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Changing Care Paradigms: A Pilot Study on User-Interface and Design Implications on the Efficacy of Medical Record Systems in Low-Resource Settings

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Abstract

Electronic Medical Record Systems (EMRS) has quickly become the backbone of the healthcare delivery ecosystem in developed countries. Their reaches range from insurance to billing to physician charting. Despite the mainstream use of EMRS in developed countries, their implementation in low-resource settings has faced more barriers and challenges. During the development of EMRS, the concerns, hurdles, and considerations of developed nations are what were used as inspiration when designing these systems. This thesis explores the use of effective User Interface and User Experience (UI/UX) design to help lower the accessibility barriers associated with EMRS implementation and usage in low-resource settings. Through this thesis, a pilot study was done on 10 users to assess how the proposed EMRS with the necessary UI/UX design implementations would impact the operational efficiency in low-resource settings. The pilot study was based on the workflow in a cancer clinic in Botswana to assess how UI/UX changes would expedite and ease care delivery in such settings with limited healthcare professionals and technology. The study compared the ease of use and efficiency of the proposed system with a commonly implemented, free open-source EMRS, known as “OpenEMR”, using both quantitative and qualitative approaches. Through the results obtained, it was shown that the proposed workflow was able to reduce workflow times by up to 300% for commonly done tasks such as data entry and data retrieval across both highly experienced and novice EMRS users.

Keywords

EMRS. electronic medical record systems, low resource settings, developing countries, medicine, operations, decision-making

Disciplines

Business Administration, Management, and Operations | Data Storage Systems | Diagnosis | Digital Communications and Networking | Operations and Supply Chain Management | Quality Improvement | Systems and Integrative Engineering | Telemedicine

Changing Care Paradigms: A Pilot Study on User-Interface and Design Implications on the Efficacy of Medical Record Systems in Low-Resource Settings

By

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Table of Contents

Abstract

Electronic Medical Record Systems (EMRS) have quickly become the backbone of the healthcare delivery ecosystem in developed countries. Their reaches range from insurance to billing to physician charting. Despite the mainstream use of EMRS in developed countries, their implementation in low resource settings has faced more barriers and challenges. During the development of EMRS, the concerns, hurdles, and considerations of developed nations are what were used as inspiration when designing these systems. This thesis explores the use of effective User Interface and User Experience (UI/UX) design to help lower the accessibility barriers associated with EMRS implementation and usage in low-resource settings. Through this thesis, a pilot study was done on 10 users to assess how the proposed EMRS with the necessary UI/UX design implementations would impact the operational efficiency in low-resource settings. The pilot study was based on the workflow in a cancer clinic in Botswana to assess how UI/UX changes would expedite and ease care delivery in such settings with limited healthcare professionals and technology. The study compared the ease of use and efficiency of the proposed system with a commonly implemented, free open-source EMRS, known as “OpenEMR”, using both quantitative and qualitative approaches. Through the results obtained, it was shown that the proposed workflow was able to reduce workflow times by up to 300% for commonly done tasks such as data entry and data retrieval across both highly experienced and novice EMRS users.

Introduction

Electronic Medical Record Systems (EMRS) have quickly become the backbone of the healthcare delivery ecosystem in developed countries with its reaches ranging from insurance to billing to physician charting. An EMRS has many different variations and technical implementations that essentially allow "health-related information on an individual [to] be created, gathered, managed, and consulted by authorized clinicians and staff within one health care organization" (*Personal Health Records, Electronic Health Records Key to India's National Digital Health Mission Comment Letter | HIMSS*). Traditionally healthcare records have been kept on paper, however, multiple catalysts all over the world have promoted different regions to adopt an EMRS due to its many benefits. For example, in the US, Hurricane Katrina of 2005 was a crucial catalyst that led to the widespread adoption of EMR systems as people lost many things — including detailed patient records spanning decades. However, despite the mainstream use of EMRS in developed countries, their implementation in low resource settings has faced even more barriers and challenges. During the development of EMRS, the concerns, hurdles, and considerations of developed nations are what were used as inspiration when designing these systems (Kasthurirathne et al.). Consequently, the constraints placed in developing nations have not been considered, resulting in the development of EMRS systems that are not optimal for low resource settings (Kasthurirathne et al.; *Community Health Information and Tracking System (CHITS): Lessons from Eight Years Implementation of a Pioneer Electronic Medical Record System in the Philippines | Acta Medica Philippina*). Additionally, the stakeholders considered in this development process are not representative of the workforce constraints present in low resource settings, resulting in the development of less streamlined workflows that are unfeasible to be implemented in low resource settings (Sood et al.). Consequently, there is a growing need to identify which metrics can be used to optimize the use, scalability, and deployment of EMRS in low resource settings.

Literature Review

Benefits of Using EMRS in Low Resource Settings

According to the work of Oluoch et al. and Driessen et al., EMRS systems, even in low resource settings, have documented benefits in improved quality of care, reduction in loss-to- follow-up, and increased efficiency. Furthermore, it has also been demonstrated that EMRS systems facilitate the automatic collection of certain data from patients with a higher degree of accuracy than manual collection whilst saving human resources (Wright et al.). EMRS systems implemented with efficient and effective data retrieval systems have been identified in improving productivity and enabling critical tasks such as patient case synthesis and research data abstraction (Hanauer et al.). According to the work done by Hanauer et al., an analysis of 43 EMR studies has shown that there is a 51% chance that an EMR can improve office practice. When grouped by area, there were modest improvements in preventive care (66.7%), work practice (64.3%), and disease management (57.1%).

Studies have also shown that EMR systems do not only influence how patient records are managed but also how they communicate with each other to provide patient care services and perform job-related tasks (Wager et al.). EMRS also provide immediate cost benefits through the elimination of the duplication of data prevalent in paper-based systems (Wager et al.). Studies have shown that there is a return on investment in low-resource settings after 3 to 5 years of implementing an EMRS (Wager et al.).

Concerns of Using EMRS in Low Resource Settings

Financial Barriers to Implementation

Developing nations are forced to navigate the struggles of managing growing populations with limited resources. These strains are further felt in resource-straddled healthcare systems. One of the biggest barriers to implementing an EMRS is the high cost associated with it. Additionally, the supporting infrastructure, such as appropriate network and computer hardware, needs to be purchased alongside a new EMRS. Furthermore, appropriate in-house technical support teams need to be incorporated into the system such that crucial patient data is not lost. All of these added costs further exacerbate the implementation barriers already faced by developing countries (Hillestad et al.).

These issues are continually propagated as EMRS providers develop their systems in line with the needs of developed countries and not with the needs of developing countries. As a result, most of these systems are not engineered to run on cheaper, less powerful equipment that would otherwise make the financial barriers to implementation more manageable for developing nations.

To this extent, these financial barriers can be circumnavigated if EMRS systems conducted a comprehensive analysis of the available equipment across developing nations to develop a novel EMRS or repurpose older EMRS to provide the same essential features at a lower price point with significantly lower equipment related barriers to entry (Williams and Boren).

It is also important to note that developing countries are dependent on foreign aid to help develop the infrastructure in their countries. Consequently, these developing countries would have to face strict regulations when applying for and using these funds. Concerning EMRS implementation, this creates the added complexity of having to navigate legal and financial regulations to ensure the satisfaction of both parties involved in the agreement. This is not the case with developed countries that have enough funds to fund their EMRS without having the added complexity of navigating negotiations. This translates to higher legal fees, bureaucracy, and time costs for developing countries when implementing an EMRS (Thapa).

To this extent, a viable solution would be the intervention of the World Health Organization (WHO) to select and deploy a standardized EMRS across developing nations. The WHO can mandate the standard equipment and software needed to implement an EMRS such that foreign aid-giving countries know what they would need to provide ultimately resulting in the removal of the financial and legal burdens faced by developing countries in navigating negotiations. Traditionally, WHO has developed frameworks to improve the effectiveness of health aid through "Sector-wide approaches (SWAps)" and "Global Health Partnerships (GHPs)" (*What We Do | WHO*). An addendum to these frameworks recognizing the importance of EMRS on medical outcomes would lay the groundwork to navigate the aforementioned barriers.

Technical Barriers to Implementation

There are numerous organizational, cultural, and environmental factors to be considered between developed and developing nations. Consequently, an EMRS built for developed countries would have features that are not needed for developing countries and vice versa. For instance, certain diseases are more endemic in developing countries such as malaria or dengue. Consequently, an EMRS implemented in such countries should have charting features and notations to aid and ease in capturing such cases in the EMRS (*Community Health Information and Tracking System (CHITS): Lessons from Eight Years Implementation of a Pioneer Electronic Medical Record*

System in the Philippines | Acta Medica Philippina). However, most EMRSs provide a generalist approach to patient charting that increases the work needed to capture these endemic diseases and further burden the healthcare systems of developing countries.

These issues are further exacerbated due to the lack of standardization in current EMRS products on the market. As a point of reference, in the US alone, there are 280+ offerings of EMRS which do not always guarantee interoperability with other EMRS (Kasthurirathne et al.). As a result, it becomes increasingly difficult to gauge the system requirements needed to run such an EMRS and makes implementing an EMRS increasingly more complex. For example, if a particular clinic chooses one particular EMRS earlier in the adoption period while another clinic adopts a different system later, there is a reasonable possibility that the records cannot be exchanged between these systems (Thapa). If these issues are framed in the context of developing nations, due to resource limitations, an EMRS would be rolled out in phases across the different hospitals in the country. Inevitably, this process could take years with each phase of the rollout adopting new equipment and hardware. Consequently, due to the lack of standardization, a systematic roll-out of EMRS is no longer a viable option as there is a high probability of incompatibility between EMRS implemented at different phases. Therefore, developing nations are forced to either adopt a system across all their hospitals at once or not at all.

To circumnavigate these hurdles, common research can be conducted to consolidate the needs of developing nations concerning EMRS. This open set of data should lower the barriers to developing appropriate software. In tandem, the WHO could establish certain standards alongside other regulatory bodies to ensure that EMRS have the basic features of interoperability and thus make a systematic rollout of an EMRS viable (Kasthurirathne et al.; *What We Do | WHO*).

The availability of steady electricity in developing countries is another concern. In many developing nations, the main forms of power generation are dependent on sustainable methods such as hydroelectricity, solar panels, and windmills (*Data Redundancy - an Overview | ScienceDirect Topics*). Despite the obvious environmental benefits associated with these technologies, power generation isn't always guaranteed with potential power outages caused by non-ideal environmental factors. Consequently, an EMRS developed for developing nations should consider unique data storage and retrieval systems that incorporate multiple backups to prevent data corruption during power outages and universal data retrieval systems such that a health record could be accessed via a mobile phone or a battery-powered device during a power outage. Given the sensitivity of the patient health records being stored, it is of paramount importance to have data redundancy features incorporated when implementing an EMRS, especially in countries with inconsistent means of powering equipment. These data redundancy protocols require additional equipment such as extra hard drives to store backups as well as heavy-duty networking infrastructure to support concurrent access to the patient records and backing them up.

Navigating data redundancy would be a country-specific ordeal and is less straightforward than finding solutions to the previous barriers. Given that data redundancy is a resource-limited problem, the only solution is to be able to finance additional storage space (*Data Redundancy - an Overview | ScienceDirect Topics*). To this extent, EMRS could be developed with compression protocols to reduce the footprint of each record (*Compressing Medical Records for Storage on a Low-End Mobile Phone*).

Additionally, cloud computing solutions could be used to offload less frequently accessed data from local storage (*Cloud Storage of Medical Records - MDA National*). The viability of these solutions is heavily dependent on the network infrastructure, financial limitations, and hardware accessibility of the country in question

Factors Determining Successful Integration in Low Resource Settings

Evaluation — Success Criteria

Different studies point to the various criterion to determine the extent of success of implementing a particular EMRS. Traditionally, EMRS have shown a modest improvement in productivity (63.6%), whereas user satisfaction had the least improvement (18.2%) (Hanauer et al.). About one-third of the studies and measures were not able to show an impact (Hanauer et al.). Less than one-fifth of the studies and measures had a negative impact (Hanauer et al.). No significant differences were found based on adoption rates by country, by time period, and by study design (Hanauer et al.). Due to these varying impacts, it is essential to develop a standardized evaluation criterion to identify and isolate factors surrounding successful EMRS implementation.

Given the overlap between many of these studies, the criterion can be categorized into the following seven as explained in the table below:

Table 1 Success Criteria for EMRS implementation according to current literature

Category (deRiel et al.)	**Description (deRiel et al.)**
Functionality	System Features (E.g.: Data Handling and Reporting), 'Fit Factor', 'Ease of Use'

Technical	Infrastructure Requirements, Software Architecture, Data Standards, Privacy/Security, Responsiveness
Organizational	Managerial Effectiveness in Leadership and Governance concerning staff involved with the EMRS
Training	Computer Literacy, Educational Background, User Support
Political	Countrywide Policies, General willingness to change, Extent of Political Involvement in the Healthcare System
Ethical	Privacy/Security, Regulations, Cultural Concerns
Financial	Return of Investment, Cost Implications/Funding
Sustainability	Ability to transfer system with stakeholder progression, adaptability of EMRS, scalability of EMRS

The criteria proposed here provide a detailed look into the externalities produced by an EMRS. Given how many different workflows an EMRS affects, to adequately assess the benefits of using an EMRS must be assessed over a broad range of factors.

Key Takeaways from Implementation

1) Importance of Design

Interface and Template Design play a pivotal role in reducing time spent on information retrieval and capture (Lau et al.). With curated, workflow-specific designs, EMRS can be designed to reduce training time and improve the speed of access to pertinent health data (Lau et al.). It has been estimated that design improvement could reduce time-on-task by saving an average of 21 hours of hospital physicians' time over the course of a month (Kuqi et al.). Such savings can be achieved using the Design Structure Matrix (DSM) Modeling technique to improve the design of EMRS. DSM techniques bring attention to the elements of a complex system and their relationships to provide deeper insights into the design and optimization of complex systems ("The Design Structure Matrix (DSM)").

2) Technical Performance

The EMRS system needs to be fast and reliable in its ability to store and retrieve data (Lau et al.). To ensure optimal data handling, the technical architecture and infrastructure should be robust enough to handle the demands of the system (Lau et al.). The EMRS must be designed in such a way that it remains scalable whilst taking into consideration of the hardware/infrastructure that is available in a particular locale (*Data Redundancy - an Overview | ScienceDirect Topics*). Two important factors that need to be considered are the availability of reliable power and networking infrastructure (*Data Redundancy - an Overview | ScienceDirect Topics*).

3) Creating a "best fit" workflow

An EMRS needs to adapt to and improve on the existing workflow, to ensure sustainable and long-term adoption of an EMRS in a low resource setting (Lau et al.). Having transparent and standardized protocols would aid in ensuring the long-term use of the system (Kasthurirathne et al.). Furthermore, clear documentation of the workflow would aid in reducing training times (Murphy). Furthermore, comprehensive handover strategies would need to be devised to ensure that once a pilot has been conducted, the system can easily migrate to daily use. The devised workflow should have room to scale as needs change over time. Having specified time frames for review with a pre-determined review scope would ensure that an EMRS can be adapted as time progresses to ensure that the EMRS would continue to be successfully integrated (Newton et al.). The importance of this is further highlighted as the availability of resources is in constant flux in low resource settings (Fritz et al.; *Data Redundancy - an Overview | ScienceDirect Topics*). To avoid any possible harm, healthcare-related IT projects need to be carefully planned in line with industry best practices (Fritz et al.).

4) Demonstrate Value for Money

To ensure widespread adoption of an EMRS, a combination of patient outcomes and financial incentives would need to be incorporated. By leveraging "pay-per-performance" schemes with Chronic Disease Managements or improving patient safety, a convincing case can be made to improve the adoption of the EMRS among the staff (Lau et al.).

5) Adequate Resourcing and Time

The importance of adequate technical infrastructure and resources has been explored earlier. Similarly, there should be adequate availability of human resources such that the staff using the EMRS, such as nurses, physicians, and administrators, have the right skills to ensure high efficiency (Lau et al.). Strong project management and commitment must be present from decision-makers that choose what EMRS to implement through the provision of ample training programs as well as a comprehensive support structure (Lau et al.). This would ensure a positive attitude amongst users contributing to the overall sustainability of the project. Concerning support structures, a strong technical support team should also be included to minimize downtime (Wager et al.). Effective leadership, the presence of a system champion, availability of technical training and support, and adequate resources are essential elements to the success of the EMR (Wager et al.; Murphy).

6) Systems should Engage Patients

Research done by Asch et al. has identified that the best practices that improve healthcare delivery include the implementation and design of technology that engage the patients as much as it engages healthcare staff. So, in the case of EMRS, it would be beneficial to have patients engaged in the workflow as it can create positive externalities such as improved adherence to schedules and treatment protocols (Murphy). Additionally, it can reduce the resources allocated to patient management as patients would be more proactive about their health (Asch et al.).

7) Defining Operating Budgets
Most projects are donor-funded or are pilot studies. Without a stable funding source, projects can become derailed before the return on investment is realized resulting in a negative attitude towards the use of EMRS systems (Fritz et al.).

Study Design in Low Resource Settings

It is important to note that a wide range of studies focusing on low resource settings is based in Africa and Asia. "Most papers were evaluations or lessons learned from African countries, published from 1999 to 2013" (Fritz et al.). A vast majority of these studies looked at specific disease areas such as HIV (Fritz et al.).

Furthermore, the installed EMRS are based on open-source systems which often only possess the basics. In one study, approximately 45% of the analyzed papers had open-source EMRS implemented (Fritz et al.). These systems still pay attention to privacy, security, use of standards, and special user requirements (Fritz et al.). A ground-up approach to developing an EMRS for a particular low resource setting has not been adequately studied. Namely, current literature has not identified whether such an approach would result in better outcomes than simply adapting an open-source system to a low resource area.

A common limitation seen across different studies is that important global information was usually missing such as the number of users, the amount of data being processed, the funding source for the EMRS project, or for how long the EMR system has been used (Fritz et al.). The lack of large quantitative data sources results in the employment of largely qualitative methods such as semistructured interviews and observations (Ehrenstein et al.). This limits the extent of analysis that can be performed given that an EMRS already tracks the global information.

OpenEMR

OpenEMR is the most popular open-source electronic health records and medical practice management solution currently available (*OpenEMR*). The core features of OpenEMR pivot around its open-source nature which has allowed it to create a highly interoperable solution. It envisions competing with more expensive EMRS offerings by keeping the software free to use and supported through its network of volunteers and contributors (*OpenEMR*). These individuals aid with answering questions on deployment & maintenance to engineering new features. Currently, OpenEMR supports 30 languages and has 30 vendors in 10 different countries that handle deployment and customer service. These countries include the US, Argentina, Canada, France, Greece, Hong Kong, India, Kenya, Nepal, Puerto Rico, Singapore, Southern Africa, Uganda, and the UK (*OpenEMR)*. Furthermore, OpenEMR supports numerous features that are standard in off-the-shelf EMRS such as scheduling, e-prescribing, medical billing, Centers for Medicare & Medicaid Reporting (required for US deployment), lab integration for ordering results & tests, automated clinical decision support rules, and advanced security including HIPAA compliance.

OpenEMR was first developed by Synitech with the first version released in June 2001 as MedicalPractice Professional (*The OpenEMR Community - OpenEMR Project Wiki*). A year later on 13th August 2002, OpenEMR was released as an open-source project and was consequently registered on SourceForge ("OpenEMR"). Despite its widespread community support and volunteer-based development, there were almost 30 security flaws in the OpenEMR system found by Project Insecurity in 2018 ("Health Records 'Put at Risk by Security Bugs'"). Since then, these issues have been addressed but the open-source nature of the system means that it is hard to verify the integrity of the security of all deployed solutions.

Data & Methodology

Overview

A pilot study was done to assess how the proposed EMRS with the necessary UI/UX design implementations would impact the operational efficiency in low-resource settings. The pilot study was based on the workflow in a cancer clinic in Botswana to assess how UI/UX changes would expedite and ease care delivery in such settings with limited healthcare professionals and technology. The study compared the ease of use and efficiency of the proposed system with a commonly implemented, free open-source EMRS—known as "OpenEMR"— using both quantitative and qualitative approaches.

Proposed System Architecture

The proposed system is a highly specialized EMRS designed with the workflow of a Botswana cancer clinic kept in mind. The application was designed using Google's Flutter development library which utilizes the Dart language. The benefit of using Flutter is that it allows developers to manage one single codebase that can easily be deployed on a plethora of platforms including Windows, macOS, Linux, Android, iOS, and the Web. This not only expedites the development process but ensures that the system will look uniform across all platforms. The designed application leverages Google's package library that aids with quickly implementing essential services such as local, secure data storage. All the necessary mathematical calculations and logic, besides providing the UI for data entry & retrieval and API access, are handled by this Flutter application. This designed application is hosted on Heroku to allow users taking the test to log in remotely.

This application communicates with a MySQL database that securely handles all the medical records on a HIPAA compliant server in a remote location. The MySQL database is the same backbone found in the OpenEMR system. MySQL databases provide the most scalable and easy-to-implement solution on the market, based on our experiences. This database is also hosted on Heroku for secure remote access.

The frontend Flutter app communicates with the backend MySQL database using a custom-made API that handles the necessary create, read, update and delete actions on the database. This API is coded using PHP and is also hosted on Heroku for remote access.

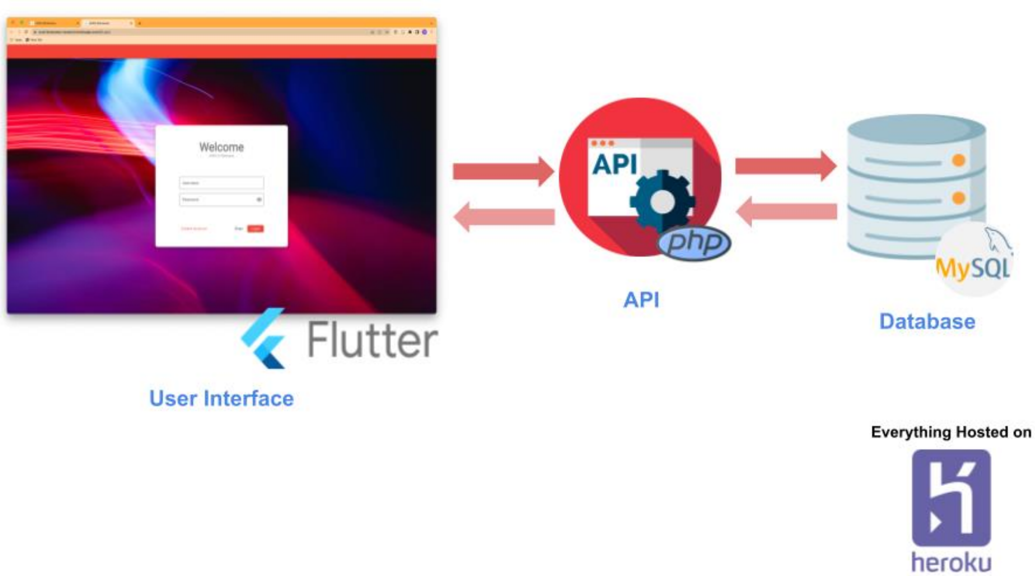

Figure 1 System architecture of the Proposed System.

The standout features of the proposed system are the implementation of intelligent search bars that predictively autofill search queries, the ability to be deployed on numerous devices, an accessible

API that can allow for interoperability with other software packages, a material design inspired visual UI, and intuitive form validation & user feedback.

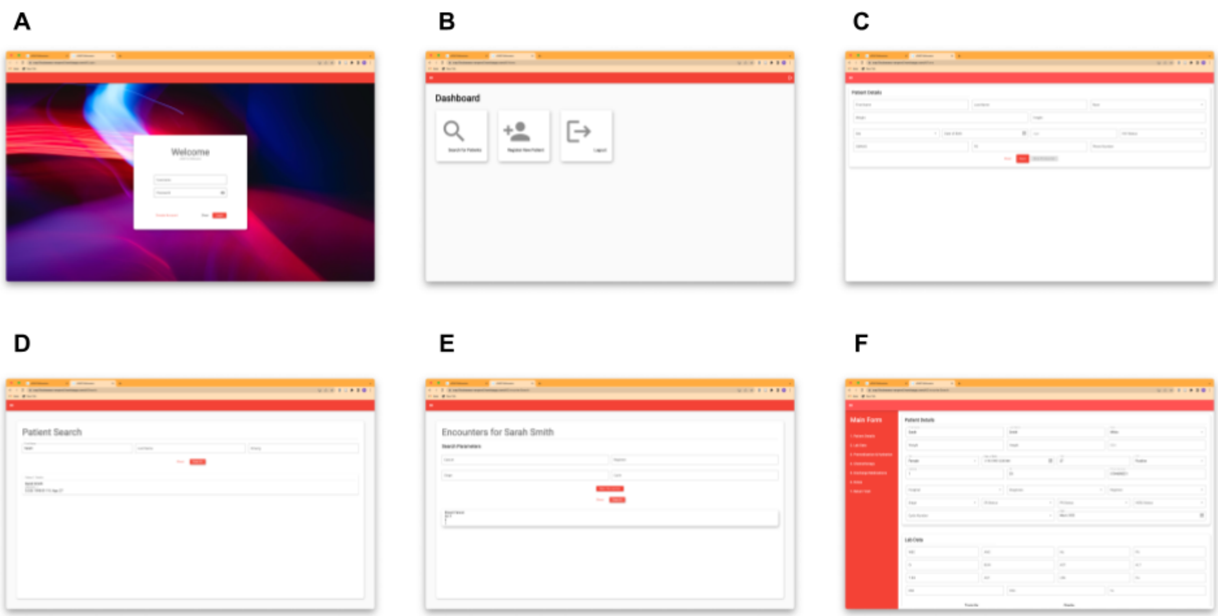

Figure 2 User Interface Overview for the Proposed System — A) Login, B) Dashboard, C) Patient Creation, D) Patient Search, E) Encounter Search and F) Add Encounter (Vitals & Laboratory Results)

OpenEMR Architecture

The OpenEMR implementation we used is the out-of-the-box, quick installation that they provided. The system was set up in under an hour on an AWS server as outlined by their instructions. The system is purely designed on PHP and handles all the logic using JavaScript with the front end designed on HTML/CSS. Consequently, OpenEMR is designed to be run as a web application with no ability to be ported to run natively on other platforms in its current state.

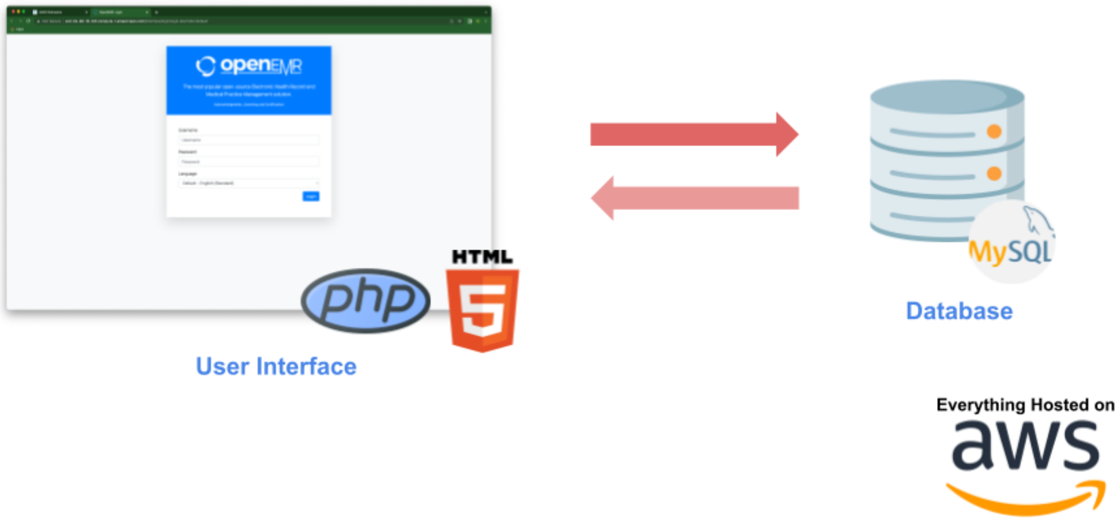

Figure 3 System architecture of OpenEMR.

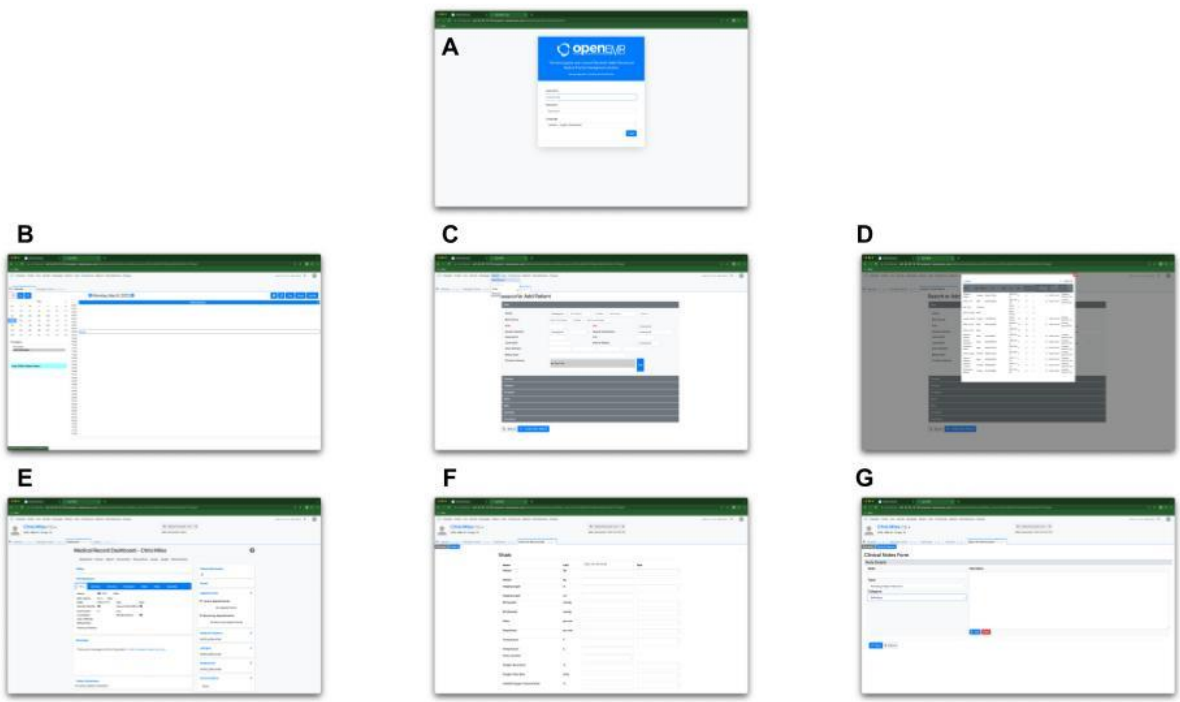

Figure 4 User Interface Overview for OpenEMR — A) Login, B) Dashboard, C) Patient Creation, D) Patient Search, E) Encounter Search, F) Add Vitals and G) Add Laboratory Results

Methodology

Qualitative Assessment

The goal of the qualitative assessment is to evaluate the user's perceptions of the proposed workflow and the OpenEMR system. Using a survey form, the users were asked to answer the questions mentioned below after the use of each system.

Using a Likert scale on the range of 1-5, the following metrics were assessed, as outlined in *Table 2*. These questions are designed to assess the speed of data retrieval, speed of data entry, visual appeal of the system, quality of data representation and quality of data visualization.

Table 2 Qualitative assessment questions using the Likert scales.

Question	Scale		
Did this electronic medical record system feel tedious to use or easy to use?	1 *Tedious*	–	5 *Easy*
Rate the visual appeal of the system between 1 to 5	1 *Bad*	–	5 *Great*
Rate the speed of data retrieval between 1 to 5	1 Slow	–	5 *Fast*
Rate the quality of the data representation between 1 to 5	1 *Poorly represented*	–	5 *Well represented*
Rate the value add of the information provided between 1 to 5	1 *Cluttered*	–	5 *Intuitive*
Rate the speed of data entry between 1 to 5	1 *Slow*	–	5 *Fast*

To identify more specifically, the parts of the workflows of each system the user found convenient, inconvenient, and time-consuming, the users were asked to answer the following short answer questions, as outlined in *Table 3*. These responses were assessed qualitatively to identify the most frequent opinions or if there was a trend to be seen.

Table 3 Qualitative assessment short answer questions.

Questions
What are the most time-consuming actions in this workflow?
What was the most convenient aspect of the current workflow?
What was the most inconvenient aspect of the current workflow?

Quantitative Assessment

The goal of the quantitative assessment is to be able to quantify the efficiency of the proposed system that would be realized through actualized time saved under usage, compared to other available EMRS such as OpenEMR.

The pilot study recorded the activity of 10 users who have varying levels of experience in the use of EMRS. Each user was given an identical set of instructions to assess the 3 commonly used functions of EMRS in the Botswana Cancer Clinic, namely – registering a new patient, searching for old patient data, and updating an existing patient's data. This timing data is instantly sent to a database to be stored and is recorded at a millisecond level. The instructions given to the users are given below in *Table 4.*

Table 4 Tasks given to the users for quantitative assessment.

Tasks
What are the most time-consuming actions in this workflow?
Name: Chris Miles Sex: Male D.O.B: 1988-07-15 Phone Number: 7504199183 Height: 178 (cm) Weight: 87 (kg) Race: White
Find the age of the patient — Sarah Smith.
Add the following encounter to the patient you created:
Neuropathy: 3 Ototoxicity: 2

The users were presented with a homepage that depicted the instructions they had to perform beforehand so that they can familiarize themselves with the tasks at hand, before conducting the test under timed conditions. When the users have been familiarized with the required instructions, they are logged in first to the OpenEMR system on a separate tab where they always have the instructions on the tab with the homepage. When the user starts the test, a timer is activated for the user to conduct the necessary action and extract the necessary information. Once each instruction is completed, the user presses the stop timer button. In one question, the user has a short answer field to fill in to deem whether the user was able to extract the right data from the system. Upon successful completion and validation of an instruction, the user can progress to the next instruction for the time needed for completion to be recorded here. This will be repeated until all three instructions have been completed and the times have been submitted. If the user feels like they are struggling and cannot do the appropriate action, the user has the option to skip the instruction and move on to the next. However, the user cannot go back and complete a previously skipped instruction.

This protocol is again repeated with our proposed system with the same instructions but varied preloaded data to ensure that the users are not validating their actions using the values they may remember from the first test.

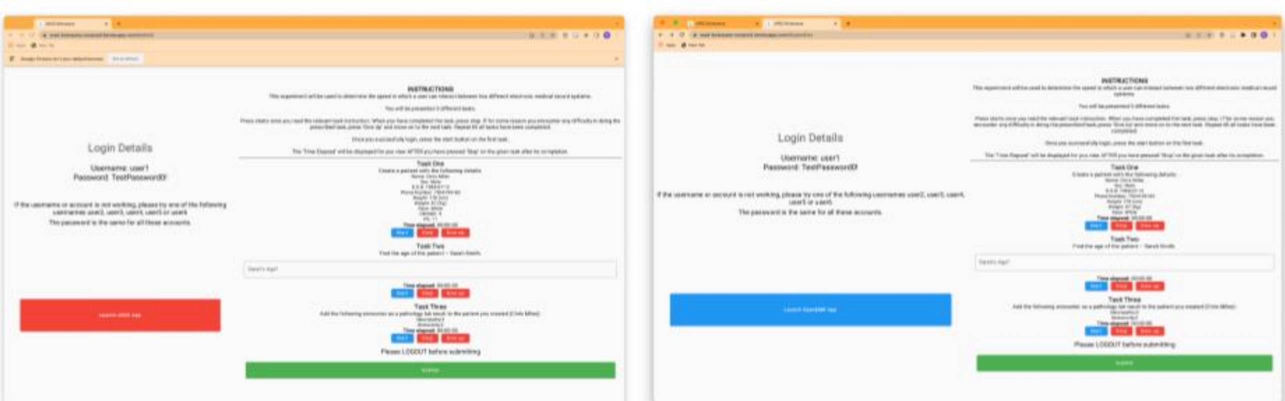

Figure 5 Instruction screens for the subjects of the pilot study — Proposed system (left) & OpenEMR (right).

Results

The following results were obtained anonymously from 10 different candidates with varying levels of experience with EMRS in general. The participants range from students to healthcare practitioners and scientists.

Quantitative Results

The results obtained can be seen in *Figure 6.* Across the board, the proposed workflow had faster times for data entry and data retrieval. However, it is important to note that data entry seems to be the biggest bottleneck on the OpenEMR system as evidenced by the higher time taken to complete tasks 1 and 3 which are data entry tasks. For the two data entry tasks, the proposed workflow provided faster interactions with more streamlined forms and easier navigation. Furthermore, it can be seen that the proposed workflow provides a faster alternative to the OpenEMR system for data retrieval.

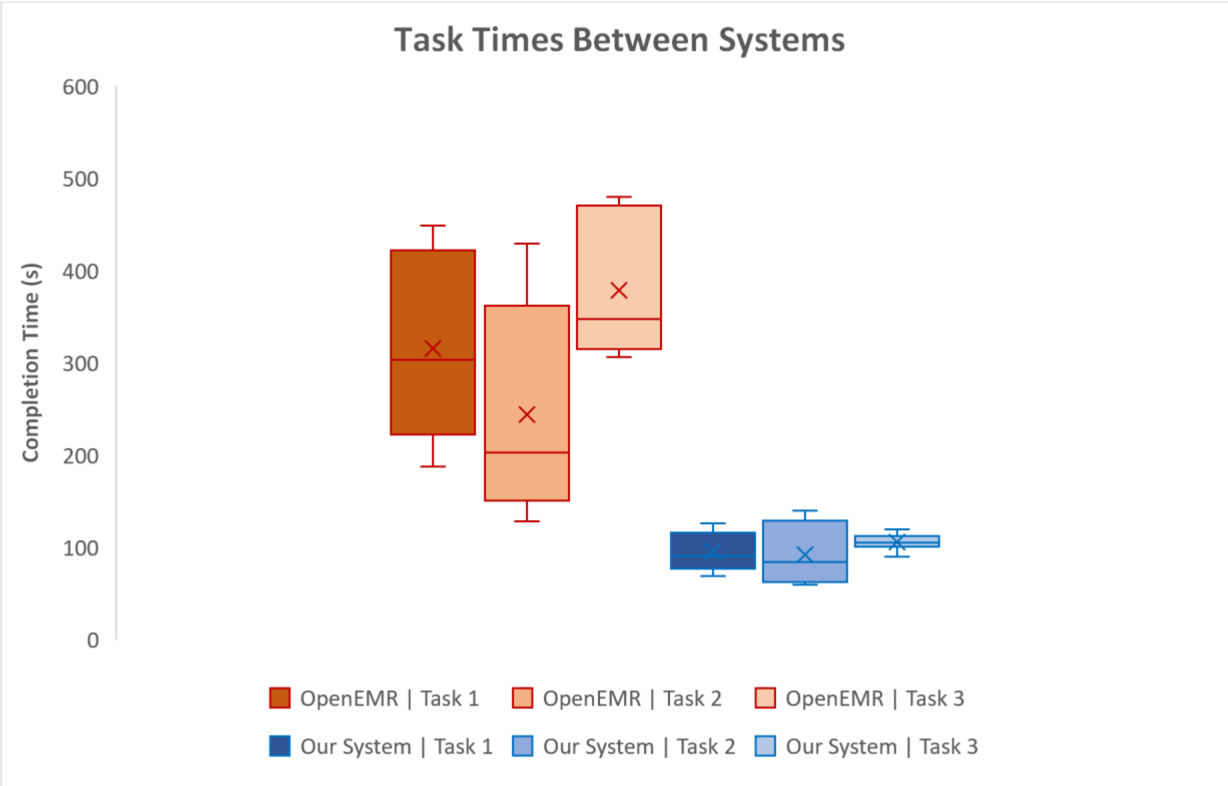

Figure 6 Quantitative results between the two systems for the time taken to complete the given 3 tasks.

Qualitative Results

Based on the survey results, the proposed workflow was perceived to be easier to use, faster to enter & retrieve data, and visually more appealing. The margins were significantly different for the survey questions for the two different systems as evidenced by on average ~1.5 higher Likert points for the proposed system than OpenEMR. It is important to note that higher Likert values for all the questions positively reflect the system in question.

With the short form questions, different users mentioned different things with the most common issue with the proposed system being that the information displayed on the patient cards is not detailed enough and that the term “add encounter” is confusing for novice users. With the OpenEMR system, the most common complaint was that the navigation system is very confusing for both experienced and novice users.

Based on these results, it can be seen that there is a clear perception that the proposed workflow is seen better on all the aforementioned metrics. With further fine-tuning, the proposed workflow could be stretched further to perform better than these preliminary results.

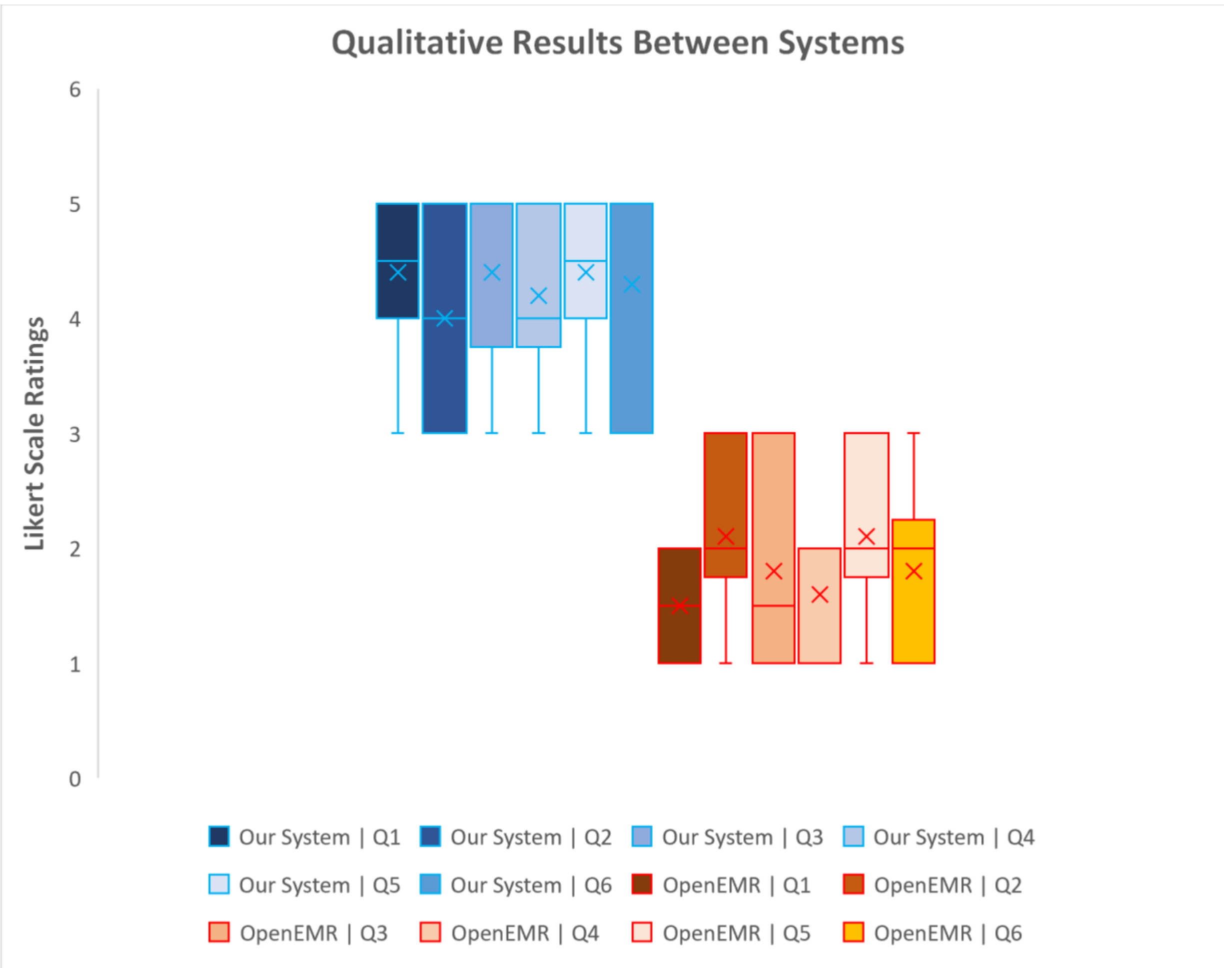

Figure 7 Qualitative results between the two systems for Likert scale-based questions

Discussion

Future Work

Despite the positive improvements in the time metrics seen by the implementation of this system, there are numerous avenues upon which the system could be improved. In terms of experimental design, the conducted experiment only measured the time taken to complete 3 tasks whereby the users had to go through numerous interactions before a particular task is completed. Therefore, our experiment was not able to capture interaction-level time data such as the time taken to press a particular button, or the time taken to navigate to a particular screen. This granular level of information could provide better insight into potential holdups in the medical record system workflow (Je et al.). Furthermore, more work should be done to assess the impact of different visual layout styles. For example, different button styles, color schemes, and search bar placements could have been tested using A/B testing protocols ("6 Essential Tips for A/B Testing UX & Design | Adobe XD Ideas").

The proposed system would also benefit from research done into the various software integrations that can be implemented to create an end-to-end workflow for patient and resource management in low-resource settings. Future research needs to be done to assess how much inefficiency is introduced when using different, siloed software for specific tasks in the healthcare ecosystem. For example, assessing how much time is lost to input data recorded on the EMRS to a medical inventory management system to ensure timely supply orders.

The work presented here can also be adapted to include other commonly used workflow improvements such as keyboard shortcuts and intelligent search functions. By reducing the number of steps a user has to execute to complete a task, we can improve overall efficiency. Although one may argue that these shortcuts may introduce a steeper learning curve at the beginning that can reduce interim efficiency, the ultimate efficiency dividends may outweigh this (Lane et al.). Furthermore, this won't even become a hindrance if the system is designed to be as efficient as possible without the reliance on these technologies. This way, users of all experiences would be able to enjoy faster systems. Finally, the system could also benefit from research on the cultural norms associated with using technology (Marcus). For example, in Japan, the PlayStation system uses the "O" button as the confirmation button whilst "X" is used as the cancel button. However, the rest of the world has this configuration swapped since in Japanese culture "X" is denoted as being wrong whilst, the rest of the globe is more concerned about the button placement than what the actual symbol denotes ("Sony Is Changing The Confirm And Cancel Buttons In Japan And Folks Aren't Happy").

Finally, a significant amount of research should be done to assess how much existing security protocols are secure and how much overhead they add to existing workflows. Significant work should be done to assess how HIPAA compliance can be implemented as easily as possible to ensure faster EMRS deployment (McKnight and Franko). In addition, with the increasing use of blockchain technology, work should be done to assess how this technology can be feasibly incorporated. This would help secure medical records in low-resource settings where cyber security is most likely at its weakest (Liu et al.) as evidenced by the numerous successful cyber-attacks on Sri Lanka's governmental websites ("Anonymous Wanted to Help Sri Lankans. Their Hacks Put Many in Grave Danger"). With blockchain technology implemented, it would be harder for all medical records to be compromised in an attack and would be even harder to be modified. This is because a large majority of the blockchain would need to be hijacked at once (Liu et al.).

Social Impact

The work presented in this thesis illustrates how the use of effective UI can reduce the bottlenecks associated with data retrieval and data entry in medical records tremendously whilst lessening the training time associated with the system. This reduction in training time and speed of use would allow more resource-limited regions to deploy the system and be able to reap the operational benefits in a relatively short time (deRiel et al.).

Furthermore, the work presented here aims to address the technical barriers to entry of traditional EMRS (deRiel et al.). The proposed system has been designed to operate on all major computer and mobile operating systems such as Windows, Linux, macOS, Android and iOS, and the web. Consequently, given the proliferation of smart devices throughout the world and their increased adoption in low-resource settings, hospital systems would no longer need to spend additional money to acquire the necessary equipment as is the usual norm with the most popular, commercially available EMRS. Furthermore, with the possibility of using HIPAA compliant cloud storage and cloud deployment of the medical record system, medical practitioners would also be able to use their devices without compromising the security of patient records whilst still being centrally accessible for the overall medical records database (*Cloud Storage of Medical Records - MDA National*). This would allow for even more regions and resource-strapped economies to adopt the system.

By widening the data collection scope through these accessibility measures, low-resource settings would be able to get access to new data insights that they can redirect their existing resources or make more informed investment decisions on their healthcare system to rapidly improve the healthcare ecosystem (deRiel et al.). These data insights could be further extrapolated by incorporating them into a country's medical inventory management system. This would not only allow for better load balancing of crucial, life-saving resources but also allow for securing essential resources preemptively. This would unlock even more economies of scale and bulk purchasing privileges (deRiel et al.) and help resource-limited locales extend their existing resources and budgets greatly.

As discussed in the future work section, the proposed medical record system utilizes an API that would allow for the implementation of blockchain technology. This would allow for the complex medical record of each user to be saved in an optimized file format whilst allowing for improved traceability of a patient's health trajectory. Given the vulnerability of the cyber security of certain low-resource settings, this technology would help address any security concerns out of the box, given that the blockchain would be preconfigured. As of now, the current system, if launched on our pre-configured cloud-based servers, the system is secure and can be remotely managed. Therefore, this system can be run externally from potentially compromised regional websites of low-resource settings (*Cloud Storage of Medical Records - MDA National*) As evidenced by the numerous hacks on Sri Lanka's governmental websites over the years including hacks by the *Anonymous* hacktivists group that resulted in multiple distributed denial-of-service (DDoS) attacks on governmental websites in April 2022 ("Anonymous Wanted to Help Sri Lankans. Their Hacks Put Many in Grave Danger") and the presidential website hack by a Teenager in August 2016 (France-Presse).

Limitations

One of the biggest limitations is that the proposed workflow was designed for a very specific use case — an EMRS for a cancer clinic in Botswana. Therefore, the proposed workflow had form fields and search bars optimized for cancer patients and conditions. Consequently, the proposed workflow is heavily streamlined to the oncology realm whilst the OpenEMR system was designed to be a generalist EMRS. Hence, the OpenEMR system had many extraneous features and workflows to help it remain useful as a generalist EMRS meanwhile the proposed workflow was able to be highly specific. This ultimately led to faster task completion times on the proposed system. As a result, these sets of experiments may not completely illustrate the potential gains and losses of optimizing UI for faster data entry and retrieval in an EMRS.

Furthermore, the conducted experiments were only concerned with two types of actions — data retrieval and data entry. However, an EMRS is used for many more tasks beyond just these two tasks and includes data visualization, automated form creation, file storage, etc. Therefore, the complicated UI of OpenEMR may be a necessity since it houses all these features. As a result, we cannot definitively relate UI optimization with workflow optimization and work efficiency, despite the strong correlation indicated by our results.

Finally, these experiments were conducted on free service tiers of the respective cloud platforms. Therefore, the experiments faced limitations and constraints on how quickly the system loaded up on the different test subjects since our applications were not prioritized on the servers during load balancing. Consequently, some of the results seen may not be completely representative of the real-world performance of the two systems (Bhadani and Chaudhary). Furthermore, these load balancing effects may have happened whilst the test subject was in the middle of their experiment which may have biased the results of one system over the other. However, it is important to note that there is a significant difference in the task times between the two systems, these aforementioned biases may not have adversely affected the conclusions drawn based on these results.

Conclusions

This thesis has illustrated how contextually aware UI design can help improve the operational workflow in using EMRS in regions where access to these systems is limited and require extensive training. This enables quick deployment of the system without tying up already strained medical practitioners with software training boot camps. The system proposed in this thesis has conclusively shown that pragmatic UI design would allow for faster data entry and retrieval without the need for extensive software training. The proposed system is also highly scalable and provides different methods of deployment given the needs of the region. With cloud-based technology and pre-configured security, the proposed workflow has the potential to redefine the care paradigm in low-resource settings to compete with more developed healthcare systems and allow for a data-driven approach to improving the healthcare ecosystem.

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