV_{e-HAMS} = \sum_{i=1}^{5} Cost\ (I_i + T_i + P_i + M_i + U_i + Si) - Cost_{e-HAMS}\ (I + T + P + M + U + S) \quad (3)$$

Assuming that the cost value of all the variables remain constant for all applications, then,

$$CSV_{e-HAMS} = \sum_{i=1}^{4} Cost\ (I_i + T_i + P_i + M_i + U_i + Si) \quad (4)$$

The positive value of CSV_{e-HAMS} indicates that the development of e-HAMS will offer the anticipated cost savings benefit.

ii. *Users' needs assessment*

Users' preliminary needs assessment that necessitated the development of the e-HAMS was conducted with 400 health workers (doctors, nurses, pharmacists, hospital accountants, hospital account auditors, cashiers, medical laboratory technologists and health stakeholders) drawn from hospitals in South Western part of Nigeria and whose distribution is presented in Figure 3. Questionnaire and oral interviews were used as instruments for the e-HAMS needs assessment while descriptive statistics was adopted to analyze the data gathered.
Having evaluated the features of e-HAMS especially as it tends to offer high cost benefits, all the respondents embraced the need for its development as presented in Figure 4. Initial investigation was conducted to identify the major challenges limiting wider use of e/m-Health technologies prior to users' needs assessment. In order of rising concern among healthcare workers and stakeholders, high cost scored 94%, lack of privacy (77.5%), insecurity (66%), low quality (53.5%) and technical know-how (28.5%) as shown in Figure 5. This investigation revealed that cost is the major factor limiting the adoption and use of emerging ubiquitous e/m-Health technologies for efficient and quality of service delivery in healthcare systems in the study area.

b. e-HAMS Architectural Development Plan

A four-modular architecture for the integrated development of e-HAMs is presented in Figure 6. This architecture was designed to allow for a detailed implementation plan that can guarantee quality of intermediate development processes and strict compliance with users' requirements specification to realize a robust e-HAMS. It allows for cost and benefits assessment especially the post-development profitability prospect of e-HAMS. Early detection of project risk is also made possible.

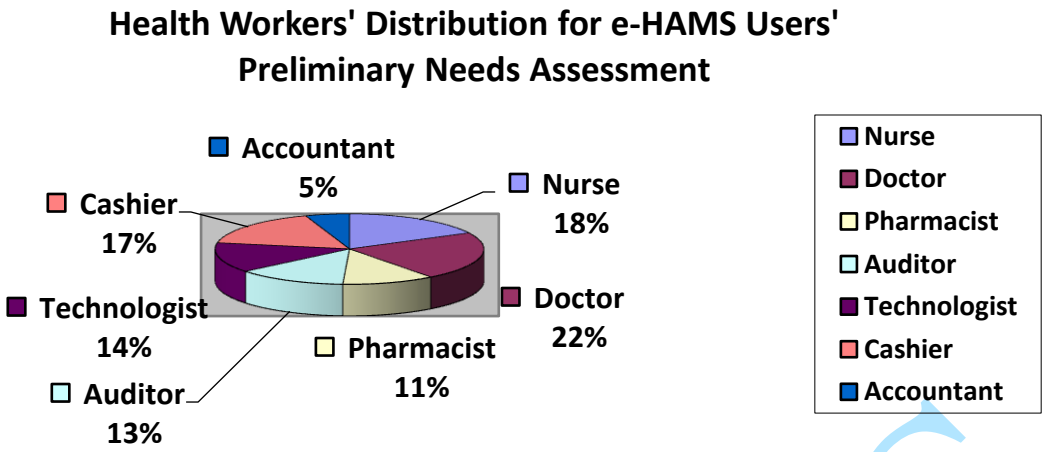

Figure 3: Pie-chart showing the distribution of e-HAMS' Needs Assessment Respondents

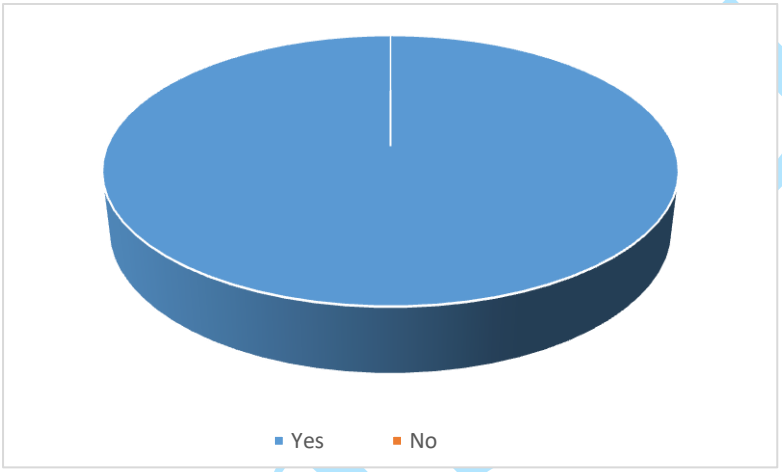

Figure 4: e-HAMS Preliminary Needs Assessment Result

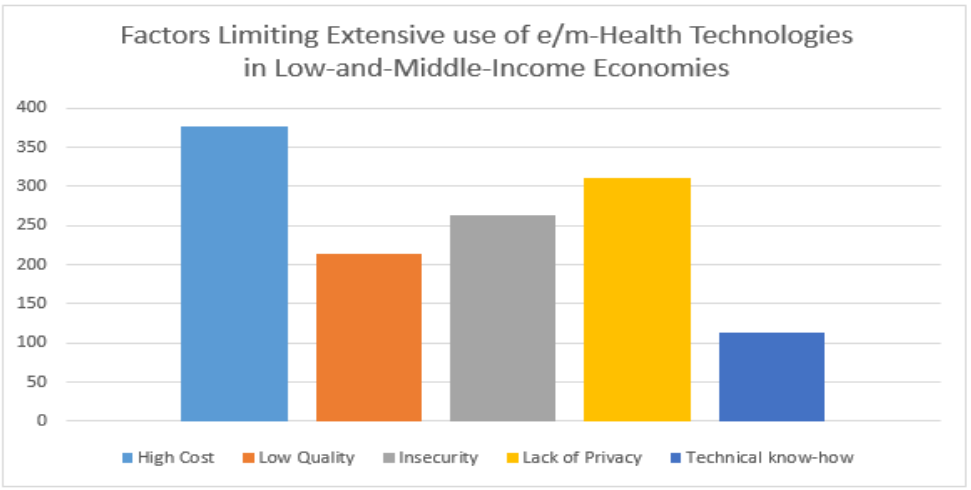

Figure 5: Chart Showing the Factors Limiting Extensive Use of Health Technologies in Low- and Middle-Income Economies

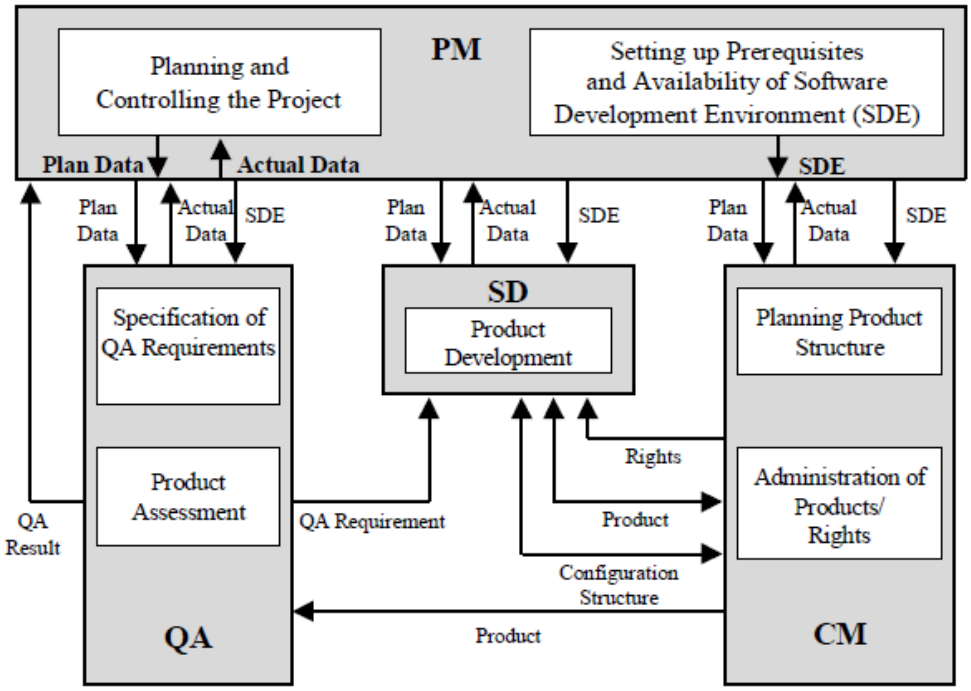

Figure 6: The Underlying Architecture for the Integrated Development Plan of e-HAMs

The Project Management (PM) module regulates the activities of initiating, planning and monitoring the development of e-HAMS. It defines the framework, cost / benefit analysis, phase review for compliance check with expected outcomes. On the other hand, System Development (SD) module manages how the e-HAMS is developed in terms of the required activities and features. This module sees to user-centric e-HAMS requirement analysis, e-HAMS design, software and hardware requirement analysis, software architectural design and implementation, integration of e-HAMS disconnected sub-systems and deployment to clients' environment. The Quality Assurance (QA) module allows the system design and associated components to be validated before use. The activities, processes and products are accessed before being accepted. Evaluation of assessment reports is also carried out by this module. Configuration Management (CM) module guarantees the unique identification of any e-HAMS's feature at any time and the seamless collaboration of neighbor applications. However, specifications' change management and administration of the e-HAMS are the key characteristics of this module.

c. Development Life Cycle of e-HAMS

e-HAMS was developed using the *V*-shaped software development model. *V*-model was adopted in this study because it is co-design friendly, easy to use and simple. It allows users of e-HAMS to participate in its design, development and management processes. It also offers support for a variety of development methodologies including structured and object-oriented system development. The steps involved include users' requirement specifications gathering and analysis, program and system design, implementation, software integration, testing and deployment.

i. *e-HAMS' users requirement specifications*

At this foundational stage, the potential users of the system were consulted in order to establish the goals, requirements, and services that the end-users require and expect from e-HAMS through a co-design approach. Requirement specifications for e-HAMS involve the development and integration of the following health applications:

1. electronic patients' Health Record Management System (e-HRMS): This system is concerned with an up-to-date management of patients' health record and history (biodata, family health history records, patient's diagnosis and prescription history information) across regional health facilities.
2. electronic Pharmacy Services Management System (e-PSMS): This system is responsible for the management of records of pharmacy operations and services (for example, drugs in stock, drug sales, drug prescription and administration all with its associated activity timestamp.
3. electronic Healthcare services Payment Capturing System (e-HPCS): This system is responsible to capture payments for doctors

visit, laboratory tests and drugs among other cost-oriented hospital services.

4. electronic Cash Flow Audit system (e-CFAudit): This system is saddled with the ability to generate instant, time variant audit report (personnel, patient, ailment and financial auditing) with detailed reports. For example, this is required to determine the number of visits a patient has made to a healthcare centre between any two distinct periods and total amount expended on drugs, visits and the various doctors that she had consulted. This system is expected to facilitate the monitoring and determination of financial transactions in the healthcare system which in turn could be generated as a report at any required time. It curbs illicit financial recklessness and lack of accountability or hidden flow of cash. Total income between any two distinct periods is a click away. Total sales made by each unit of the healthcare system can be easily determined and generated as a report when required.
5. electronic Personnel Record Management System (e-PRMS): This system maintains up-to-date health personnel records, employment history as well as track their activities and specialities among other things to create a coordinated communication pattern among hospital departments. It could be used to evaluate health personnels' efficiency and quality of rendered services.

The following technical requirements were identified:

1. Two-stage security authentication procedure: To guide against unauthorized access and malicious attacks to the backend data, a combined RSA and Least Significant Bit (LSB) stegano-cryptographic security algorithm was adopted.
2. Privacy of data (only the right hospital personnel should have access to patients' records) was ensured to enhance confidentiality of patients and personnel records via a row-level anonymized encrypted mechanism.

ii. *Design of e-HAMS*

Based on the earlier identified requirement specifications, design of e-HAMS was prepared to help in specifying the hardware and software requirements and also help in defining the overall system architecture. In this section, the unified conceptual models and the entity relationship model for some applications integrated into e-HAMS are presented in Figures (7-12).

a. *e-HAMS' unified conceptual models*

Models are presented in figures 7-11.

b. *e-HAMS Database Management System*

SQLServer 2012 was used as the database management system for e-HAMS development. In Figure 12, the abridged Entity Relationship Diagram (ERD) for the e-HAMS is presented.

iii. *Implementation*

C# programming language was used to develop the e-HAMS in a Visual Studio 2015 integrated development environment based on its prior system design. SQL Server 2012 express was used to design the underlying metadata and database backend. e-HAMS composite applications as presented in Table 1 were the actual applications developed at this stage. These healthcare systems were implemented as web-based but mobile-compliant applications accessible via personal digital assistants, tablets, mobile phones and some low configuration mobile devices. Sample implementation interfaces are presented in Figures (13-21).

Table 1: e-HAMS' Integrated Healthcare Services Management Systems

e-HAMS	e-HRMS
	e-CFAudit
	e-PRMS
	e-PSMS
	e-HPCS

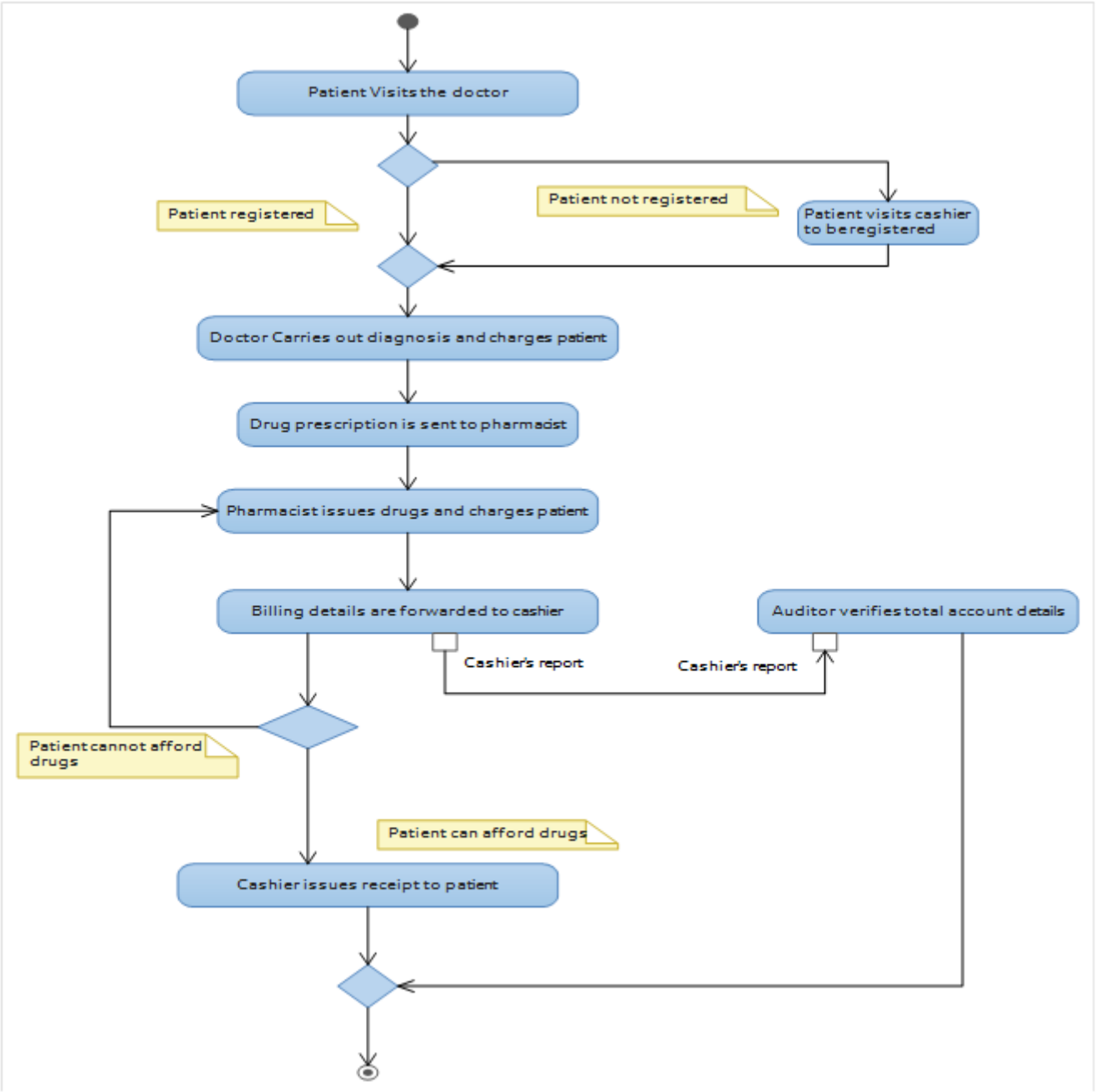

Figure 7: Activity Diagram for the e-Hospital Auditing System

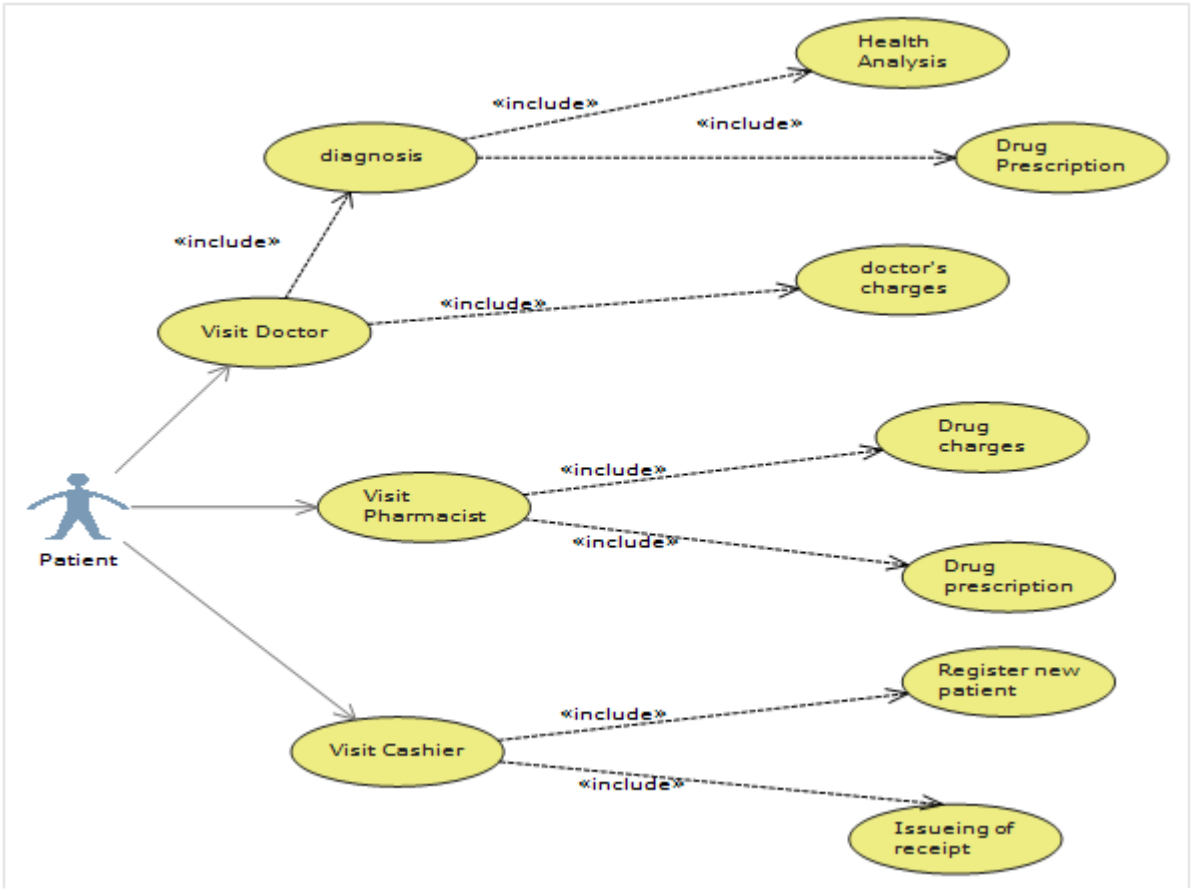

Figure 8: Patient Role Use Cases

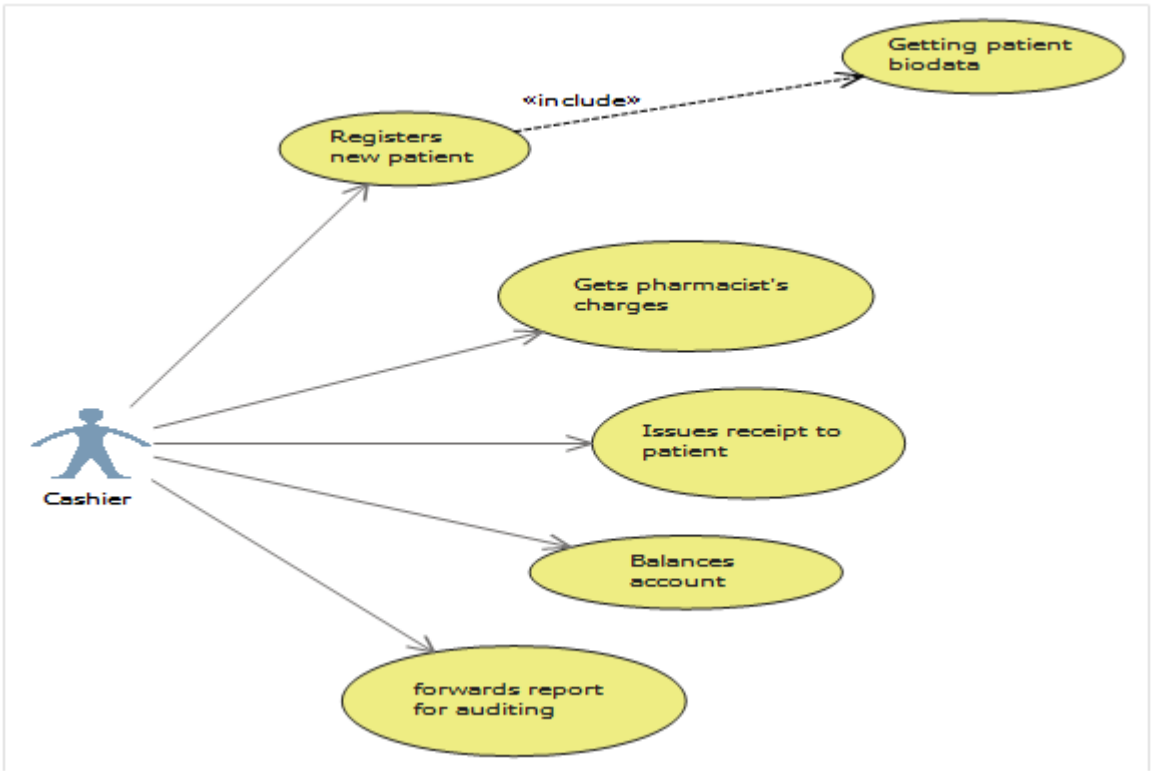

Figure 9: Cashier Role Use Case Diagram

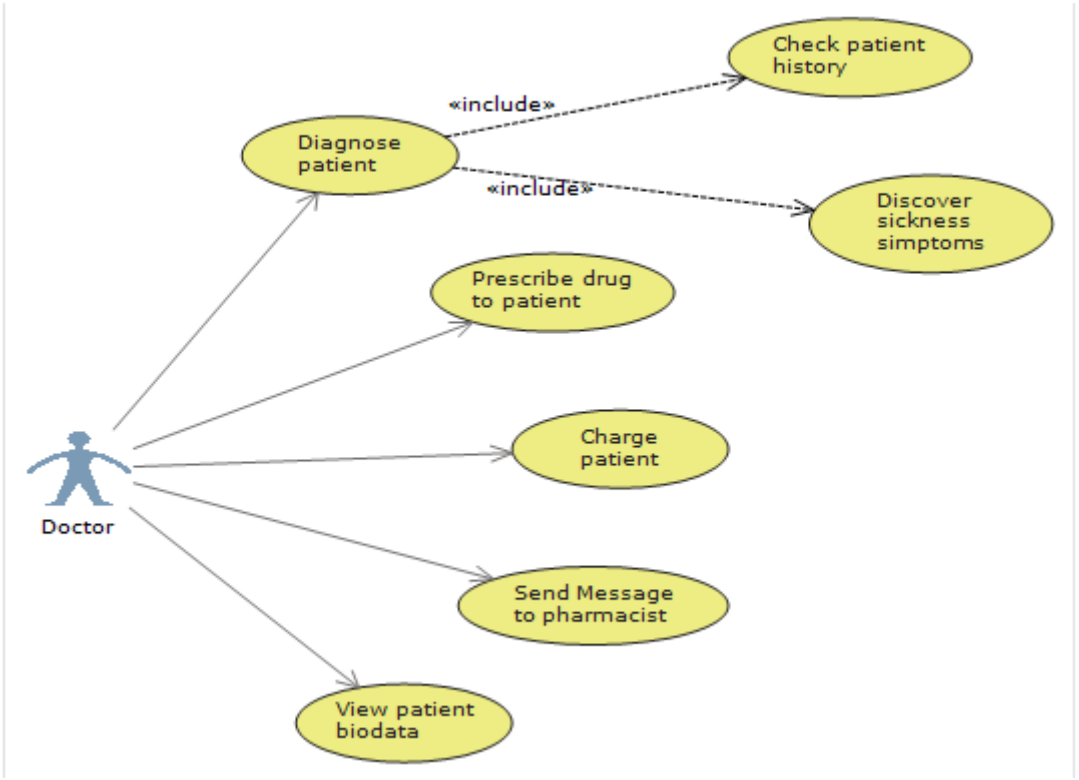

Figure 10: Doctor's Use Case Diagram

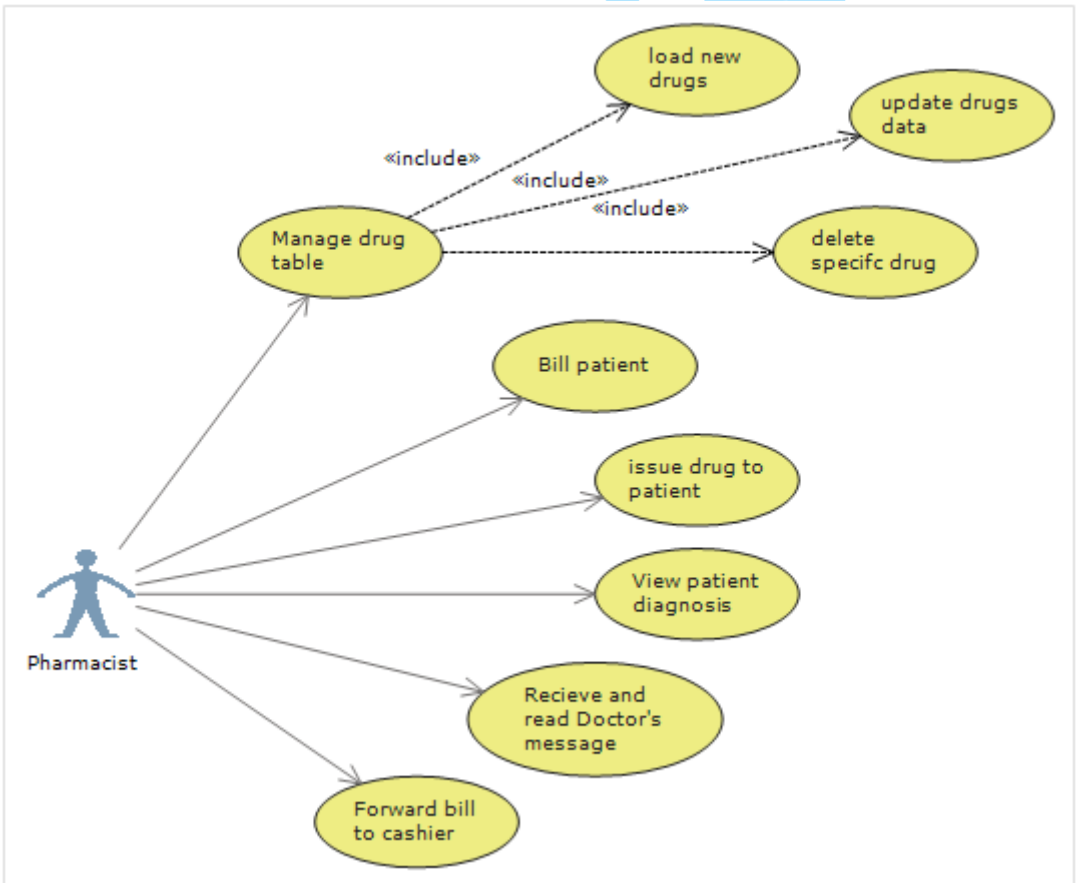

Figure 11: Use Case Diagram for the Pharmacist Role

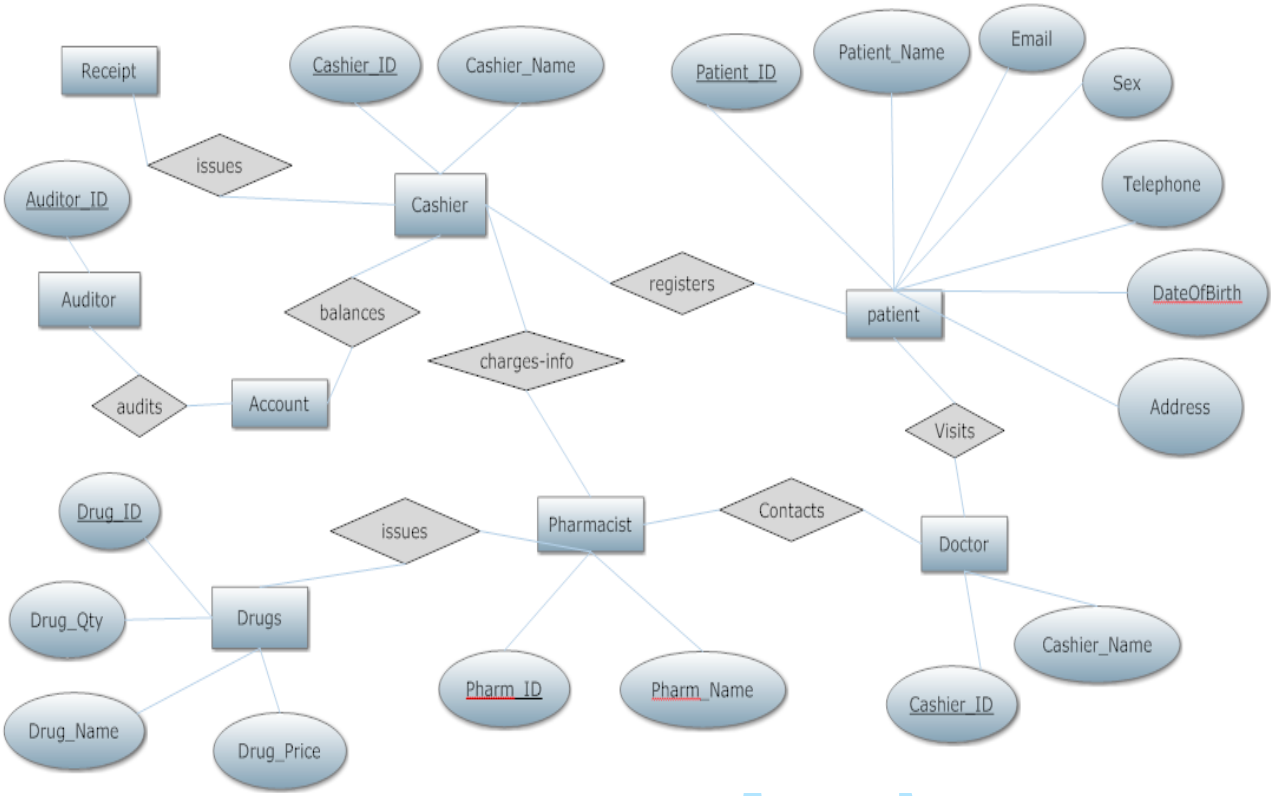

Figure 12: Entity Relationship Diagram for e-HAMS

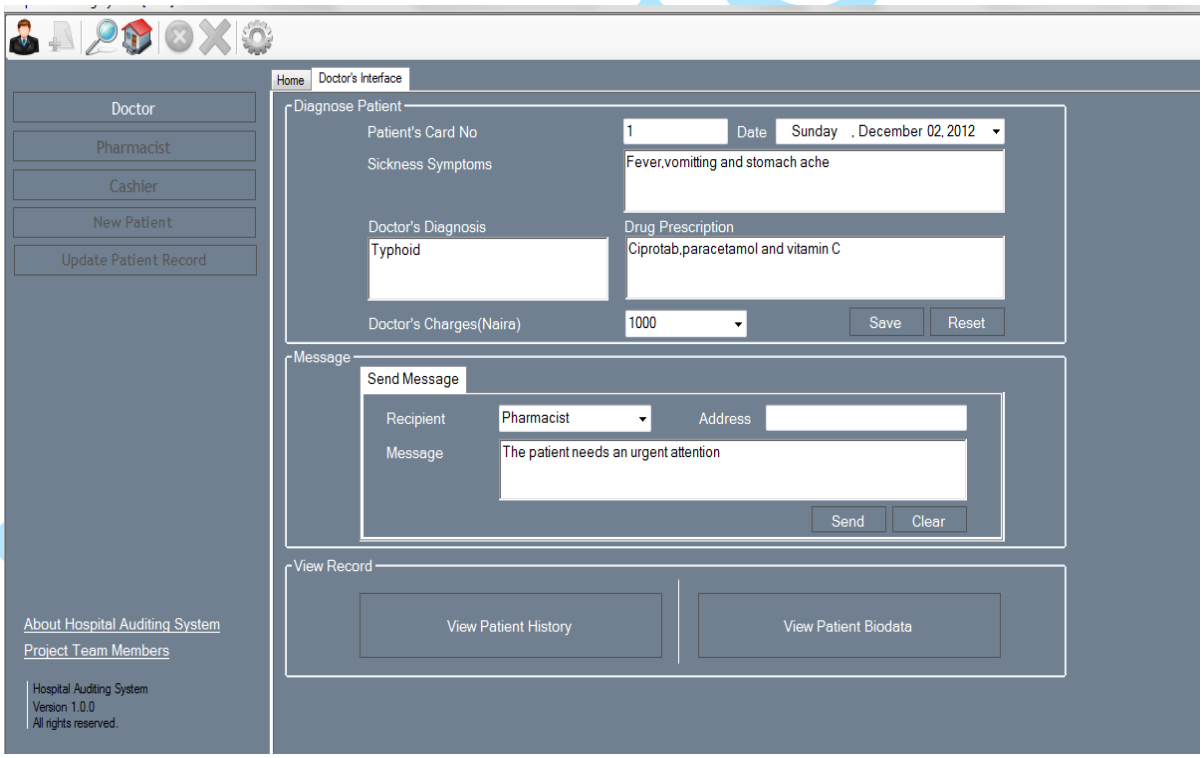

Figure 13: Sample e-HRMS' Doctor's interface

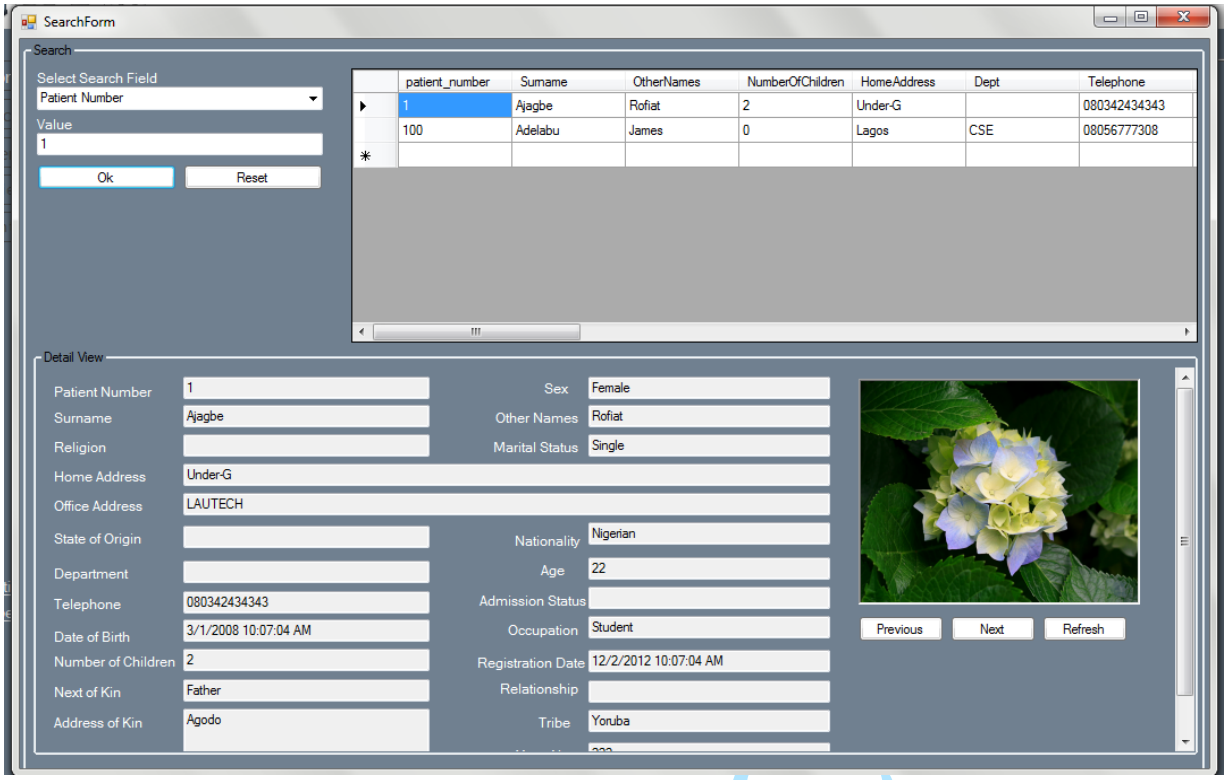

Figure 14: Sample e-HRMS' patient biodata interface

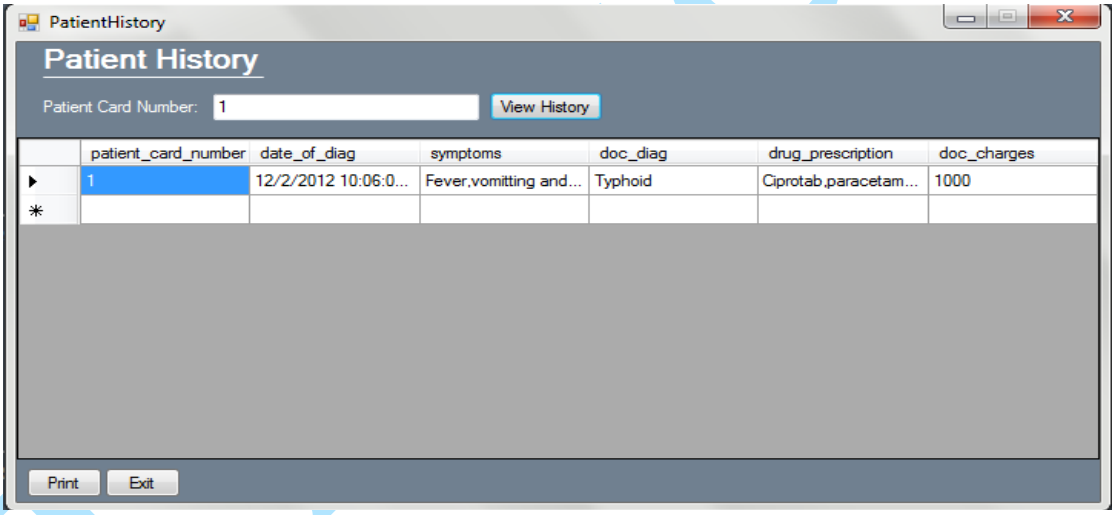

Figure 15: Sample e-HRMS' patient's history interface

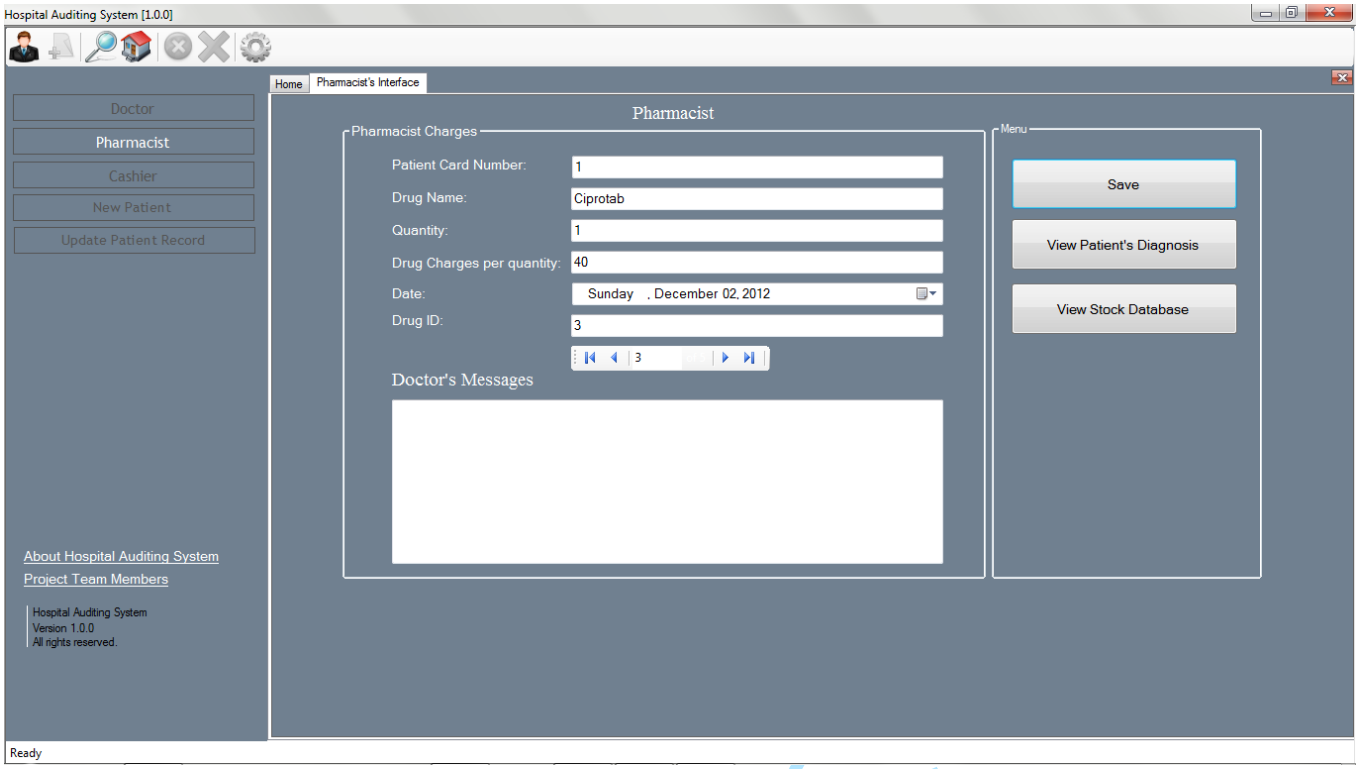

Figure 16: e-PSMS Sample Interface

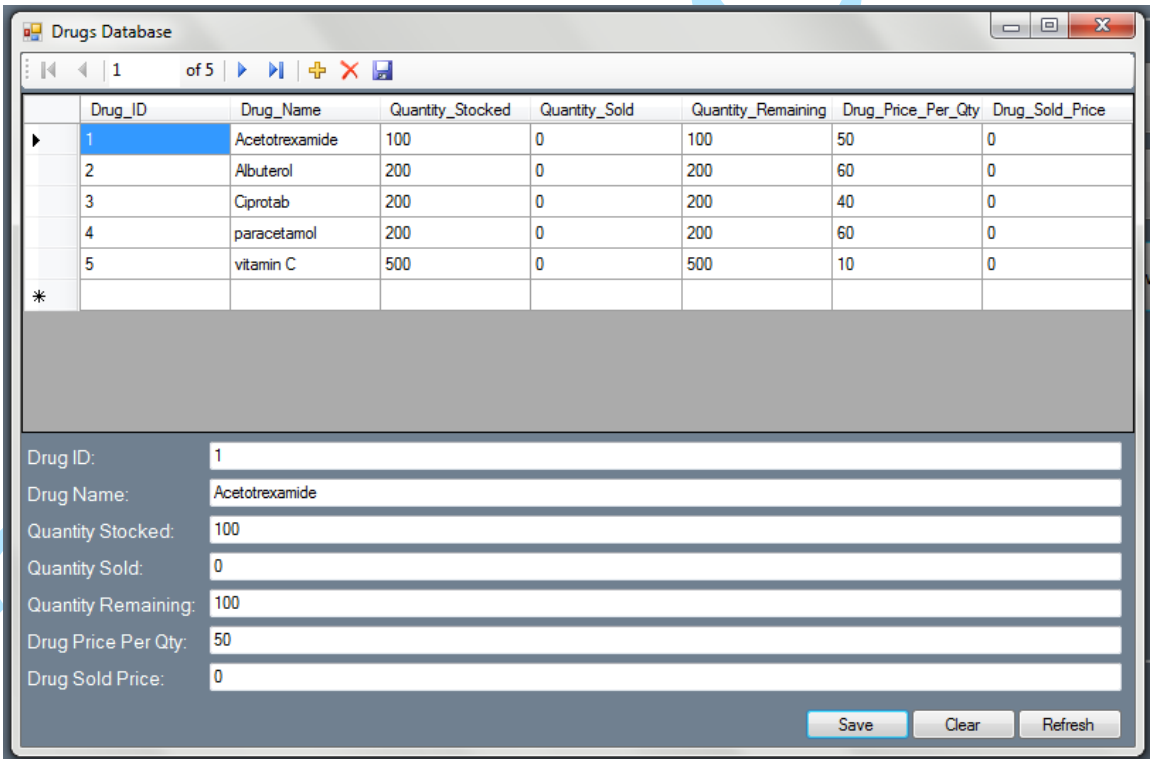

Figure 17: e-CFAudit Sample Stock Interface

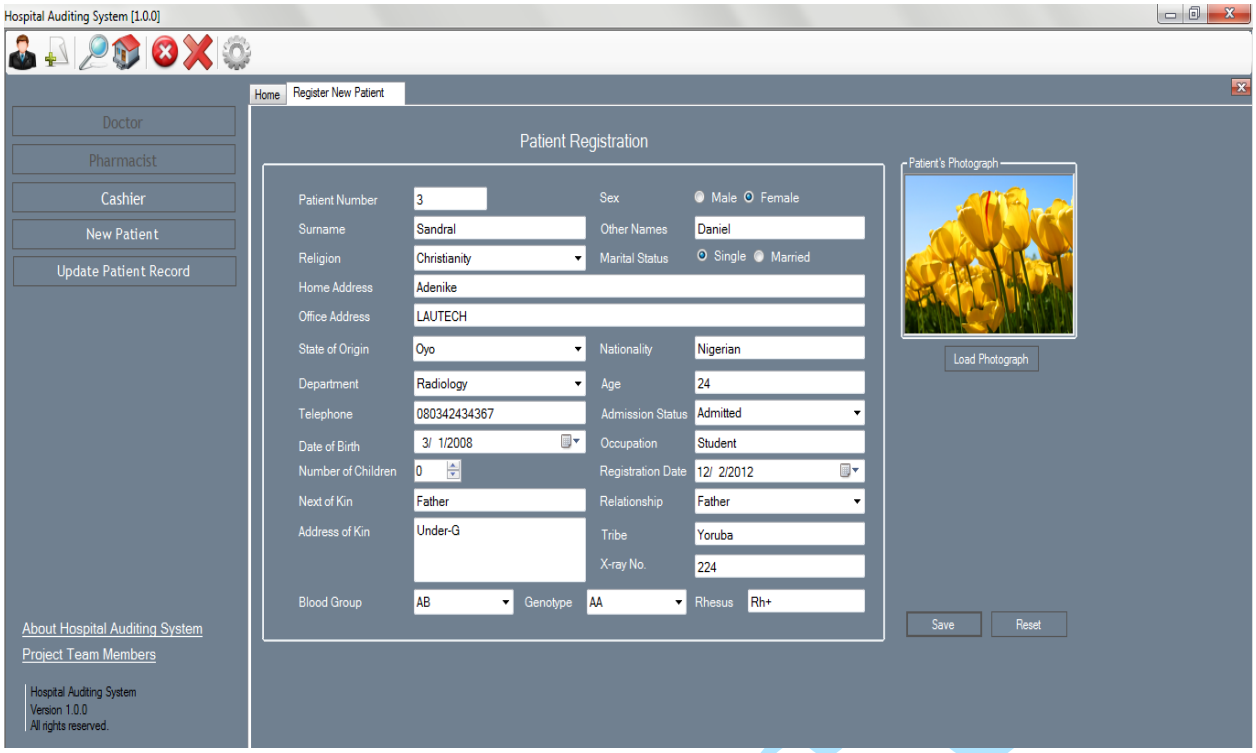

Figure 18: Patient Registration Interface

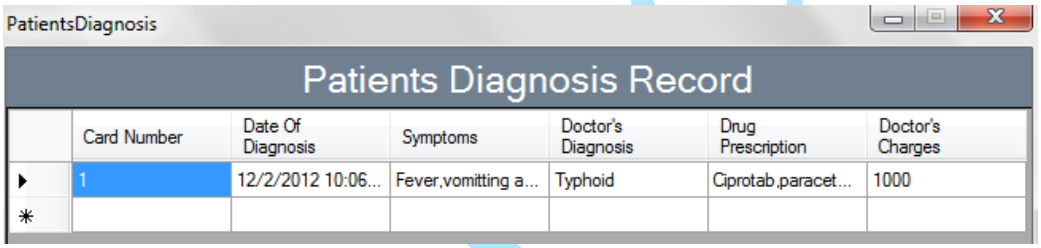

Figure 19: Sample Patients' Diagnosis and Prescription Record

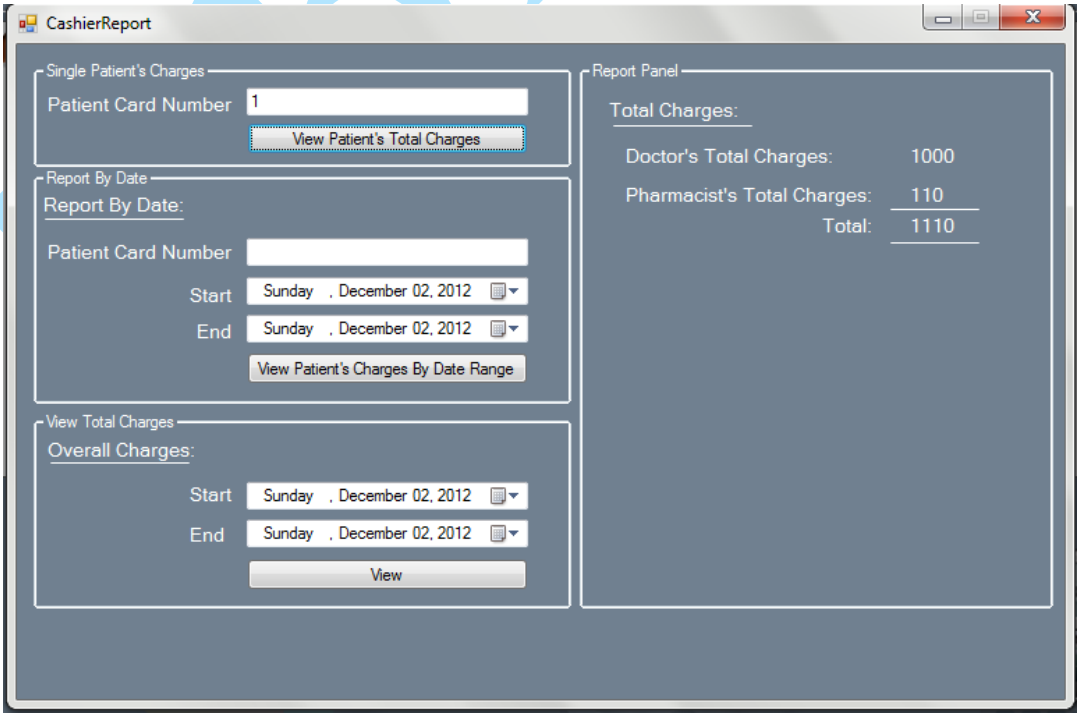

Figure 20: Sample e-CFAudit Auditing Process of doctors' and the pharmacists' charges

The Patients Diagnosis Record (figure 19) This contains doctor's diagnosis history of each patient with details including consultation charges, symptoms, diagnosis, prescription and date of the diagnosis.

iv. *Software integration*

At this stage, e-HRMS, CFAudit, e-PRMS, e-PSMS and e-HPCS developed at the previous stage were integrated together through a common web interface and tagged as e-HAMS.

v. *Testing*

Users' evaluation of e-HAMS was conducted in terms of cost savings, quality assurance, ease of use, security, privacy, user friendliness, user interface design, availability, reliability.

vi. *Deployment*

e-HAMS is available as an intranet system in low-income settings, even though, internet and cloud-based migrations are possible in middle-income healthcare services delivery environments. As tested, a computer with Windows 7 Ultimate 64-bit operating system, AMD Athlon (tm) X2 DualCore T3200 central processing unit, a speed of 2.2GHZ, 6GB random access memory and 500GB hard disk drive is capable to host e-HAMS as an intranet server.

4 RESULT AND DISCUSSIONS

The 400 health workers that earlier conducted e-HAMS's needs assessments were requested to evaluate the post-implementation performance of e-HAMS in terms of the aforementioned metrics. Using simple percentages to analyze the user evaluation data, it was observed from the results obtained as presented in Figure 22 that the cost savings benefit of e-HAMS is rated at 96%, quality assurance (86%), security (89%), privacy (90%), user interface design (82%), user friendliness (76%), ease of use (78%), availability (90%) and reliability (92%).

Figure 21: Integrated e-HAMS interface

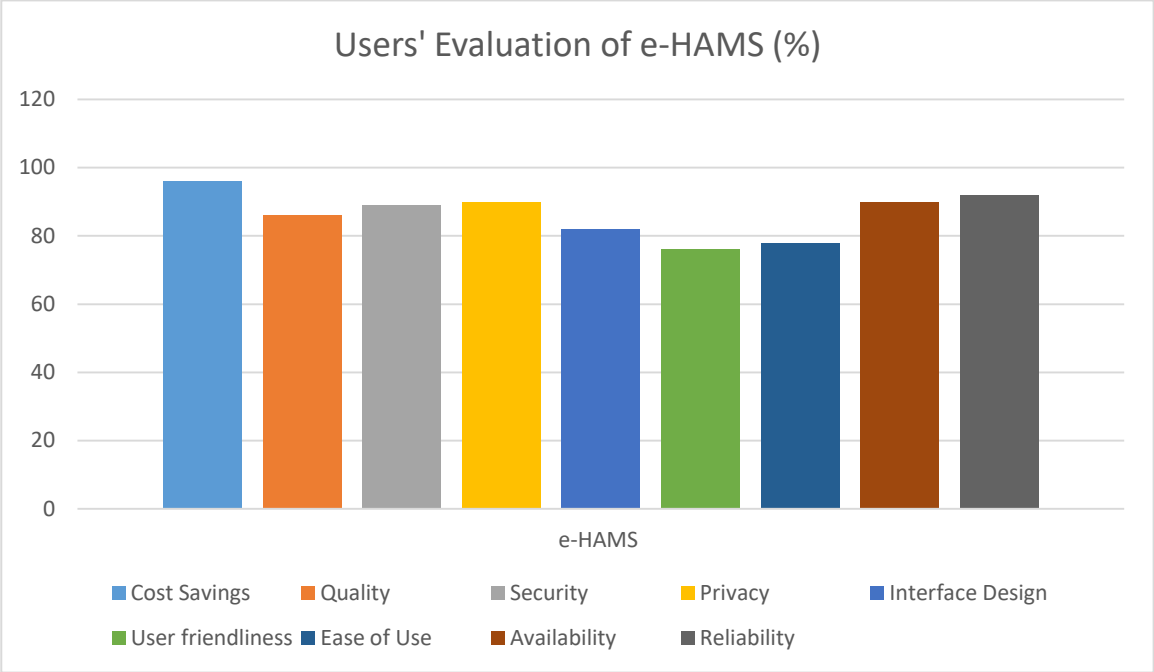

Figure 22: Users' Evaluation Results of e-HAMS

5 CONCLUSION AND RECOMMENDATIONS

In this paper, e-HAMS was developed incorporating other five (5) sub-systems namely. It was shown that integrating health services' applications is the most promising approach to obtaining maximum cost-savings and improved quality-of-care on one hand and the effective transformation of healthcare services' delivery and management on the other hand. With this holistic approach, inefficiencies in the healthcare services delivery can be completely eradicated. This paper has also proven that sustainability, quality-of-service delivery, cost, availability and accessibility in the rapidly changing ICT-in-healthcare environments can easily be evaluated and managed if an integrated approach to the development of healthcare services and management applications is adopted. However, for continuous availability and uninterrupted e-HAMS' services in case of anticipated server or hardware failure, fault tolerance approach like triple modular redundancy can be implemented. Furthermore, in other to manage the growing ubiquity of similar and decentralized e/m-Healthcare applications, future research works could develop theoretically-proven learning frameworks and systems that can facilitate coordinated and cooperative integration of many these disparate and decentralized healthcare applications and technologies. The metadata and the semantic web ontologies of such frameworks could also be developed. In the same vein, generic healthcare frameworks and architectural models that can offer flexible capacity for healthcare systems to scale, reconfigure, redevelop and integrate their intrinsic logical entities and external structures (including software features and interfaces) must be developed to make ICT intervention in healthcare services and management to become more cost-effective, efficient, sustainable, accessible and available. Future works can develop cost-effective health frameworks and models that can foster seamless integration of heath applications. Integrated health systems' policies should be implemented after they are ascertained for objective values offering.

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