Interface Redesign of an Electronic Medical Record Review System Using User-Centered Design

by

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I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The healthcare industry in recent years has seen a rise in the adoption of Electronic Medical Records (EMRs). These EMRs have replaced the traditional paper-based records at hospitals, clinics, and nursing facilities. This transition has brought with it, numerous advantages of digitization such as improved patient care, timely reminders for checkups, and better health data tracking over time. But the EMR adoption has also come with its own set of challenges. The EMR systems are maintained by the medical coders/nurses at the hospitals. The coders are expected to gather information from different sources such as patient history logs, test results from different labs, etc. followed by entry into the EMR system. Due to the unstructured nature of the task, data entry in EMRs is susceptible to errors which lead to the poor data quality of patient records. Diagnostic decisions taken by the medical practitioners based on erroneous data can adversely affect the patient and at times, even prove to be fatal. To help address this issue of poor data quality of System X, an EMR, employs a unique data review process which allows reviewers (domain experts) to check patient records and communicate back the data entry errors to the coders for required changes to ensure high data quality. In this research, the user-centered design methodology was applied to improve the review process, with the aim of facilitating easier and quicker workflow. The usability issues faced by the reviewers were identified through heuristic evaluations, video walkthroughs, and user interviews methods. To address the issues identified, a new interface design was developed by employing low fidelity and high-fidelity prototyping techniques. Involvement of the reviewers throughout the research ensured that the design proposed was continually assessed and improved qualitatively until they were satisfied. Lastly, the Keystroke Level Model (KLM) was used to quantitatively assess the performance improvement gained from the new design. The final interface design was able to reduce the task-execution time of the patient record review process by 28.51%. This resulted in saving a significant amount of the reviewer's time, thereby reducing their workload while improving data quality.

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Dedication

This thesis is dedicated to my parents and all my loved ones.

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Chapter 1

Introduction

The very first Electronic Medical Record (EMR) system was developed by the Regenstrief Institute in 1972. Since then, EMR systems have become more powerful and ubiquitous in the healthcare sector. Particularly shift towards EMR systems in united states can be attributed to the Health Information Technology for Economic and Clinical Health (HITECH) Act of 2009. The act incentivized the use of EMR systems in hospitals and for private practitioners [1]. These incentives have led to 84% of hospitals across the United States to adopt a basic EMR system, which is a 9-fold increase in adoption since 2008. In addition, by 2017, the adoption of EMR systems by physicians and private practitioners has more than doubled from 42% to 87% [2]. This increase in the adoption of EMR has resulted in the generation of large volumes of healthcare data capturing information such as laboratory values, demographics, medication history, etc.

Importance of Electronic Medical Record Data

By capturing and storing essential patient information, EMRs assist in patient care in several important ways such as risk stratification, diagnoses, and health planning. EMR data has also shown tremendous potential in improving patient care by minimizing errors, increasing efficiency, and improving care coordination, while also providing access to rich information for researchers [3]. With the current advancements in machine learning, algorithms are able to leverage this EMR data to

flag individuals who are at an increased risk of cancer, diabetes and/or heart diseases and suggest individualized screening, preventive therapies, genetic testing, etc.

In [5], Natural language processing (NLP) was used for automatic identification of postoperative complications based on the free text available in EMR datasets. In another study, by training machine learning classification models on EMR data, researchers have been able to predict sepsis, which is one of the leading causes of mortality in hospitals [5]. Recently, researchers at Google used deep learning models trained on computational tomography (C.T. images) to beat human-level performance in the task of lung cancer classification [6]. All of these applications, however, are limited by poor data quality.

Causes of Poor Data Quality

One of the primary reasons for poor data quality in EMRs is user errors. These errors may either be errors of commission or errors of omission and can largely be attributed to the work-related fatigue experienced by the EMR users [3]. Clinicians and Nurses are required to be mobile, moving from room to room for patient checkups. Patients being their primary focus, the clinicians and nurses are often talking, listening, or thinking while operating the EMR system. They often have frequently changing agenda during a single patient workflow, and interruptions are common. Context switching along with the divided attention between the patient and the EMR system can lead to errors during the EMR data entry process [3].

Data entry errors can also be attributed to the poor interface design of the EMR systems, which makes it difficult for clinicians to enter data accurately [7]. EMR workflows often do not match clinician processes and create inefficiencies. Warning messages are confusing and conflicting, which can result in clinicians ignoring potentially critical messages [7]. In addition, excessive user interaction (mouse clicks, cursor movements, keystrokes, etc.) during frequent tasks causes frustration and fatigue (both visual and audio) ultimately impacting the quality of data entered, which can have grave consequences for patients [7].

Need for Improved Data Quality

According to a study by WHO, one in every ten inpatients suffers from medical errors due to the low quality of data [8]. It is estimated that on an average, about 70,000 deaths occur in the U.S, that are attributed to the poor data quality of healthcare records. It has also been reported that approximately 20% of medication errors are caused due to Computerized Physician Order Entry (CPOE) and other data entry functions [4]. For instance, a clinician might erroneously record a child's weight in kilograms rather than pounds, and such types of data entry errors can lead to dangerous overdoses of medications that are measured out by weight. This clearly indicates that poor data quality is a major barrier to the delivery of quality healthcare to patients.

Therefore, it is important to identify and improve methods or techniques that help ensure high data quality of healthcare records. To date, there has been a lack of research or experience in developing user-centered designs to ensure high data quality while minimizing the workload of the user.

With this objective in mind, the research described in this thesis was conducted to understand and improve the medical data review process employed by SYSTEM X system, an EMR. The review process in SYSTEM X is a coordinated effort between coders (data entry professionals) and reviewers (medical experts) that ensures high data quality of medical records.

User-centered design approach was applied to understand the review process and outline the usability issues faced by the reviewers. Iterative prototyping was conducted to address these usability issues. Throughout the prototyping process, the design solution was qualitatively assessed by the reviewer, and their feedback was used to update the design solution until they were satisfied. Additionally, to quantitatively assess the improvement in the review process, Keystroke Level Model (KLM) was used to evaluate and compare the new and the old design. Results showed that the new design was successful in reducing the execution time of the patient record review task on SYSTEM X, by 28.51%.

In summary, this research project makes practical contributions to the understanding of how user-centered design and evaluation methods can contribute to design for improved medical record quality, where the primary users are clinicians. Constraints on the design and the user group made this a challenging project where user-centered methods were needed to be applied creatively and in new ways to solve the problem of improving data quality while reducing workload.

1.1 Thesis Structure

The thesis is organized as follows, the 2nd Chapter summarizes the background for this research, the 3rd Chapter provides an overview of SYSTEM X, the 4th Chapter discusses the methodology used, 5th Chapter describes the methods used for user research, 6th Chapter provides a summary of the design requirements generated during user research, 7th and 8th Chapter discusses the methods and results of low and high-fidelity prototyping phase respectively. The 9th Chapter includes the details about the summative analysis conducted using Keystroke Level Model. The last chapter of this thesis outlines the conclusion and future work.

Chapter 2

Background

In the era of Machine Learning, with the reducing costs of computing infrastructure, EMR data is being leveraged in various applications like precision medicine, patient prognosis prediction [9][10], rehospitalization prediction [11][12] [13], etc. Data quality is critical for all these applications, and the availability of good quality data is a major challenge for healthcare research [14][15]. Poor quality data introduces errors in any decision-making process that is based on the information derived from data. Incomplete data can lead to missed diagnosis, whereas inaccurate data can cause misdiagnosis, both of which can have grave consequences. Owing to these concerns, data quality has been a topic of research since the early adoption of EMRs.

Gaps in healthcare data quality research

Extensive research has been conducted on data quality in the healthcare domain, with majority interest in areas such as determining the dimensions of data quality [15], quantifying data quality [15][16][17], identifying the usability issues leading to poor data quality in EMRs [18][19] and assessing the impact of poor data quality [20]. However, research on strategies that ensure high data quality has been limited, and the primary focus has been on the development of data collection tools [21][22] [23] and standardized medical records [24]. These strategies aim at ensuring high data quality by systematic collection of data before it is entered into the EMRs. Whereas,

methods that ensure data quality improvement after the data has been entered into the EMR have remained relatively unexplored.

Specifically, little evidence was found in the literature about methods that actively employ experts to validate and correct the data already entered into the EMRs. This made it interesting to investigate and improve a unique expert-in-the-loop medical data review process employed by SYSTEM X, an EMR.

SYSTEM X review process and its challenges

The SYSTEM X review process (discussed in Chapter 3) is an expert-in-the-loop data quality improvement technique, which is an interprofessional collaborative practice involving reviewers (medical experts) and coders (nurses). By involving expert reviewers to regularly review and validate the data entered, this process ensures that the medical records present an accurate patient medical history. Now, although the review process meets the functional requirements of maintaining high-quality patient information, it presents the following challenges for the reviewers.

1. **Exclusivity of the review task:** The responsibility of the data review process exclusively lies with the reviewer. This inhibits the delegation of the task, and thus, any delay in the review can lead to a backlog of records.

2. **Time constraint:** The reviewers are medical experts who are tied up with not only clinical but also with other institutional duties. Therefore, finding the time for the review process can be extremely challenging and is an overhead on their existing workload.

3. **Poor interface design:** The poorly designed interface of SYSTEM X creates usability issues for the reviewers, thereby hindering the review process. It also aggravates the time constraint issue faced by them.

To address these challenges, research was conducted with the aim of redesigning and improving SYSTEM X's interface, and user-centered design approach was chosen as the primary research method.

User-centered design

User-centered design is a commonly used methodology in the design and development of healthcare products [25][26][27]. One of the key benefits of the user-centered design approach is that it reduces the knowledge gap between the designers and users by employing investigative and user involvement techniques such as user interviews, surveys, user observations, usability testing, etc. The understanding developed, and insights gained during the investigative stage help the designer in taking informed and considerate design decisions while developing the interface. Involving users at every stage of the design process ensures that the solution is continuously tested and validated.

Flohr et al. applied the user-centered design methodology to develop a mobile application, VitalPad, aimed at improving the efficiency of clinical decision-making by consolidating information from multiple monitoring and therapeutic devices [26]. They observed a mixed sample of 10 clinicians for a total of 54 hours to identify data needs, workflow, and existing cognitive aid use and limitations [26]. A successful working prototype was developed using an iterative participatory feedback design approach. Tang et al. used user-centered design to develop a collaboration platform aimed at facilitating the care of hospitalized patients by an interprofessional team of clinicians [25].

In this thesis, investigative methods of user-centered design, namely heuristic evaluation, walkthrough, and user interviews, were used to identify usability issues faced by reviewers working with SYSTEM X and prototypes were developed. The development process involved regular evaluations and periodic reviews using feedback documents and telephonic interviews. This ensured that the prototype adhered to the qualitative requirements and expectations. In order to quantitatively assess the prototype, Keystroke Level Model (KLM) was used.

Keystroke Level Model (KLM)

Quantitative evaluation of an EMR interface is a complicated task. If usability test is conducted with end-users (clinicians), the task execution time can get biased due to many factors such as the clinician's proficiency in the use of the systems, the response time of the computer hardware, disturbances due to the work environment, etc. [28]. KLM is a widely used analytical method that overcomes such biases and is employed in research to evaluate interfaces [29]. It is inexpensive to conduct and yet efficient in evaluating the user's task execution performance on a system. Saitwal et al. used KLM to evaluate the system's performance by measuring task execution time and the number of steps required to complete the EMR task [30]. In another study, KLM was used to compare the performance of multiple EMRs based on task execution time [28]. Working under similar constraints, to quantitatively evaluate SYSTEM X's new user interface, KLM was chosen for this research.

The user-centered approach employed to design the new SYSTEM X interface and the quantitative evaluation of the interface using the KLM method is explained in detail in the subsequent chapters.

Chapter 3

System X

This chapter is intended to familiarize the reader with the concepts related to SYSTEM X.

The first section of this chapter briefly discusses the application of SYSTEM X and its importance, followed by a discussion of the terminologies specific to SYSTEM X. The second section provides an overview of the review process. The last section provides an introduction of individual components of the SYSTEM X interface.

The information presented in this chapter is purely the result of the task analysis research conducted by the author for this thesis project.

3.1 System X Overview

The SYSTEM X is an electronic medical record that tracks programmatic quality indicators of patients with chronic kidney disease (CKD). By tracking the progression of the disease over time, SYSTEM X acts as a medical intervention which helps evaluate patients on hemodialysis (HD) for peritoneal dialysis (PD) eligibility as the primary mode of dialysis. It has been found in studies that patients on peritoneal dialysis enjoy a better physical and psychological quality of life as compared to patients on hemodialysis.[31]

In order to ensure accurate and timely PD evaluation, it is essential that the patient's information entered into SYSTEM X remains up-to-date and error-free. To address this need, SYSTEM X employs a unique data review process which involves coordination between clinicians and coders. The workflow of this review process will be discussed in detail in section 3.3.

3.2 Terminologies

This section describes the terminologies used in this thesis that are specific to SYSTEM X's context.

- **Coders:** "Coder" refers to data entry professionals who aggregate medical information from multiple systems and medical charts to update the data forms on SYSTEM X.
- **Reviewers:** Reviewer refers to expert clinicians, with a background in nephrology. The reviewers are tasked with ensuring that the data recorded by the coders is accurate and complete.

- **Custodian:** Custodian refers to either the coder or the reviewer who has access to a patient record and can edit the respective data forms on SYSTEM X. When a new patient is registered, the coder is automatically assigned as the custodian of the given patient record. When the coder forwards the patient record to the reviewer, the reviewer is assigned the custodianship and can now review and edit the respective patient record.
- **Data Stage:** Data stage is a label assigned to an individual patient record, which indicates the level of information available in the system for a given patient. For example, newly registered patients are labeled as a baseline, whereas patients with information regarding the hospitalizations or visits are labeled as outcomes. There are 6 SYSTEM X data stages, namely: Baseline, Baseline-early transfer in, Outcomes, Pre-emptive transplant, Complete and Excluded.
- **SYSTEM X ID:** SYSTEM X ID refers to the unique identification number assigned to patient records upon new registration.
- **Forwarding:** The act of transferring custodianship of the patient record is known as forwarding.

The next section explains the workflow of the review process employed by SYSTEM X.

3.3 Review Process

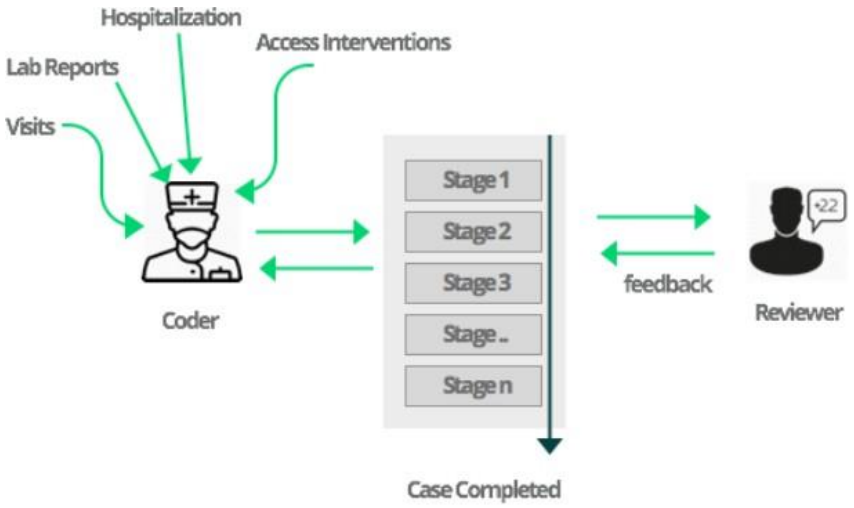


Figure 3.1: Overview of SYSTEM X review process

Figure 3.1 provides an overview of the review process in SYSTEM X. As depicted, the data entry process starts with the coders, who are tasked with collecting registration information of a patient to create a new record in the system. After the registration, coders start collecting information required to be filled across 8 thematically segregated forms (discussed in detail in section 3.4). After filling the forms with the available information, coders electronically transfer the patient records to the reviewers. This process of sending the patient record to the reviewer is called forwarding.

Once the reviewer receives the patient record, they spend time validating the data input by the coder. The reviewers check the patient record for logical accuracy and completeness, and if they notice any data discrepancies, they forward the record to the coder along with a note stating the necessary changes. This marks the end of a review cycle.

Now during each review cycle, the reviewer also evaluates the patient record to classify it across 6 SYSTEM X data stages. The data stage indicates the type of information being collected and updated for a given patient record. A patient record is continuously evaluated and moved through the data stages until it reaches the data stage called “complete”. Once the patient record has been labeled as complete, no further information about the patient is recorded in the system, thus ending the review process for the patient record.

3.4 SYSTEM X Interface

This section provides a brief description of the individual screen and components of SYSTEM X interface**. The screenshots in this section are blurred to protect trade secrets, as advised by the project stakeholders**.

3.4.1 Layout and Custodian Inbox

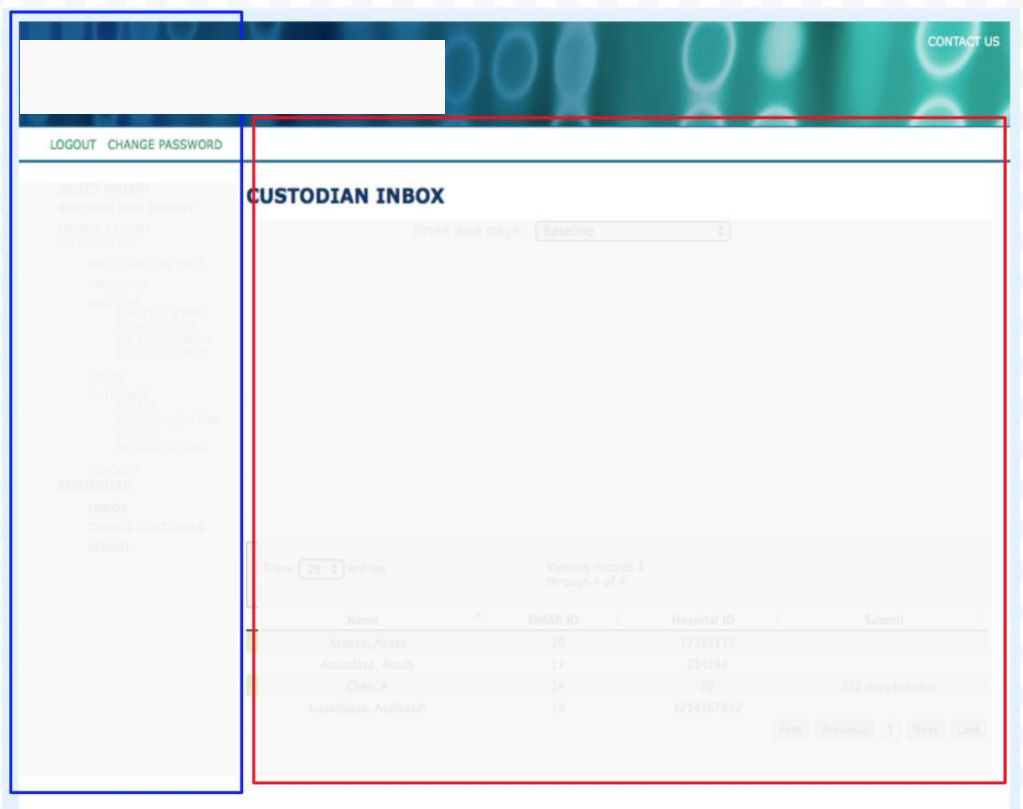


Figure 3.2: SYSTEM X layout and custodian inbox

Figure 3.2 shows the layout of the SYSTEM X screen. The blue bounding box indicates the navigation section. The navigation section presents the links to access the different data forms in SYSTEM X. The red bounding box indicates the interface area, where the data forms are displayed.

Figure 3.2 also shows the custodian inbox screen in the red bounding box. The custodian inbox presents the users with the patient records under their custodianship. The records are presented in a table and can be filtered according to the data stage by using the dropdown input at the top.

3.4.2 Tracker Section and Forwarding Window

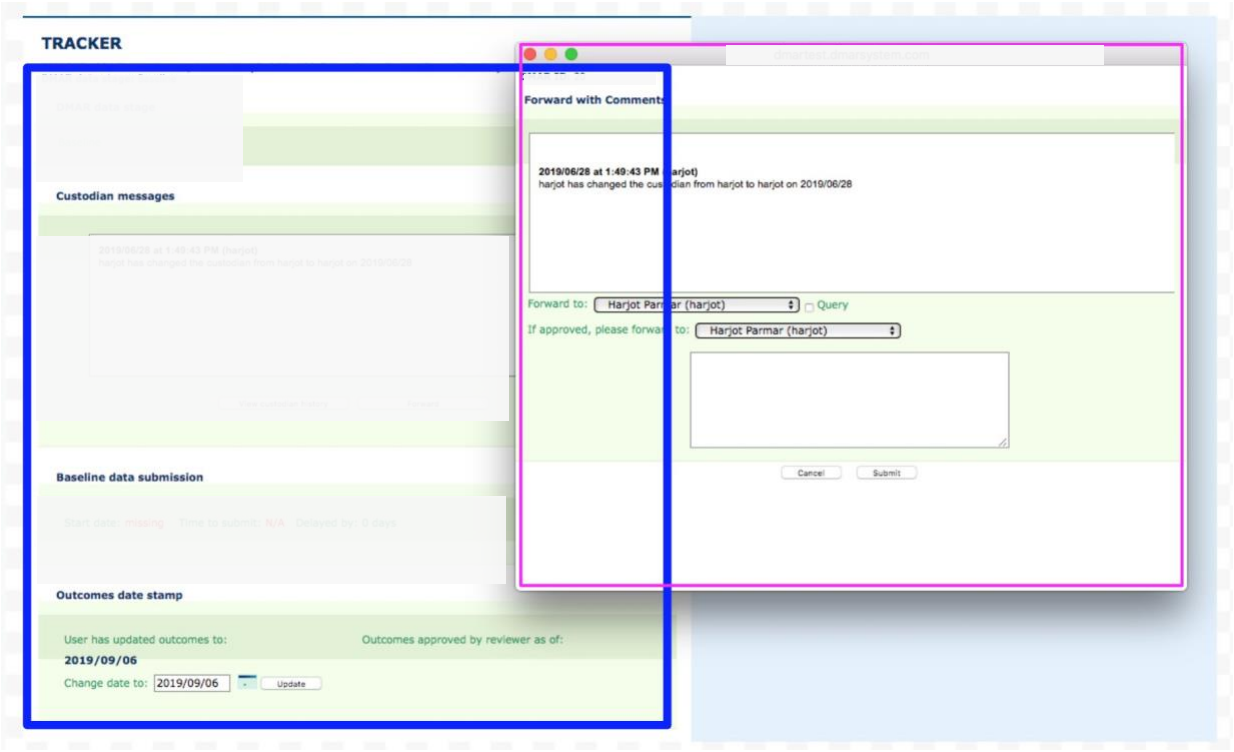


Figure 3.3: The tracker section(blue) and forwarding window(pink).

Tracker section

By clicking on the patient records in the custodian inbox list, users are directed to the tracker section. The blue bounding box in figure 3.3 shows the tracker section. The tracker section presents the user with information about the data stage of the patient

record, followed by the custodian messages in the middle, and baseline data submission and outcomes date stamp at the bottom.

- **Custodian messages**

The custodian messages section has 3 components. The first component is the custodian message box, which shows the last message for a given patient record. The second component is the view custodian history button, which allows users to access historic custodian messages. The third component is the forward button that opens the forwarding window.

- **Baseline date submission**

Below the custodian message box is the baseline date submission section. This section is primarily used by the reviewer to assign a date for the next review of a patient record. The coders have time until the assigned date to gather and update patient records with new information.

- **Outcomes date stamp**

The last section at the bottom of the tracker section is the outcomes date stamp. This section allows the users to sign off on a patient record after the completion of data entry or the review process.

Forwarding window

The forwarding window is marked by the pink bounding box, as shown in figure 3.3. It allows the user to compose messages to be sent to the next custodian. Typically, a reviewer would check the data forms and keep the forwarding window open on the side as a pop-up window, to simultaneously compose messages.

3.4.3 Registration Form

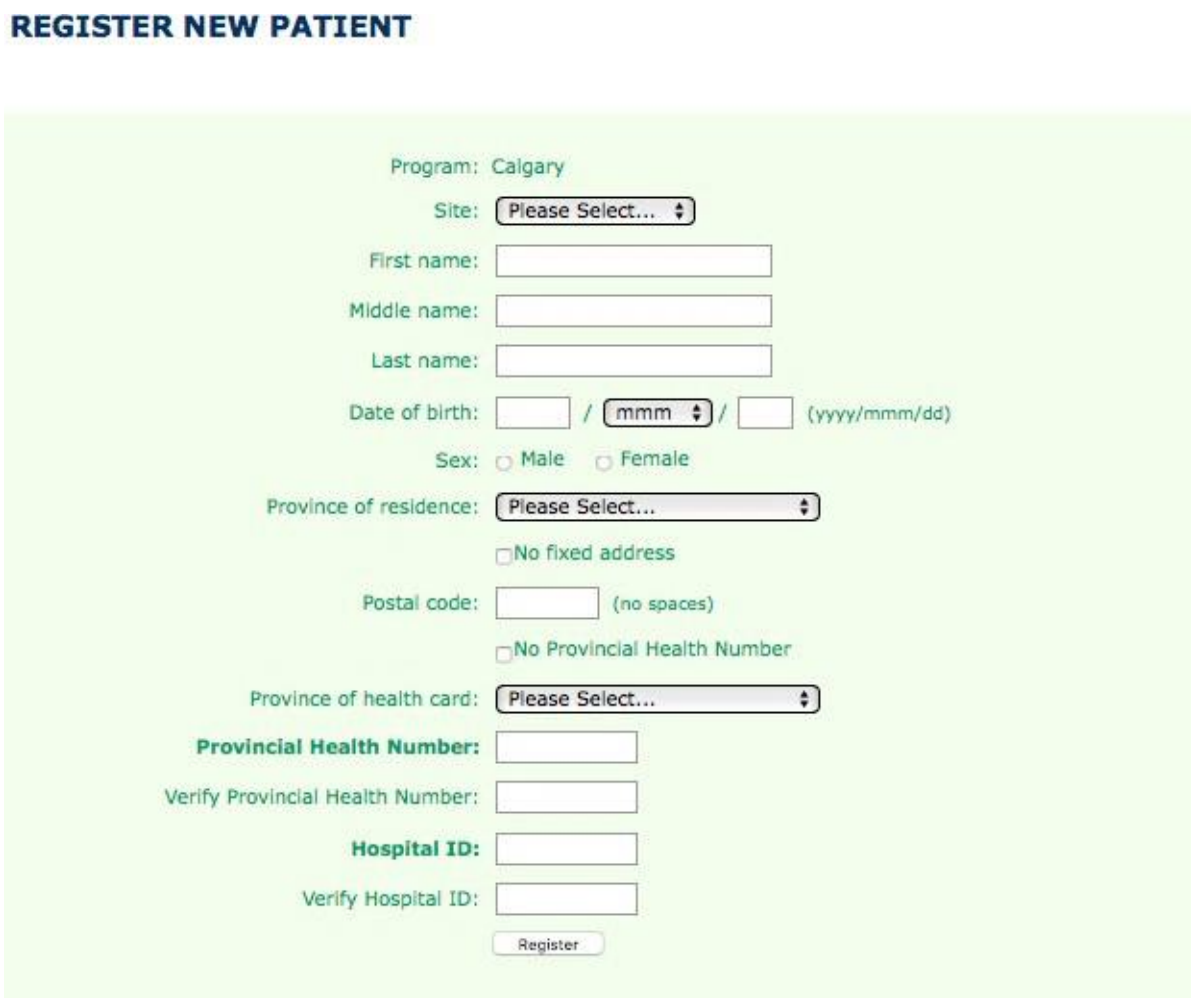


Figure 3.4: Registration form

The registration form is used in SYSTEM X to register new patients. Basic demographic and healthcare information is recorded in this form by the coders.

3.4.4 Inclusion Form

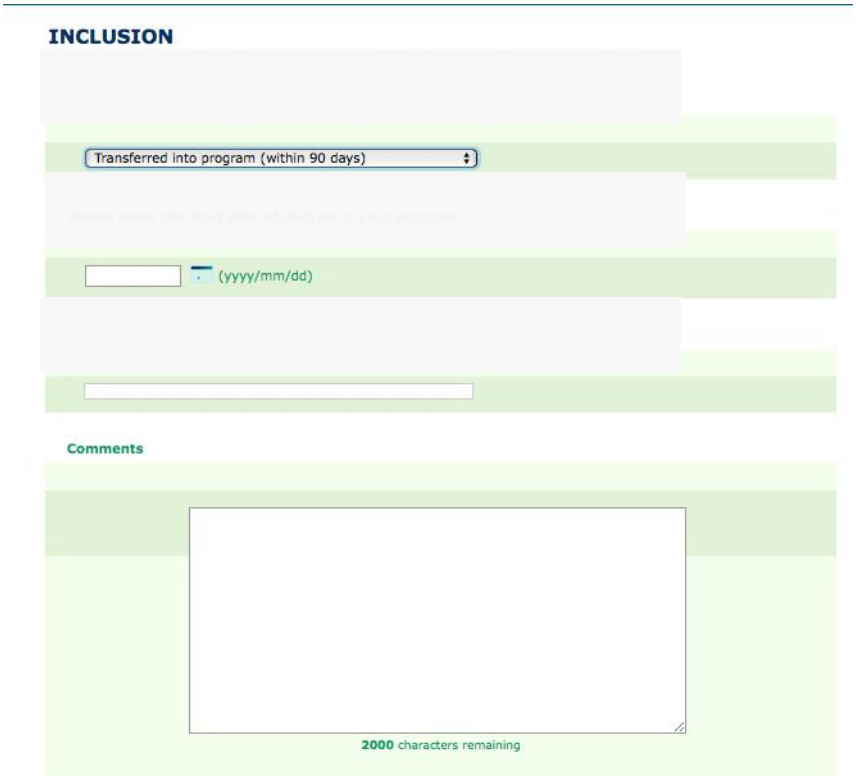


Figure 3.5: Inclusion form

After the patient has been registered, the coders complete the inclusion criteria form. This form records the reason for admittance to the program, along with the start date of dialysis if applicable. The comments section at the bottom allows the user to input specific indication related to the patient that may not be present in the dropdown options.

3.4.5 Data Forms

Figure 3.6: Side navbar

The data forms in SYSTEM X are thematically segregated into 5 categories such as registration info, inclusion, baseline, visits, and outcomes. The individual forms can be accessed using the links on the left navbar, as shown in figure 3.6.

3.4.6 Baseline Forms

Under the baseline category, there are 4 forms: dialysis start, comorbidity, HD assessment, and PD assessment. The dialysis start form records the information about the patient when they first start on dialysis. This includes information such as the nurse assigned for dialysis, date of dialysis start, whether the patient was inpatient or outpatient, etc.

Comorbidity form records information about a patient's medical history and lab results. Figure 3.7 and 3.8 show the dialysis start and comorbidity form, respectively.

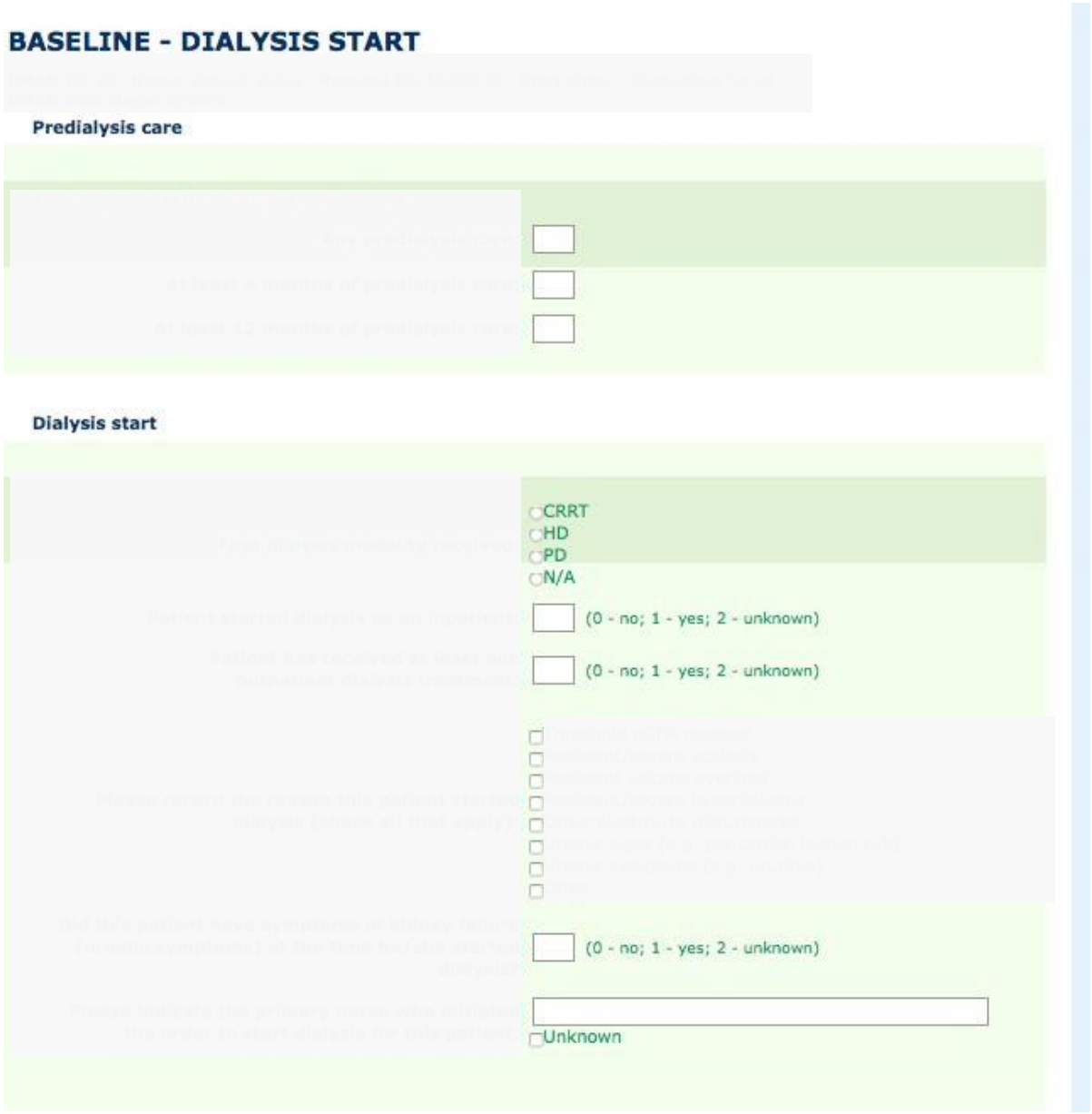


Figure 3.7: Dialysis Start

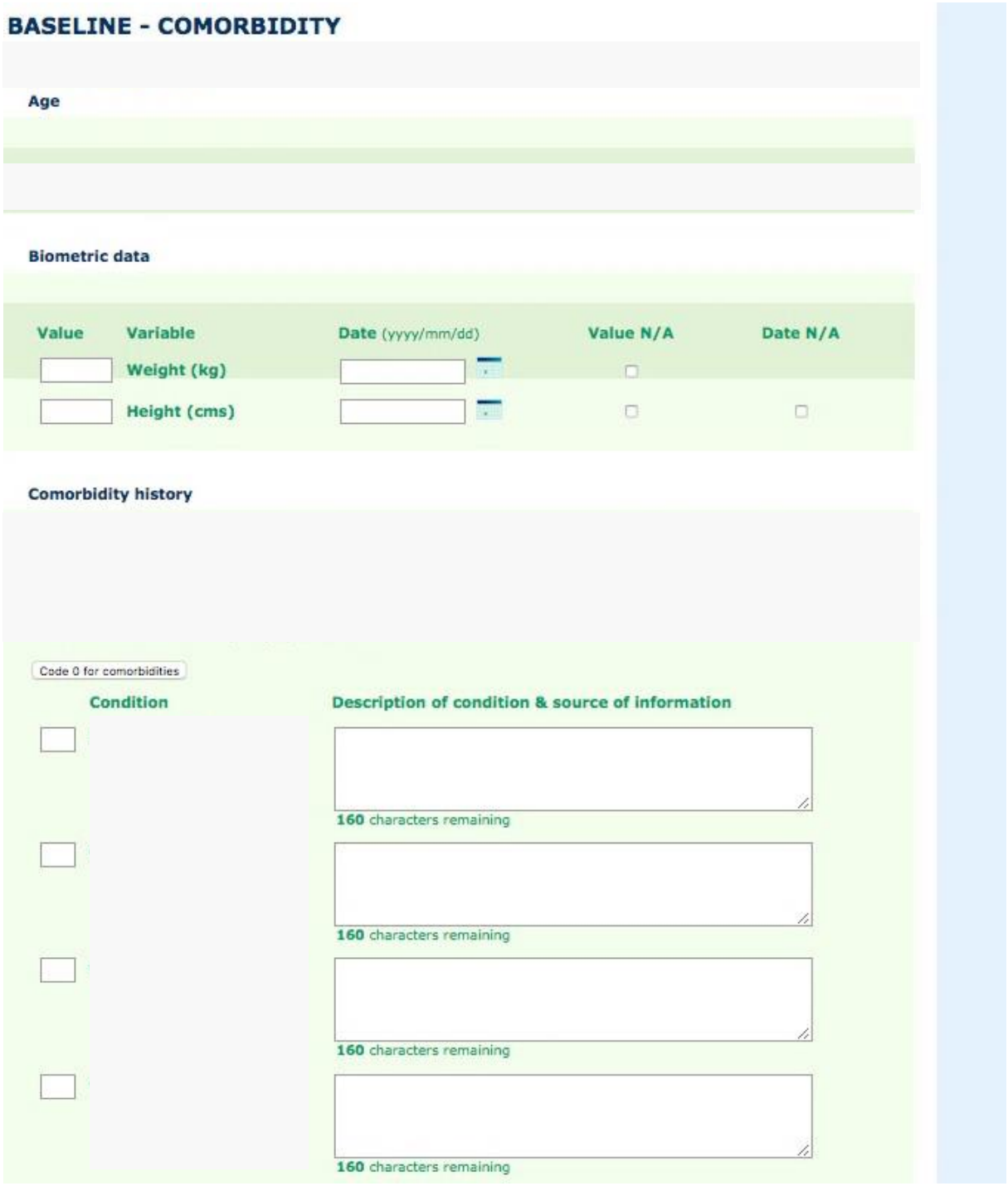


Figure 3.8: Comorbidity

HD and PD assessment forms record assessment information for Hemodialysis and Peritoneal dialysis. The rule-based questions in these forms are used to progressively evaluate patients for the two forms of dialysis. Fig 3.9 (a) and (b), show the HD and PD assessment forms, respectively.

(a) HD assessment form (b) PD assessment form

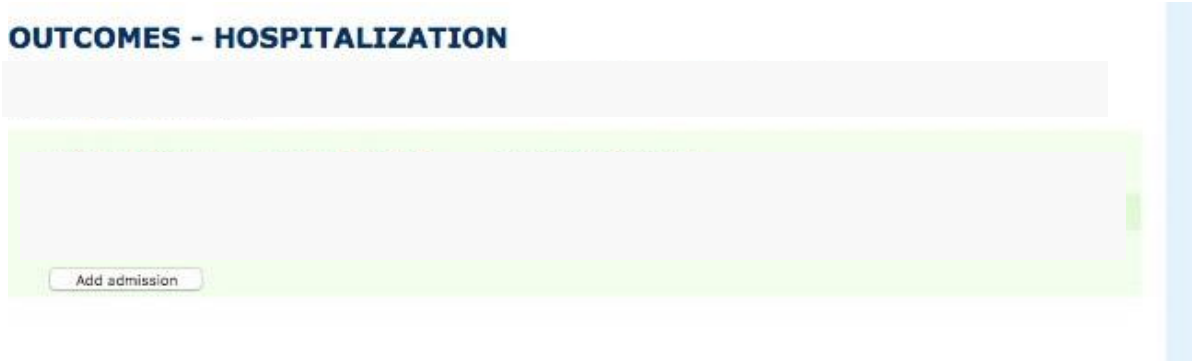
Figure 3.9: Baseline forms II

3.4.7 Outcomes forms

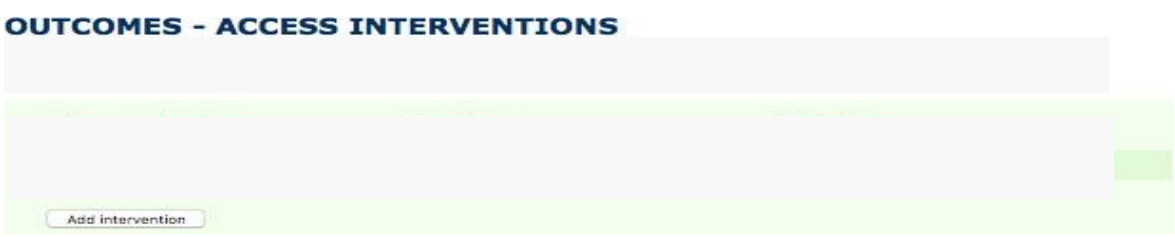
The outcomes category has 3 forms: status, hospitalization, and access intervention.

- The status form records the patient's treatment status with associated dates.
- The hospitalization form records patients hospitalization history with associated dates
- The access intervention form records the dialysis-related procedures such as angiogram, arthroplasty with the associated dates. Figure 3.10 shows the individual forms under outcomes category.

(a) outcomes-status



(b) outcomes-hospitalization



(c) outcomes-access intervention

Figure 3.10: Outcomes forms.

3.4.8 Visits form

Lastly, the visits form records patient information about the patient visits intended for their education and training. The form records information such as the date, type of session, and focus of the session for a given visit. The visits form is shown in figure 3.11.

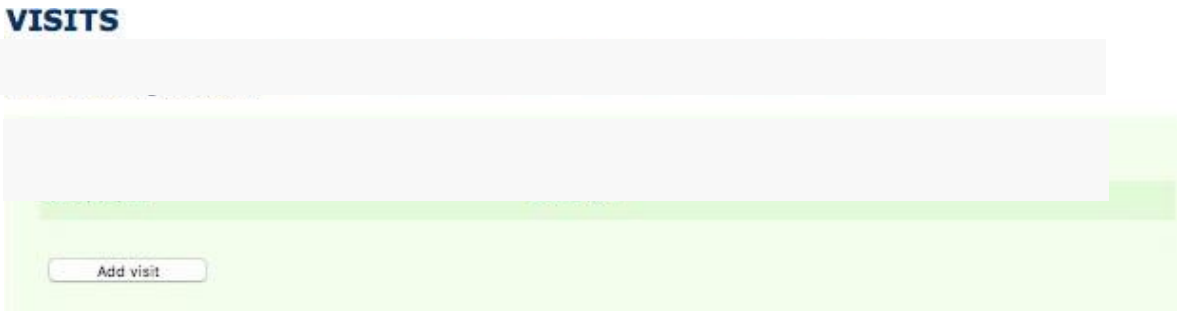


Figure 3.11: Visits form.

Chapter 4

Method

This chapter describes the methodology used for the research conducted in this thesis. The first section briefly describes the theoretical framework of user-centered design, followed by the second section which discusses the research approach used, the last section in this chapter provides details about the participants involved in the research and the limitations.

4.1 User-Centered Design

User-centered design (UCD) is a design methodology used to iteratively come up with solutions by focusing on the users and their needs in each phase of the design process. Figure 4.1 shows how UCD is broken down into cyclic and iterative process involving 4 distinct research phases.

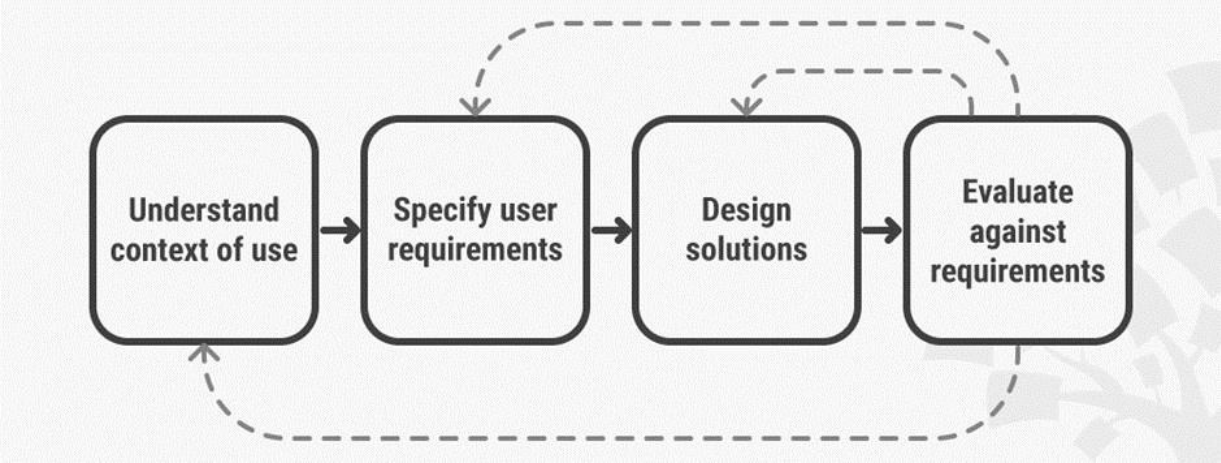


Figure 4.1: UCD Approach

The 4 phases are briefly described below:

1. **Understand the context of use:** The first phase focuses on building an understanding of the socio-technical environment in which the system and users interact. A combination of investigative methods such as user interviews, surveys, and ethnography are used for this phase.
2. **Specify user requirements:** The second phase focuses on identifying user requirements that must be met for the design to be successful.
3. **Design solutions:** The third phase focuses on generating design solutions in the form of low, medium, or high-fidelity prototypes that attempt to satisfy the requirements generated earlier. Generative methods such as paper prototyping and digital mockup are used initially for ideation, followed by high fidelity prototyping of selected designs.
4. **Evaluate against requirements:** The fourth phase focuses on evaluating the prototypes created in the third phase to address the requirements established in the second phase. Depending on the objective, formal methods such as user interview, lab testing, or informal analytical methods can be used for evaluation.

The results from the evaluation are then used in the subsequent iteration of the design cycle, which helps to progressively improve the design solution until the desired level of usability is achieved, and users are satisfied.

4.2 Research Approach

This section provides an overview of the methodology used for this thesis research. All these methods are discussed in detail in the subsequent chapter.

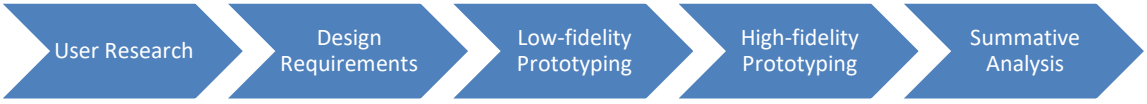


Figure 4.2: Research approach

The user-centered design approach of our research was divided into 5 steps, as shown in figure 4.2. Each step is briefly described below:

1) **User Research**: To be able to design an improved review system, it was essential to understand the internal and external workflow of SYSTEM X and also identify existing usability issues faced by the reviewer. In order to obtain rich qualitative data, the user research process was divided into 3 phases as described below.

(a) **Heuristic Evaluation:** In this phase, initial exploration of the system was conducted, to identify usability issues based on the heuristic evaluation. This phase was also intended to familiarize with the SYSTEM X interface prior to interacting with the users.

(b) **Video Walkthrough of Review Process:** The second phase of user research consisted of a reviewer participating in a video walkthrough. The video walkthrough was the first attempt to understand the review process. The reviewer was asked to provide a video recording of their review workflow by stating their goals and thought process during each interaction with the system. Post-hoc analysis of the video walkthrough was conducted to record usability issues observed.

(c) **User Interview:** The last phase of the user research process comprised of the user interviews, which was further broken into 3 parts. The first part involved the use of structured interviews to further our understanding of the review process. The second part involved the use of semi-structured interviews intended to understand the needs and challenges faced by the reviewers and the coders. The last part of the interview included the use of the in-person interview intended to discuss the issues in person and ideate possible solutions.

2. Design Requirements (DR)

In the next step of the research, the needs, constraints, and issues observed during the user research were thematically analyzed to generate a list of design requirements that were used to guide the prototyping phase.

3. **Low fidelity prototyping and Evaluation:**
   The third step in research involved the development of design ideas based on the design requirements established earlier in step 2. A mix of paper and digital prototypes were used for this process. The prototypes were continually evaluated by the reviewers, and suggestions were incorporated to update and improve the design suggestions.

4. **High Fidelity Prototypes and Evaluation:** The fourth step involved the development of high-fidelity prototypes based on the updated design requirements. High fidelity prototypes were also continually evaluated by the reviewers, and suggestions were incorporated to update the design until the reviewers were satisfied.

5. **Summative Analysis:** In the last step of the research, the keystroke level model was used to quantitatively assess the effectiveness of the new design in improving the reviewer's workflow.

At the end of the research, the final design proposed was shared with the development team for implementation.

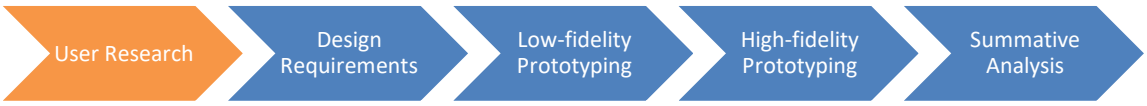
4.3 Participants and Limitations

At the time of the research, SYSTEM X was being used at two medical institutions in Canada. Due to the exclusivity of SYSTEM X and the review process, the participant pool for the research was limited to the existing user base. There were only 2 reviewers who had prior experience working with the system. Both the reviewers were closely involved throughout the user research and design process.

The scope of the research was limited to improving the review process through design intervention; therefore, the involvement of the coders was limited to the user research and design requirements phase only. Overall, 2 reviewers and 4 coders participated in the research.

Chapter 5

User Research



This is chapter discusses the individual methods used during the user research step.

5.1 Methods

5.1.1 Heuristic Evaluation

Prior to interacting with the users, the author spent time exploring the SYSTEM X interface and heuristically evaluating for usability issues. It was essential to familiarize with the system to identify usability issues. The evaluation was also intended to gain an understanding of the system to prepare for later discussions with the reviewers during user interviews.

The heuristic evaluation was conducted independently by the author over a period of 1 week, involving 2 sessions lasting 1.5 hours each. The interface was evaluated for heuristics, such as error prevention, consistency and standards, accessibility, etc. By the end of the analysis, usability issues observed were summarized and recorded, and an initial list of design requirements was created.

****Note:** Due to the privacy policy and regulatory reasons, access to live SYSTEM X system was restricted. A test instance of the SYSTEM X system with dummy data was used for the analysis.

5.1.2 Video Walkthrough of Review Process

Video walkthrough was the second method used for user research. The choice of using video walkthrough was influenced by the project timeline and availability of the reviewers. The project timeline required the redesign to be completed as soon as possible so that the development team could start working on the system implementation. Also, since the only participating reviewer resided in Alberta, outside the author's home state, in-person observation of the review process was not feasible. Therefore, video walkthrough was selected as a possible option to understand and learn about the review workflow followed by the reviewer.

The participating reviewer was requested to record themselves while performing a review of baseline patient record on SYSTEM X. They were also requested to

verbalize each step and discuss the individual interaction they had with the interface to help us understand their decision-making process.

During the walkthrough, the reviewer introduced the different sections of the SYSTEM X interface and briefly discussed their relevance. Additionally, the reviewer explained some of the mental models they used to evaluate the data entries for logical correctness. This helped reveal details and motivations implicit to the reviewer's workflow.

The recording of the walkthrough was shared with the researchers over Google Drive. The recording was then analyzed by 3 researchers (the author and two co-op students), and insights were transcribed. Notes about the terminology used, description of individual steps involved, and the relevance of the interface components were recorded. Usability issues identified were discussed and analyzed by the 3 researchers and added to the list of design requirements.

Since the scope of the research was limited to improving the review process, coders were not included in this phase of the research.

5.1.3 User Interviews

After gaining a foundational understanding of the SYSTEM X interface and the review workflow through the video walkthrough, user interviews were conducted to gain a deeper understanding of the usability issues and pain points experienced by the reviewers.

The interview process was conducted over a period of 4 months, broken down into 3 phases, as discussed below:

- **Structured Interview:** Structured interviews were conducted after the analysis of the video walkthrough was completed. The aim of the structured interviews was to further our understanding of the review process and SYSTEM X interface. Interview questions were organized based on individual sections of the SYSTEM X interface. The questions asked were in the following categories: terminologies used during video walkthrough (custodian, delay days, comorbidities, etc.), the functionality of the screen elements and forms of SYSTEM X. The interviews were conducted over the telephone, once every week for 3 weeks. Each interview was conducted for 30-45 minutes. Throughout the interview process, detailed notes were recorded by 3 researchers (the author and 2 co-op students).
- **Semi-structured Interviews:** After formalizing our understanding of the review process and the SYSTEM X interface, semi-structured interviews were conducted to initiate the discussion with the reviewers about the usability issues they faced while working on SYSTEM X. Both the reviewers were interviewed together over telephone. The involvement of both reviewers during the interview ensured that issues discussed were considered from both the reviewer's perspective, and the design requirements thus gathered addressed both the reviewer's needs without undermining any individual reviewer's workflow.

  Interview topics

  Semi-structured interviews focused on encouraging the reviewers to openly discuss their expectations from the new SYSTEM X interface. Some of the topics discussed during the interview were: the need for the consolidation of data forms to facilitate quicker navigation, the requirement for a more transparent communication channel that would help educate coders, the need to improve search and assignment of custodianship, etc.

The semi-structured telephone interviews were conducted once every week, over a period of 3 months. Each interview was conducted for 30-45 minutes.

At the end of each interview, the author and 2 co-op students, summarized the issues discussed and recorded design requirements associated with each section (tracker, custodian inbox, etc.) of the SYSTEM X interface in the form of user stories.

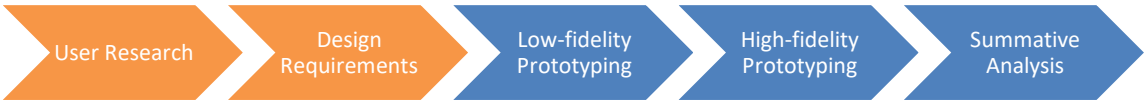
- **In-person Interview** After the completion of semi-structured interview rounds, in-person interviews were organized at hospital X in Toronto, Canada. The in-person interviews were conducted in two sessions:

  1. The first session of the interview involved the reviewers, 3 researchers (the author and 2 co-op students), and the technology development team responsible for implementing the final design output of research. The session took 3 hours and was conducted in the form of a semi-structured interview. During the interview, issues identified in the previous rounds of semi-structured interview were discussed, and possible design solutions were evaluated for feasibility of implementation by the technology team. The reviewers were encouraged to talk about an ideal review system; the possibility of leveraging artificial intelligence to automate the process was also discussed.
  2. The second session of the in-person interviews involved 4 coders (2 Nurses and 2 Data Management Coordinators) and 3 researchers discussing the issues faced by the coders. Although the scope of the research was limited to the improvement of the review process, it was beneficial to understand if the quality of data input can be improved at its source, i.e., coders. The discussion with the coders also took the form of a semi-structured interview. The coders were encouraged to share issues experienced during the data entry process, and possible solutions were discussed. The major concern for the coders was discovered to be the data gathering process outside SYSTEM X.

At the end of the user research phase, all the notes and insights generated were thematically analyzed using affinity mapping technique to generate design requirements. The next chapter goes into detail of the design requirements generated through each phase of the user research.

Chapter 6

Design Requirements



The objective of the user research step was to gain an understanding of the review process conducted by the reviewers and to identify associated usability issues. The needs, desires, constraints thus identified were thematically analyzed using affinity mapping technique to generate the design requirements used to guide the prototyping phase. The sections below discuss the requirements generated through each stage of the user research.

6.1 Heuristic Evaluation Results

Req# 1 System should have cross-browser compatibility:

The first usability issue observed during the exploratory analysis was that SYSTEM X system was only accessible through internet explorer (IE 6 sp2+) browser. It lacked cross-browser compatibility, which restricted users from accessing the system using other browsers. The new system was required to have cross-browser compatibility to provide a better and consistent user experience.

Req# 2 System should provide sufficient feedback on erroneous data entry:

Heuristic evaluation of the SYSTEM X forms revealed the lack of sufficient error feedback from the system. It was observed that the error prompts for invalid data entry bore little information about the expected input format. For example, an invalid OHIP entry would result in “The format for OHIP is incorrect.” The prompt did not provide feedback to the user on how to correct the invalid entry. The new system would require the interface to not only prompt the user about the error but also direct the user towards verifying and correcting the error. example: “Invalid OHIP number, 10-digit input expected”.

Req# 3 Should have consistency and follow standards

Figure 6.1: Inconsistent spacing between form links

The layout of the SYSTEM X interface was found to be unconventional. Links to the utility functions such as login and change password were placed separately from the contact us link. The spacing between the form links (figure 6.2) was also found to be non-uniform. The improved version of the review system required the development of consistent layout conforming to modern web standards.

6.2 Video Walkthrough Results

Req# 4 System should aid the user's memory (Recognition instead of recall)

During the video walkthrough, the reviewer stated:

> *"Typically, what I'll do is tell a story out loud so that it sticks in my head. When I jump around to other forms, to confirm some of the data or cross-reference it, I have that story in my head."*

As the reviewer navigated through a patient record in SYSTEM X, they created a timeline of the patient progress in their head. The timeline helped them evaluate the dates entered in status, hospitalization, and access intervention forms. For instance, during the video walkthrough, the reviewer noticed that the patient was coded to have started dialysis on 29 Sept '18, in an ICU setup as an inpatient, they also noticed that in status form the same patient was coded to have started outpatient dialysis on 29 Sept '18. So, by remembering the dates from the status form, the reviewer was able to adjudicate that the date entered in status form was incorrect. The reviewer reasoned that it would be atypical of a patient to be admitted in an ICU, be discharged, and also start outpatient dialysis all on the same day.

Therefore, the new system was required to make the frequently accessed variables readily available to the reviewers, to help reduce the cognitive workload of remembering information.

Req# 5 System should support coder's education:

During the video walkthrough, the reviewer stated:

> *" I could either correct it myself, or I could send it back to them and ask them to correct it. So they learn and are kinda[sic] mentored through the process."*

If the reviewer noticed any incorrect entry and was able to confidently determine the required correction, they either decided to make the correction themselves, or they wrote a note back to the coders to make the correction. The note would include the explanation stating the reason why the data entered was deemed incorrect. This way, the communication helped in educating the coder and trained them to prevent the same mistake from happening again.

The new system was required to facilitate easier communication between the reviewers and the coders, and also, facilitate coders education.

Req# 6 Should make comments easily accessible:

During the video walkthrough, the reviewer stated:

> *" Next thing I do is click on each of the hospitals stays because I have to read the comments as to why they were admitted and reason for admission."*

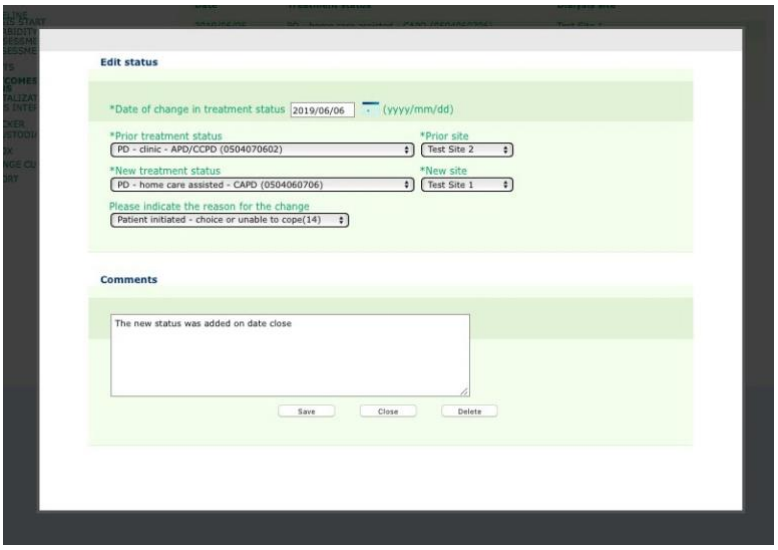


Figure 6.2: Pop-up status entry window

Checking the comments associated with each entry in the status, hospitalization, access interventions, and visits table, was part of the reviewer's workflow. But the existing interface required the reviewer to click through each entry in the table and view the comments in a pop-up window.

The new system was required to make the comments associated with each entry in the data forms easily accessible.

Req# 7 Should reduce pop-up and click interaction

It was observed that a lot of the regular functions required multiple clicks and pop-up interactions. For example, the forwarding window, where the notes and messages for coders were composed, was kept open on the side in a pop-up window. The reviewer was required to switch between the forms being reviewed and the forwarding window screen to compose the message as the reviewer went through each form.

The new system was required to reduce the redundant steps needed to complete regular tasks.

6.3 User Interviews Results

Req# 8 System should support faster navigation and review workflow

During the interviews, the reviewers expressed the urgent need for a faster, more efficient way to conduct the review. At the time of the first round of in-person interview, one of the reviewers revealed that he had a backlog of 700 cases to be reviewed over the coming weekend.

Due to limited time, reviewers had to spend off-clinic hours going over hundreds of patient records repetitively, and any delay in the review of these records resulted in backlogs.

The reviewers were looking for a layout that would consolidate all the forms and allow them to quickly go through the data entries to evaluate the patient records. This theme overlapped with the need to reduce click and pop-up interaction.

Req# 9 System should provide visibility of the changes made:

The reviewers wanted a system which would reduce the time required to provide feedback for the changes they made during a review to the coders. The desire for an automated feedback generation mechanism was expressed during the interviews.

Req# 10 System should support easier communication:

Another repeatedly observed theme during the user research phase was the need to have improved communication channel between the reviewers and the coders. Reviewers stated that existing tracker and the messaging system felt limiting, and the conversation felt impersonal. The existing messaging system was complicated and required frequent context switching between the data forms and forwarding window.

The new system was required to provide an easier and more efficient way to communicate with other users.

Req# 11 System should be aesthetic and minimal:

> *"Existing systems are boring, and look hideous, the system should look more welcoming and modern."*

Reviewers felt that the existing system presented with an outdated design, and there was a need for the interface to look more modern and welcoming.

Req# 12 System should improve the custodian inbox:

The existing custodian inbox did not allow the reviewers to accurately sort or search for specific cases. The reviewers wanted the new system to allow easier selection of the patient list at different data stages.

Req# 13 System should provide information about the primary custodian:

Both the reviewers and coders agreed on the need for a better and easy to use case transfer mechanism. In particular, the need was expressed during the interview with the coders, when one of the data management coordinators said:

> *"[reviewer] doesn't always send back the case to the right user. it is not that difficult to figure out, it is just that [reviewer] is really busy, so re-viewer] just sends it back to the last custodian."*

At times when the nurses did not have access to certain information for a given patient record, they would forward the case to the data management coordinators to resolve the missing data issue. Once resolved, the coordinators would forward the case to the reviewer for validation.

Majority of the time, after a quick check, the reviewer would return the case back to the previous custodian, in this case, the data management coordinator. This would result in records piling up in data management coordinators inbox instead of going back to the primary custodian. The coordinators were then tasked with checking the individual custodian messages to identify the primary custodian and forward the record to them. The coordinators found this task particularly troubling.

Therefore, there was a need for the new system to allow the user to quickly identify the primary custodian of a given patient record.

Req# 14 System should be able to communicate with other EMR systems:

Coders were comfortable with the SYSTEM X system, and form entry process, but found it difficult to find relevant information to complete the forms. They were expected to go through multiple healthcare systems, clinical notes, paper referrals, or soft copies of documents to collect data and then input it into SYSTEM X.

They would also have to go through imaging, look at echo, and sometimes information might not be clear in these records. Baseline forms sometimes took

them 3 hours to complete. At times they would have to reach out to the data management coordinators to find certain information, or to provide access to it.

Issues also stemmed from patients who were transferred from other facilities and were already on dialysis. It was a difficult and complex task for the coders to find relevant information from the previous institution or facilities.

A possible solution for this was to have SYSTEM X communicate with other EMRs such as Accuro, Sunnycare, etc.

6.4 Conclusion

Table 6.1 shows the consolidated list of the requirements generated during the user research phase.

Requirement #	Requirement	User Research Phase	Considered For Prototyping Phase
Req#1	System should have cross-browser compatibility	Heuristic Evaluation	❌
Req#2	System should provide user sufficient feedback on erroneous data entry	Heuristic Evaluation	❌
Req#3	System System should have consistency and standards	Heuristic Evaluation	✅
Req#4	System should aid user's memory (Recognition instead of recall)	Video Walkthrough	✅
Req#5	System should support coders education	Video Walkthrough	✅
Req#6	Should make comments easily accessible	Video Walkthrough	✅
Req#7	Should reduce unnecessary pop-up and click interactions	Video Walkthrough	✅
Req#8	System should allow reviewers to add comments to changes	User Interviews	✅
Req#9	System should support faster navigation and review workflow	User Interviews	✅
Req#10	System should support easier communication	User Interviews	✅
Req#11	System should be aesthetic and minimal	User Interviews	✅
Req#12	System should improve the custodian inbox	User Interviews	✅
Req#13	System should provide information about the primary custodian	User Interviews	✅
Req#14	System should be able to communicate with other EMR systems	User Interviews	❌

Table 6.1: Consolidated list of requirements

Out of the 14 requirements generated, 3 requirements (#1 for cross-browser compatibility, #2 error feedback, #14 communicate with other EMRs) were excluded from the prototyping phase. These requirements would be addressed by the software development team during implementation. The remaining 11 requirements were used for ideating possible design solutions during the prototyping and design phase of the research. The details of the prototyping phase are discussed in the next chapters.

Chapter 7

Low Fidelity Prototyping

After establishing the design requirements, the next step involved the development of low fidelity prototypes of a possible solution and evaluating them with the users. This chapter describes the method used for this step of the research, followed by the results of the low fidelity prototyping phase.

7.1 Method

7.1.1 Low Fidelity Prototyping

For the prototyping phase, 3 researchers(the author, 2 co-op student at the AIDL lab) individually analyzed the design requirements and developed paper-based wireframes ideas for layout and screen elements (figure 7.1 below). The paper-based prototypes served as a quick and inexpensive way to brainstorm ideas during the formative stages of designing a solution.

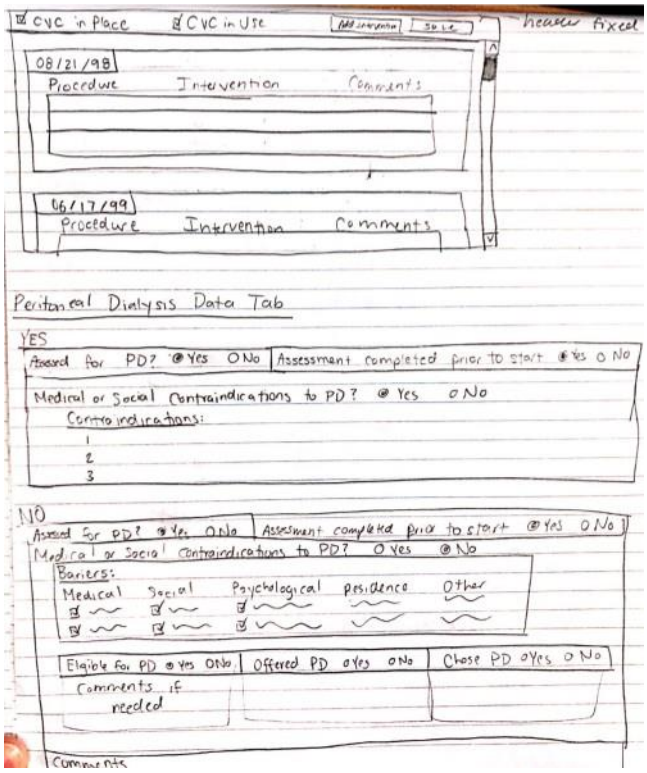


Figure 7.1: Early Design Sketches

Next, the 3 researchers met every day for a period of two weeks to discuss their individual design ideas. The design ideas such an embedded messaging module to support easier communication (Req #10), quick access button to view all comments

in a given form (Req #6), search and filter options to facilitate easier case selection in the custodian inbox (Req #12) were discussed.

The layout ideas were iterated by creating and placing paper cutouts of screen elements representing forms, buttons, and tracker section on a table (Figure 7.2). This was intended to come up with layout variations that facilitated faster navigation across forms (Req #9) and reduced pop-up and click interaction (Req #7). The researchers took turns arranging the cutouts to discuss their visions of possible layouts.

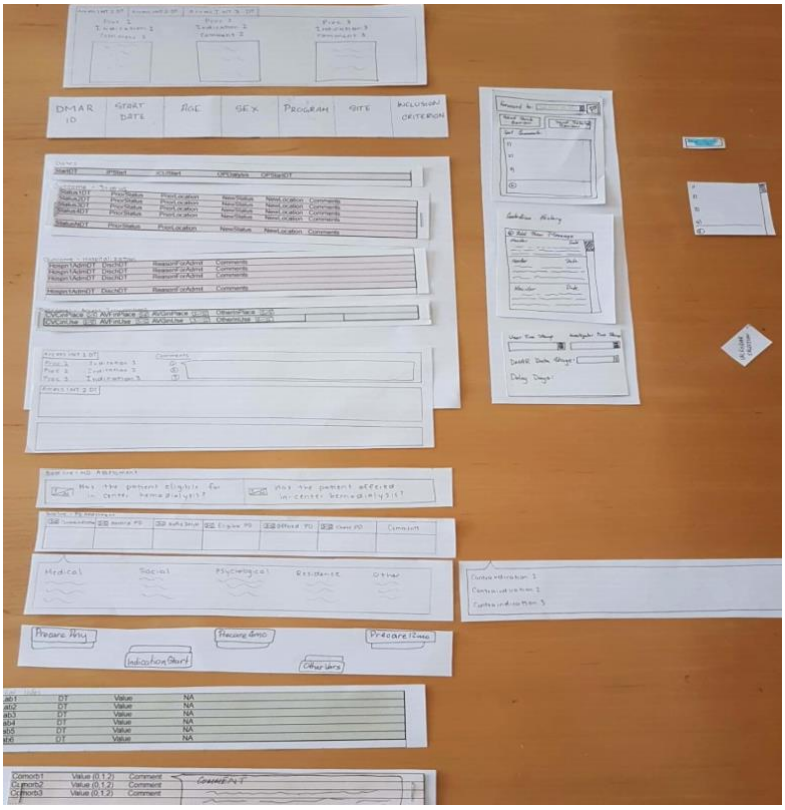


Figure 7.2: Layout Design Iterations

Based on these brainstorming sessions, a list of possible designs solutions targeting the design requirements was created. These design ideas and layouts were then discussed with reviewers during telephone interviews to eliminate design divergence.

The reduced list of design ideas was then digitally reproduced using Axure RP (a wireframing, mockup, and interface design tool) and shared with the reviewers for feedback and user testing.

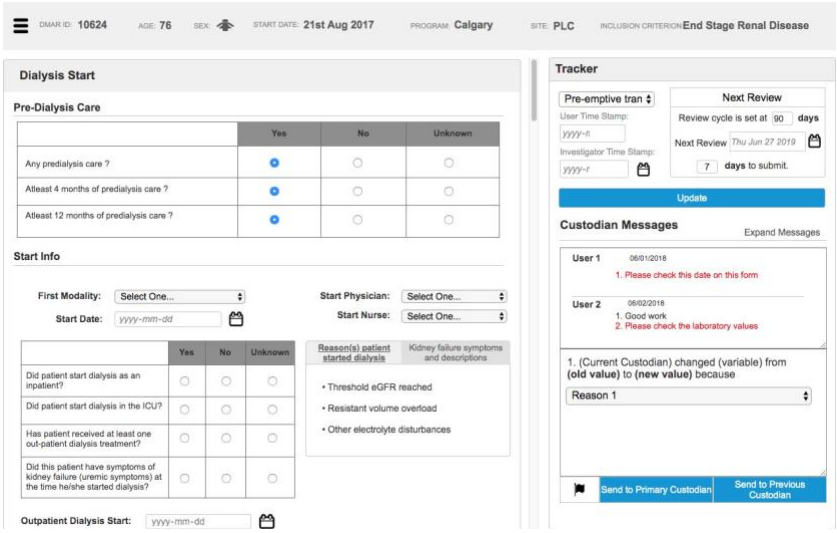


Figure 7.3: Interactive prototype created in Axure.

Next, an interactive mockup was also created using Axure XP. The interactive mockup was intended to demonstrate the functionality and proposed layout of the interface to the reviewer.

7.1.2 User feedback

To gather user feedback from the reviewers, digital mockups were compiled into feedback documents on Google docs and shared with the reviewers. The feedback document comprised of design ideas along with a text description of the feature implemented.
Google docs were chosen as the preferred medium as it facilitated easier online collaboration between the 2 reviewers and the 3 researchers. It also helped in maintaining a single source of truth. Another advantage of using google docs was that it provided the reviewers the flexibility to evaluate the design as and when permitted by their schedule.

Feedback from the reviewers was collected using the feedback documents and follow up interviews were conducted. Based on these interviews and the text feedback, notes were recorded to update the prototypes for the next design cycle.

7.2 Results

Due to the dynamic nature of prototyping task, this section limits the discussion to the key results obtained by the end of the low fidelity prototyping and evaluation phase. The section is divided into 3 subsections as listed below.

- **Accepted Designs**: This section provides a summary and discussion of design ideas accepted by the reviewers.
- **Rejected Designs and Concepts**: This section provides the summary and discussion of the design ideas rejected by the reviewers.

- **Summary of Low Fidelity Prototyping**: This section presents the summary table outlining the design ideas that were developed and accepted by the reviewer, along with a list of new features requested.

7.2.1 Accepted Ideas

1) Single Page Consolidated Layout

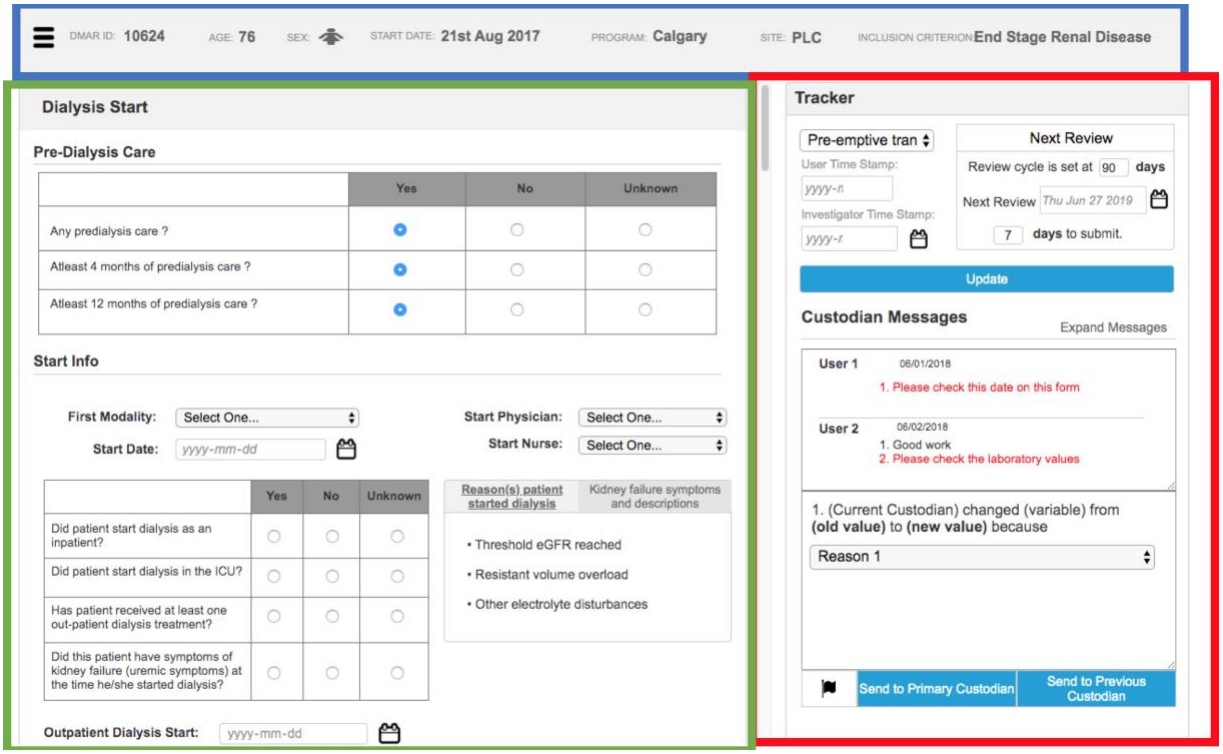


Figure 7.4: Single Page Layout

Features Addressing Design Requirements

Single page layout was established to address the Req #9, #7, #4 of the design requirements. The layout was designed with the intent of consolidating all the components of SYSTEM X into a single page, reducing clicking and pop-up interactions (Req#7).

As shown in figure 7.4, the layout design comprised of 3 sections. The static patient info bar at the top is presented in the blue bounding box, the messaging module in the red bounding box, and the green bounding box representing the forms section.

The patient info bar section was intended to show the reviewer frequently accessed variables. This promoted recognition instead of a recall and aided the reviewer's memory (Req#4).

The messaging module was intended to address the Req#10 specifically. It brought together the features from the tracker section and the forwarding window, to allow the user to compose messages and update submission dates, without the need to use pop-up windows (Req#7).

Reviewer's Feedback

> *" Overall, I think this looks really good. I like the organization, sans serif font"* - **Reviewer 1**

> *"Overall, I really like the font choices and layout. I am assuming that we are only making minimal changes to the backend database and user[coders] forms for this project."* - **Reviewer 2**

The reviewers were satisfied with the new layout suggested but expressed concerns whether the changes to screen layout would affect the backend of the system and therefore wanted to keep the changes to the form design as minimal as possible. After discussion with the software implementation team, they were assured that the design would not affect the back-end implementation.

2) New Messaging Module

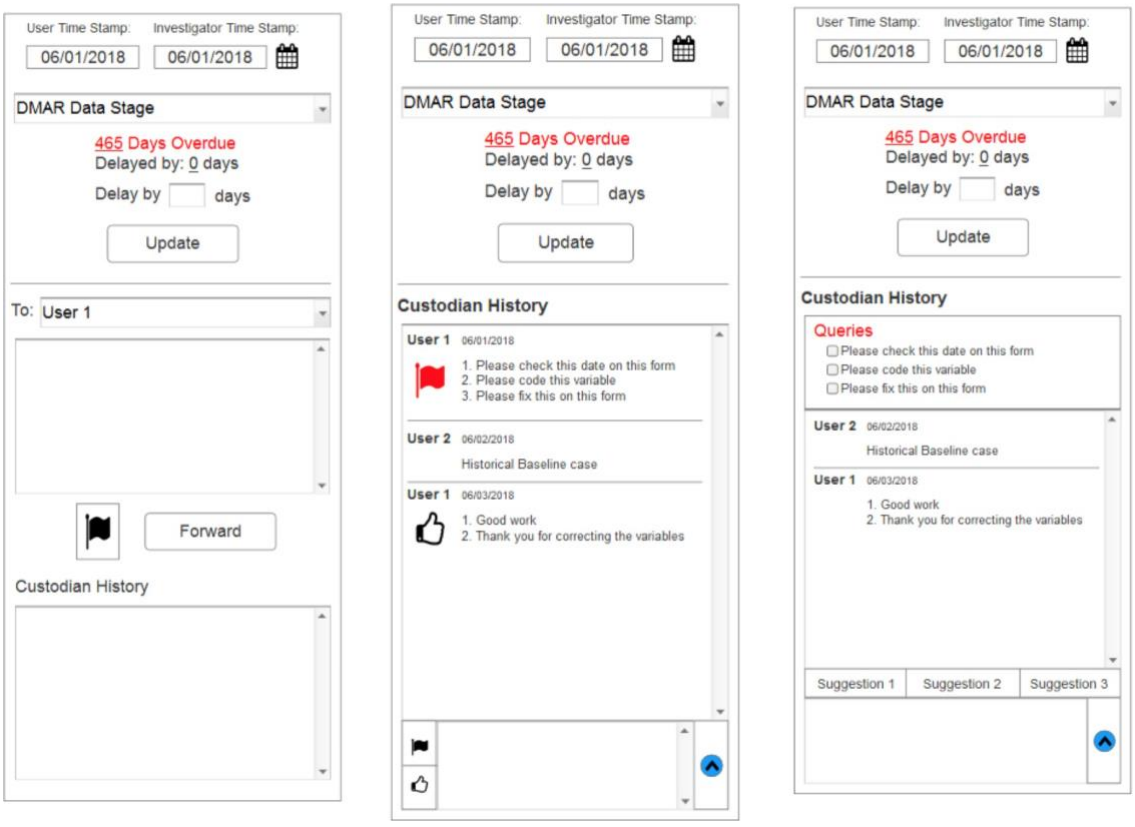


Figure 7.5: Messaging Module Prototypes

Features Addressing Design Requirements

Messaging module was proposed to address the requirements Req#4, #5, #7, #10, #13. The messaging module was designed to consolidate tracker section features such as message history, forwarding window, submission date, and the investigator time stamps section. This consolidation helped prevent the need for the user to operate using the pop-up forwarding window open (Req#7).

Figure 7.5 presents the 3 variations of the messaging module generated initially in the design process. Features included use of personalization elements such as buttons, ability to provide an automated suggestion and ability to create checklists.

Some other features discussed were incentivization of coders performance through reward schemes and gamification, and incorporation of links to training video in the messaging module.

Reviewer's Feedback

Overall the reviewers liked the idea of having the messaging module embedded on the review screen, which allowed them to quickly compose messages for the coder. Figure 7.7 shows the final design proposed and accepted by the reviewers by the end of the prototyping phase.

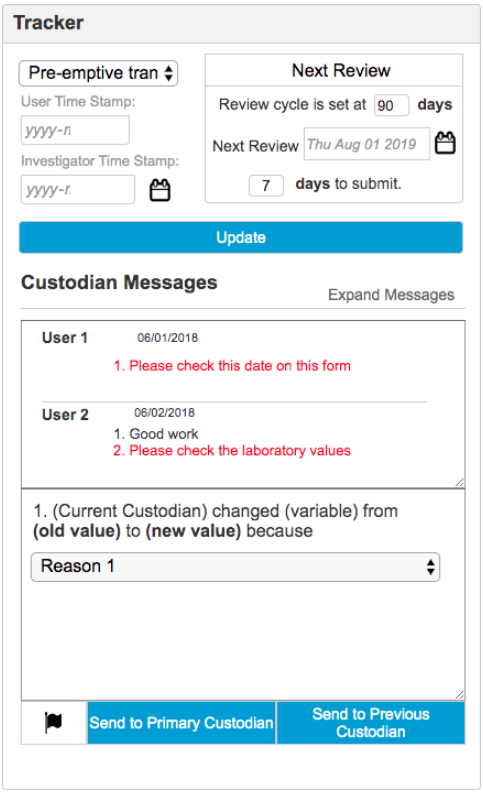


Figure 7.6: Messaging module design

The final design of the messaging module, as shown in figure 7.6, included the tracker section at the top, allowing the reviewers to update the investigation time stamp and assign the submission date. The bottom section comprised of the custodian messages section, which allowed the reviewer to compose new messages and view previous messages.

To address the need of finding the primary custodian (Req#13), quick send buttons such as “send to the primary custodian” and “send to previous custodian” were also discussed, but it was decided that the new design would include dropdown selector to select the next custodian. The primary and previous custodian would be marked explicitly in this dropdown list.

3) Form Comments

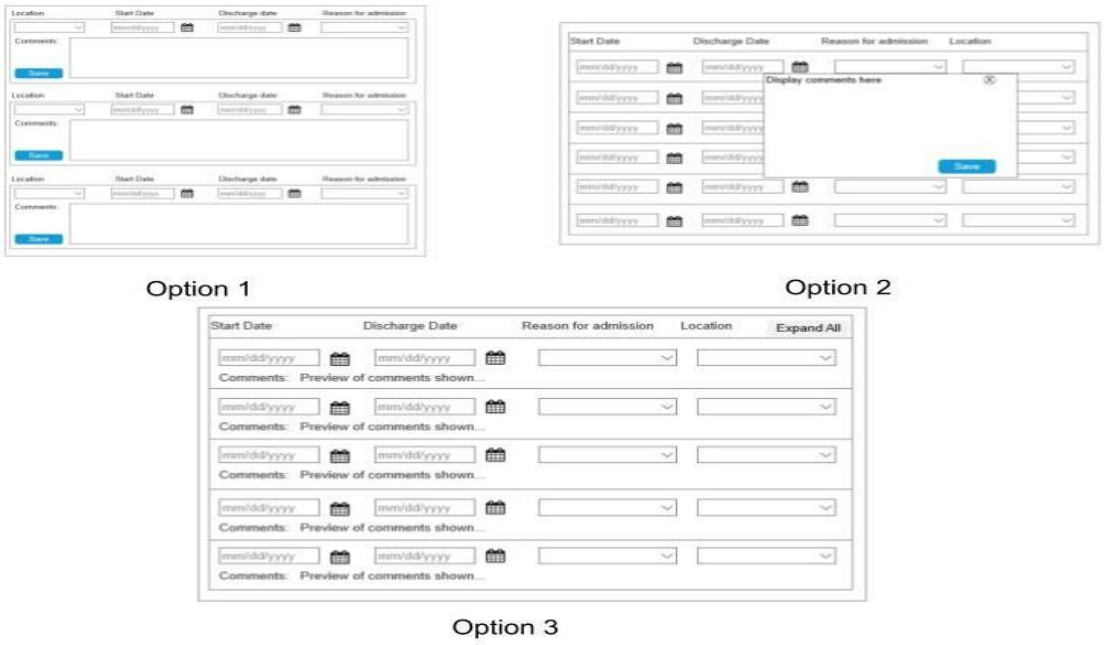


Figure 7.7: Prototype ideas for displaying form comments

Features Addressing Design Requirements

Design ideas were developed to address the specific requirement to view comments associated with each entry in hospitalization, status, visits, and access intervention forms (Req#8).

Figure 7.7 presents some of the designs ideated to address the requirements. The first option readily presented the user with all the comments associated with the entries, and the second option allowed the reviewer to hover over table entries to view the comments, the third option presented the comments in collapsed and shortened text format below the table entries. The show-all button in the third option allowed the reviewer to expand and view all comments in the table.

Reviewer's Feedback

Reviewers rejected the first option since they found it a little busy and mentioned that the design would hinder their ability to quickly assess the dates and visualize patient progress.

The second option was rejected since the reviewers did not want to have hover based interaction, with one reviewer stating:

> *"It can be irritating sometimes if your cursor keeps triggering a pop-up windows."*

Reviewers accepted the third design for displaying the form comments, the concept of the using show-all comments button to disclose all the comments associated with the table entry was accepted as the final design.

4) Custodian Inbox

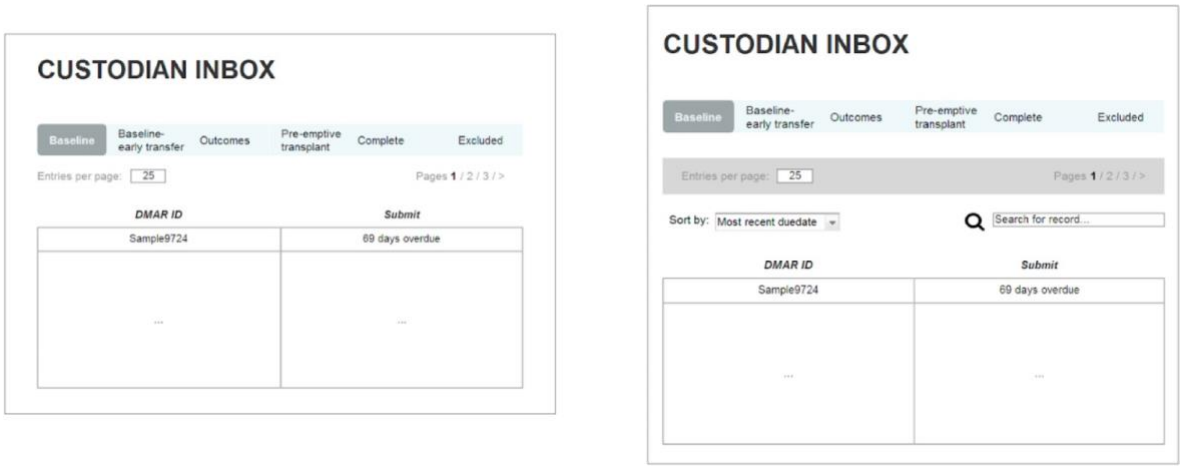


Figure 7.8: Custodian Inbox Prototypes

Features Addressing Design Requirements

Prototypes were designed to address the Req#12, #9. Figure 7.8 presents some of the final designs discussed.

To make the navigation and selection of patient records in the custodian inbox easier, the dropdown selector was removed, and the tab-based selection for the 6 data stages of SYSTEM X was suggested.

Reviewer's Feedback

The reviewers accepted the second design presented in figure 7.8. The second design allowed the reviewers to quickly switch between data stages, at the same time the search feature allowed the reviewer to search for a specific record, a feature which was not included in the earlier design.

7.2.2 Rejected Ideas

Due to the vast scope of the design ideas discussed during the low fidelity prototyping phase, this section limits the discussion to key rejected ideas or themes that influenced design decisions during the high-fidelity prototyping phase.

1) Summarization of data forms

Figure 7.9: Data form summarization ideas

In order to address (Req#9), summarization of data form was discussed with the reviewers. The intent of the summarized forms was to provide the reviewers with a quick view of the forms, to facilitate faster data review (Req#9). Some of the designs are presented in figure 7.9.

Reviewer's Feedback

Although the reviewers liked the summarization ideas during the initial prototype iterations, it was later decided to not change the design of the forms as the

summarization of forms would limit the reviewer's ability to make any changes to the form if required. The reviewers wanted to retain the ability to freely change the data values if needed.

2) Hover and toggle button interaction

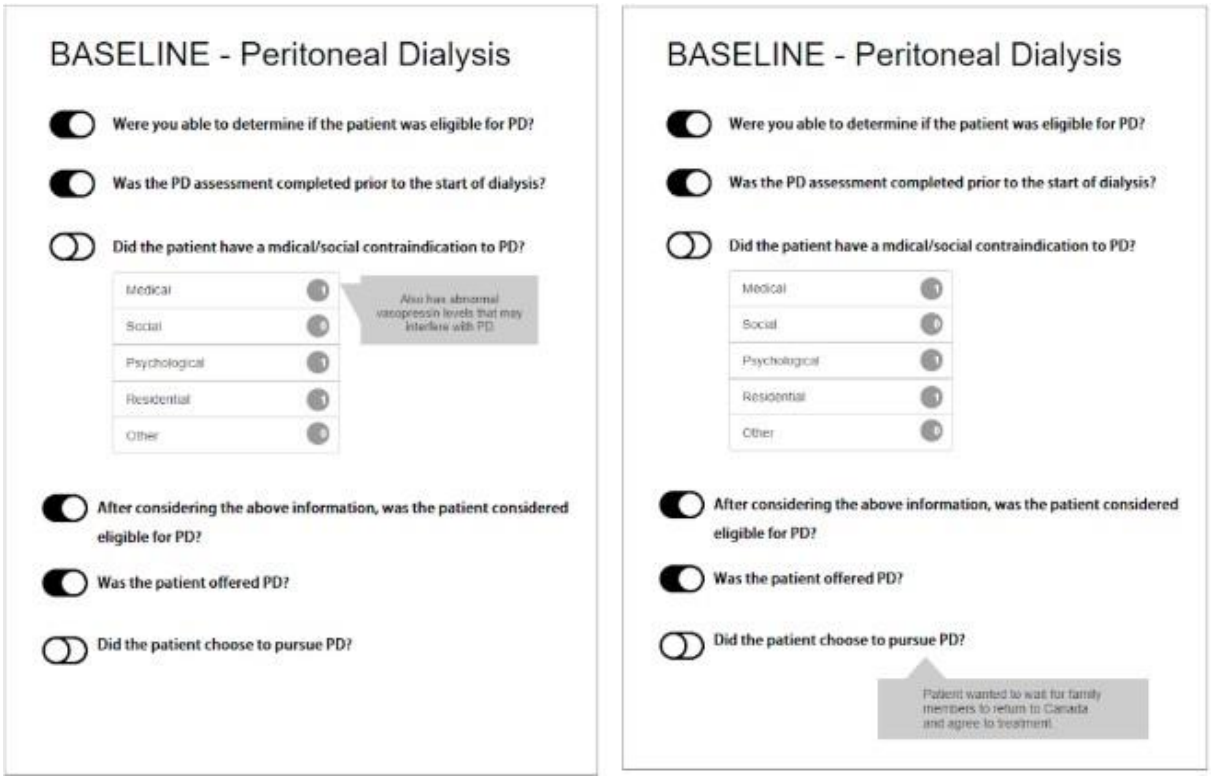


Figure 7.10: Hover and toggle interaction prototypes.

The toggle interactions were rejected by the reviewers as the toggle button would force the form questions to be answered in either a yes or a no (binary). Reviewers wanted to retain the ability to leave the answers as blank in case the answer was unknown. Whereas, hover interactions were also rejected as the reviewers found them annoying.

7.2.3 Summary of Low Fidelity Prototypes

By the end of the low fidelity prototyping phase, design ideas addressing individual design requirements were discussed and qualitatively assessed by the reviewer. Some new design requirements were also generated.

These new design requirements are discussed below:

- **Layout Reorganization:**

  The reviewers requested to have more space assigned for the messaging module by moving the submission date and investigator timestamp sections. This would allow more space to compose messages and view previous messages.

- **Accelerators**:

  Another requirement expressed during the evaluation of the low fidelity prototyping phase was the “next patient button”. The next patient button would allow the reviewer to move to the next patient record without the need to navigate back to the custodian inbox. Another requirement was to allow the reviewer to search a patient record and transfer custodianship of the record to themselves. Both the requirements addressed Req#9, #7.

- **Changes preview:**

  The Req#8 required the system to provide the reviewer and coders visibility of the previous changes made to the patient record. The reviewers wanted to automatically summarize the changes made by them and save them to the custodian messages without the need for them to explicitly type and explain the changes to the coders.

Table 7.1 presents a summary of the designs implemented to address the respective requirements. The second column in the table presents the requirements, and the third column presents the design ideas approved by the reviewers, the fourth column presents the design changes requested at the end of the low fidelity prototyping phase.

Requirement #	Design Requirement	Approved solutions	Design Updates Requested
Req#3	System System should have consistency and standards	**To be addressed**	
Req#4	System should aid user's memory (Recognition instead of recall)	• **Patient info bar** Present all the frequently accessed variables • **All custodian messages presented**	**Layout Reorganisation :** • Move the baseline data submission to patient info section • Move the outcomes date stamp to the patient info section
Req#5	System should support coders education	• **Messaging module**	
Req#6	Should make comments easily accessible	• **Show all comments button :**	
Req#7	Should reduce unnecessary pop-up and click interactions	• **Messaging Module** • **Inline Table Editing** Inline form elements editing, deletion	
Req#8	System should provide visibility of the changes made	**To be addressed**	**Changes Preview :** • Present the coders with summary of changes made by the reviewer
Req#9	System should support faster navigation and review workflow	• **Single page layout** Consolidated the forms and tracker and messaging section into one page. • **Embedded Messaging Module** allows the reviewer to compose messages on the same page and forward the case to the reviewer.	**Accelerators:** • Next patient button to navigate to the next patient record in the custodian inbox. • Transfer to myself button, for quick custodian change • Search and transfer patient record from the review screen
Req#10	System should support easier communication	• **Embedded messaging module**	
Req#11	System should be aesthetic and minimal	**To be addressed**	
Req#12	System should improve the custodian inbox	• Search and tab option implemented to quickly change between custodian list	
Req#13	System should provide information about the primary custodian	• Messenger section dropdown indicates primary custodian	

Table 7.1: Summary of the design requirements, approved solutions, and design updates requested.

Chapter 8

High Fidelity Prototyping

After establishing the layout and design components, the next stage of the research process involved the development of high-fidelity prototypes. The high-fidelity prototyping phase used the ideas, insights, and suggestions generated during the low fidelity prototyping phase to update and improve the design. The high-fidelity prototyping phase was also dedicated to addressing the requirement for an aesthetic and minimal system (Req#11).

The first section in this chapter will provide an overview of the design system, followed by the method used to develop the design system for SYSTEM X. The second section discusses the results of the high fidelity prototyping phase.

8.1 Method

8.1.1 Development of Design System

Similar to Lego blocks, a design system is a collection of standardized reusable components, for example, buttons, fonts, and cards elements, etc., that can be combined in different combinations to iterate over interface design ideas and still maintain the aesthetic consistency of the output. (Req#3, #11)

A commonly used methodology for the development of the design system is atomic design. Atomic design establishes that interfaces need to be built bottom-up. Similar to atoms forming the building block of all materials; shapes, fonts, and color form the basic building blocks of interfaces. Once these atomic elements are established, they can be combined to form, interface elements or molecules, such as form elements, buttons, etc. Lastly, using these molecules a complete user interface system can be built.

Owing to the systematic nature of the method, the atomic design technique was chosen to develop a design system for new SYSTEM X interface.

In order to build a design system for SYSTEM X, it was important to gain an understanding of the reviewer's expectation of colors, fonts, and design patterns. To achieve this, the reviewers were requested to create a mood board on Pinterest. The mood board was then analyzed by the author, and common design patterns of color schemes, shapes of interface elements and fonts were recorded.

Online color palette generators such as Palettefx and Canva Palette Generator were also used to extract possible color schemes. Screenshots of the mood board were passed as input to the color palette generator, which outputted color scheme suggestions based on the composition of colors present in the mood board. Sketch (an interface prototyping software) was then used to iterate over possible design system options.

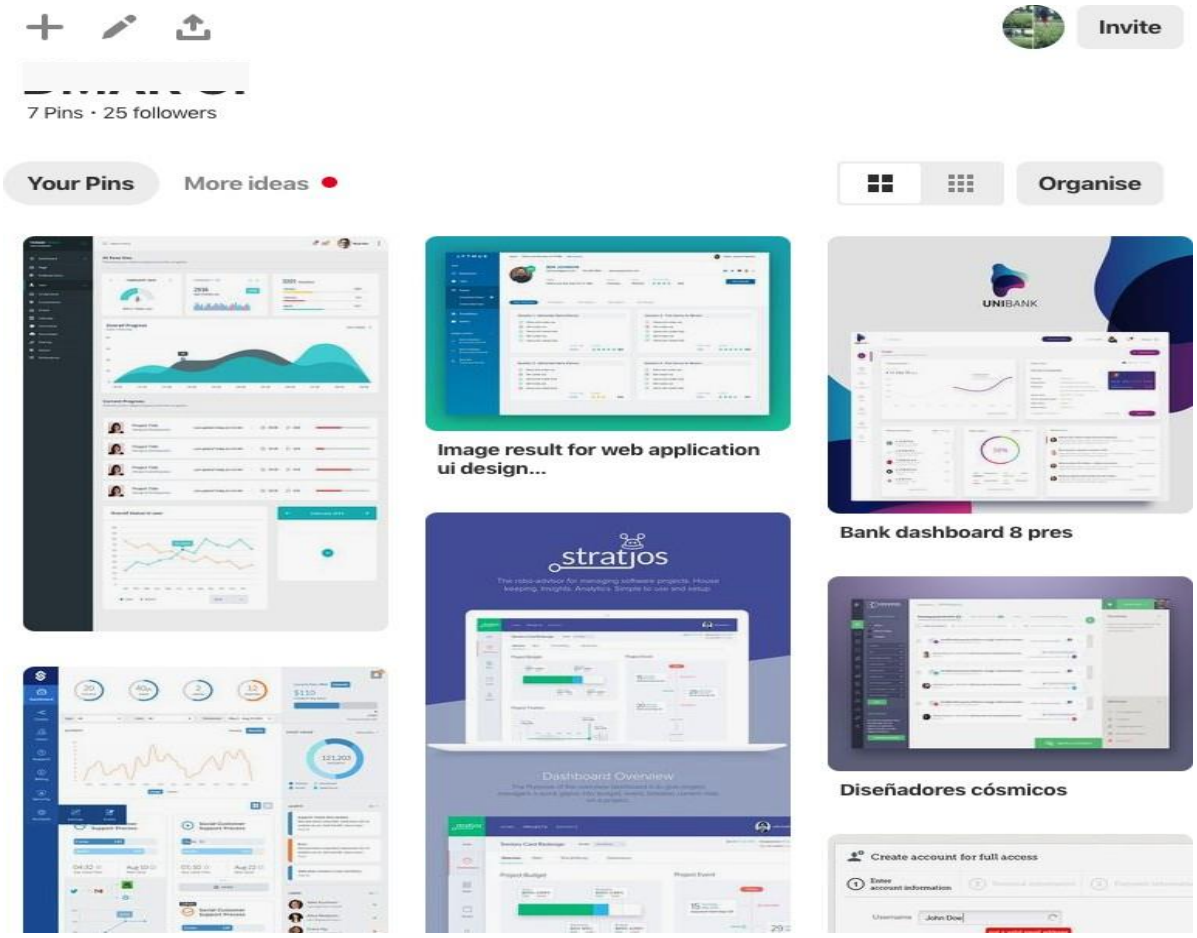


Figure 8.1: Moodboarding

Using the atomic design principles 6 design systems were ideated. The layout of the design prototypes (Figure 8.2) was based on the layout finalized during the low fidelity prototyping phase. These 6 prototype options were then shared with both the reviewers. The reviewers were asked to comment on the color scheme and form elements. Initial feedback was gathered using email and follow up discussions were conducted using telephonic interviews. The design system was then updated to incorporate color schemes and design element choices of the reviewers.

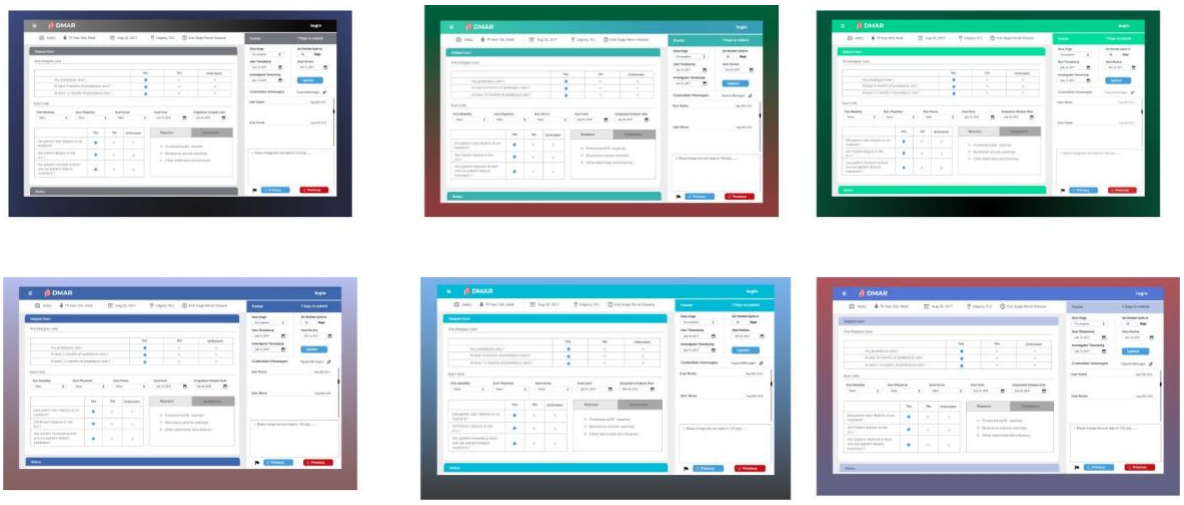


Figure 8.2: The 6 Color scheme options presented to the reviewer

Design system thus generated was used for the last iteration of high-fidelity prototyping. New design elements such as the summary of the changes modal and workflow accelerators such as the next patient button (Req#9) and transfer to me button (Req#9) were also incorporated in the design.

8.1.2 User Feedback

To gather feedback on the design proposed, feedback forms outlining the design of the individual forms, custodian inbox, and the review screen were created and shared with the reviewers for comments. Reviewers were also interviewed over the telephone to gather feedback.

After reviewing the final design, both the reviewers expressed their satisfaction. The approved design was then shared with the software development team for implementation.

8.2 Results and Discussion

This section is divided into 2 subsections outlining the results at the end of the design development phase:

- **Design System:** This subsection is dedicated to the discussion of the design system established by the end of the high-fidelity prototyping phase.
- **Design Updates:** This subsection is dedicated to the discussion of the designs developed to address the additional requirements of the changes modal and workflow accelerators.

8.2.1 Design System

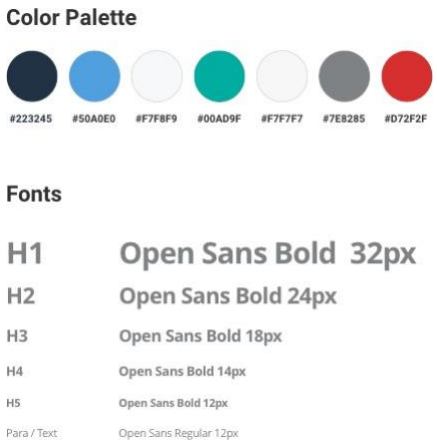


Figure 8.3 Design System

Both the reviewers were inclined towards blue color schemes. In the end, with the agreement of the reviewers, midnight blue and light gray were established as the

primary colors for the high-fidelity prototypes (figure 8.3). Light green, light blue, and red were selected as secondary colors. Lastly, a Sans-Serif font, Open Sans, was established as the base font-family.

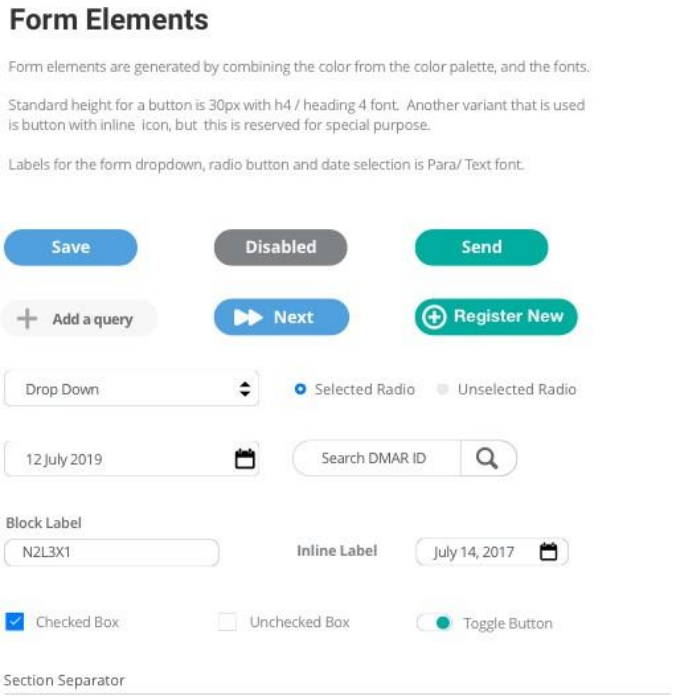


Figure 8.4: Design System II

By combining insights from the low fidelity prototyping phase and the pattern observed in the mood board, design options were developed for the form elements. The reviewers had a preference for designs that included a combination of icons and text during the low fidelity prototyping phase. Therefore icons were incorporated in the form element design. Round edged buttons were also observed to be the preferred choice based on the pattern observed in the mood board. All the design choices were validated by obtaining feedback from the reviewers.

The insights gained about the shapes and form were then combined with the color and fonts established earlier to generate the form elements as presented in figure 8.4.

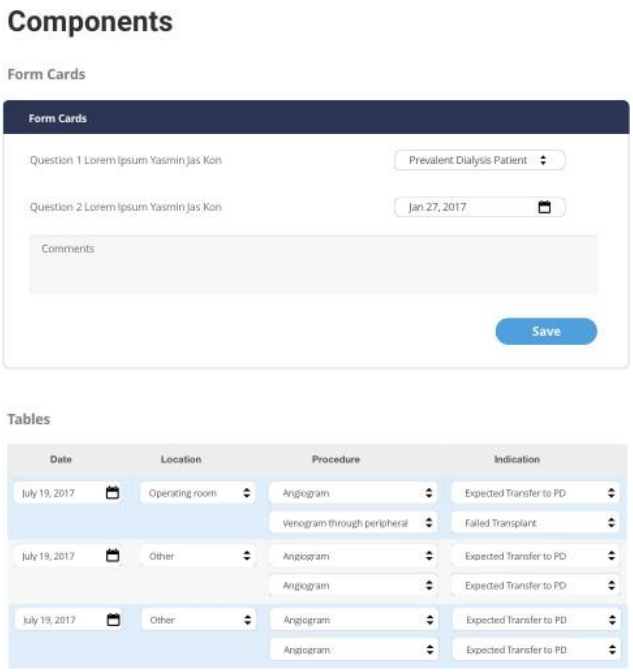


Figure 8.5: Design components

Next and the last step of the design system development involved the creation of interface components. The components (figure 8.5) were recreated based on the wireframes established during the low-fidelity prototyping phase, and by using the form elements and colors established earlier in the atomic design process.

8.2.2 Design Updates:

This section provides details about the design updates made and new components that were created to address the design requirements generated during the low the fidelity prototyping phase: 1) Layout reorganization, 2) Accelerators and 3) Changes Preview.

1) Layout Reorganization

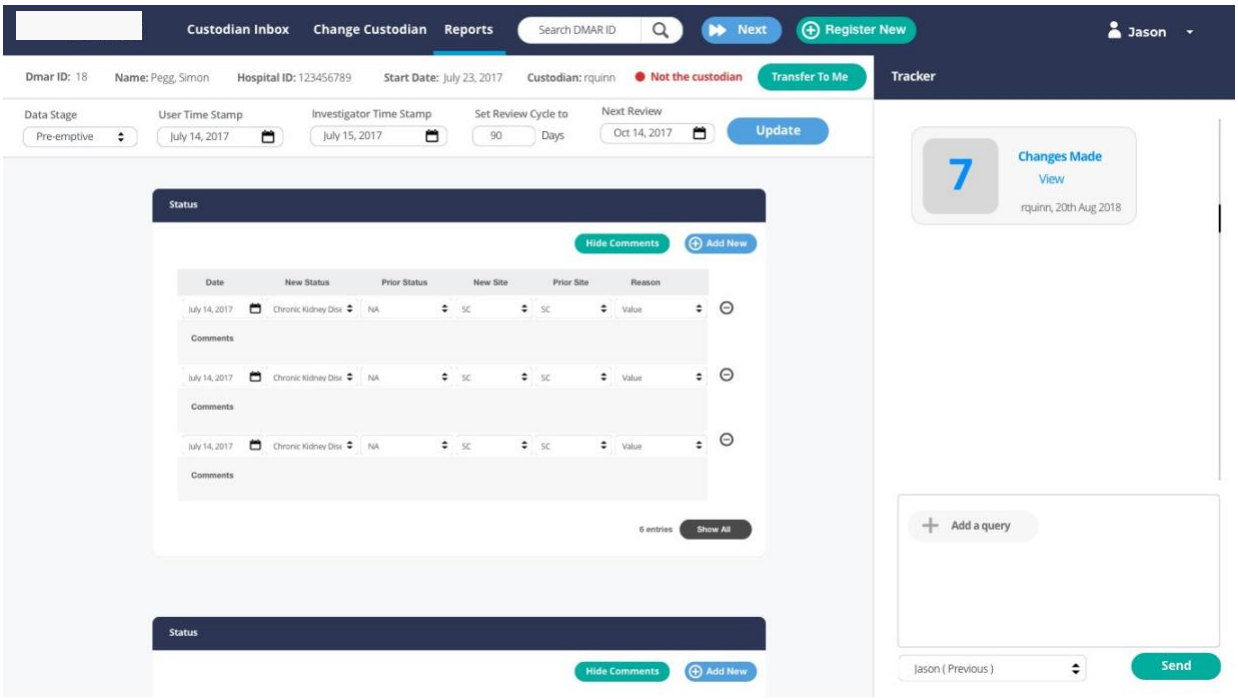


Figure 8.6: Final Design

The layout was reorganized to provide the reviewer more space in the messaging section as requested. As shown in figure 8.6, the submission date, investigator timestamp sections were moved below the patient info bar. This facilitated more space in the messaging module to view the previous messages and to compose new messages.

2) Accelerators:

Figure 8.7: Accelerators

The green bounding box in figure 8.7 shows the next patient button. It was designed to allow the users to quickly switch to the next patient record after completing the review of the current patient record. This eliminated the need for the reviewer to navigate back to the custodian inbox to select the next patient record to review.

The orange bounding box in figure 8.7 shows the search bar. The search bar was added to the navbar to allow the reviewers to search for patient records from the reviewer's screen. The search results were designed to be presented in a pop-up window, as shown in figure 8.8. The transfer to me button in the pop-up window allowed the user to transfer custodianship to themselves.

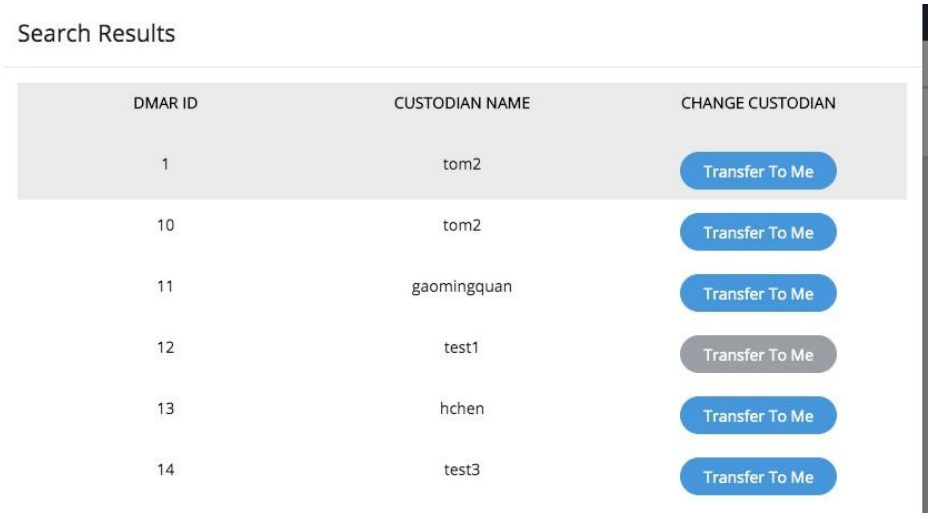


Figure 8.8: Search results

3) Changes Preview :

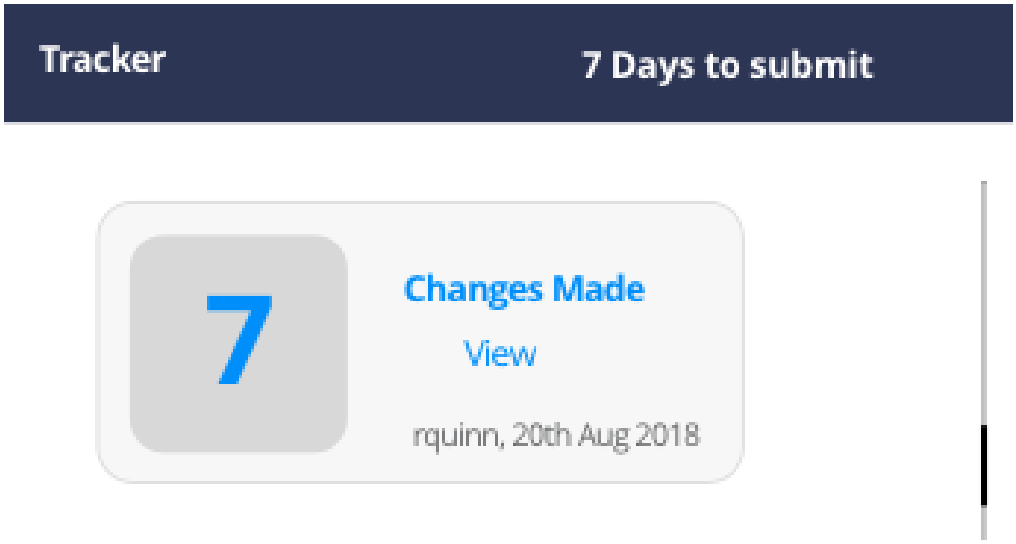


Figure 8.9: Changes Preview in the messaging module

As shown in figure 8.9, the Changes Preview notification was designed to provide the user with the summary of the changes made by the previous custodian. The notification presented the users with the details about the number of changes made along with the date and the name of the custodian who made the changes. The Changes Preview was automatically generated and eliminated the need for the reviewer to textually explain the changes they made in the forms to the next custodian or coder. This feature addressed the Req #8.

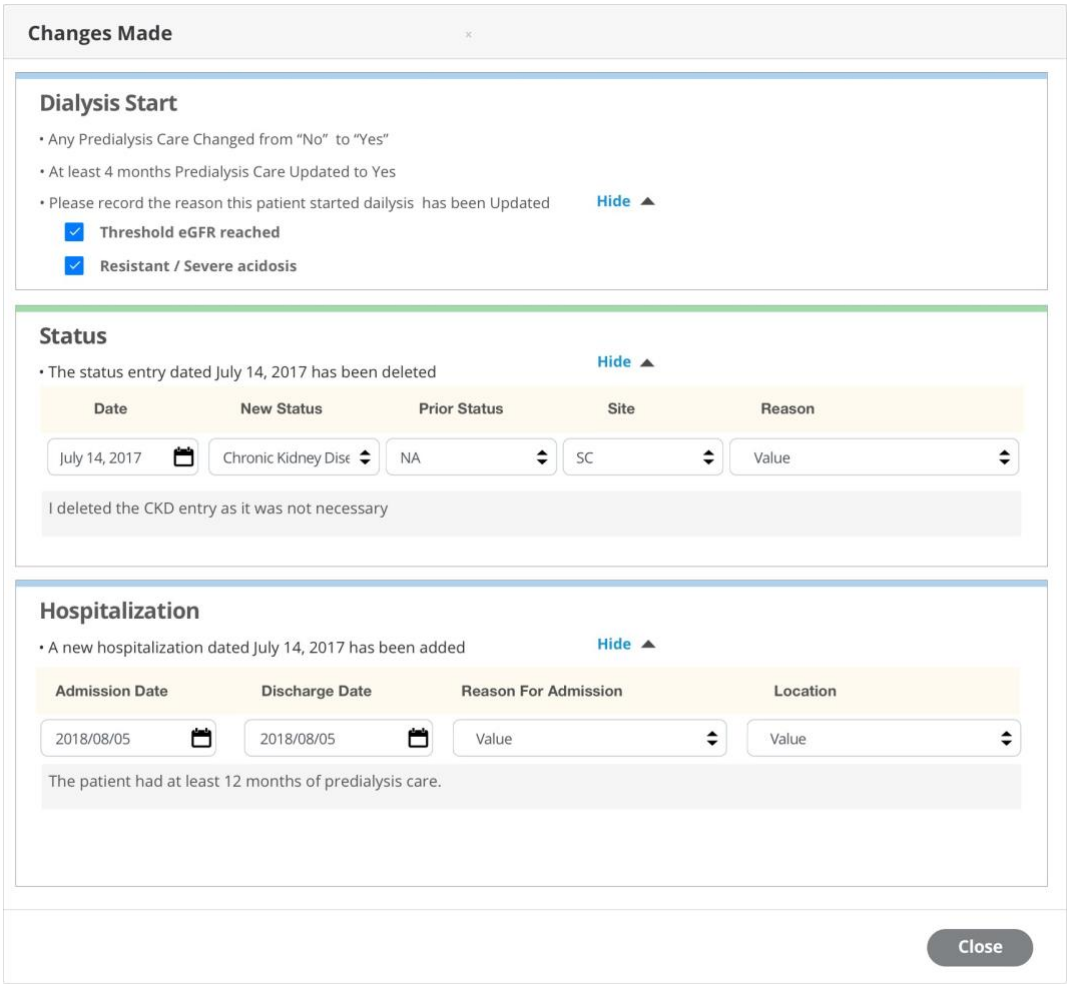


Figure 8.10: Changes Pop-up Modal

Upon clicking the Changes Preview notification, users were presented with a pop-up modal that summarized the changes. This pop-up modal is shown in figure 8.10. To encourage recognition instead of recall (Req#4), the changes presented in the pop-up modal were organized and segregated based on the form sections. This allowed the reviewers and the coders to quickly assess and associate the changes made to individual forms.

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8.3 Conclusion

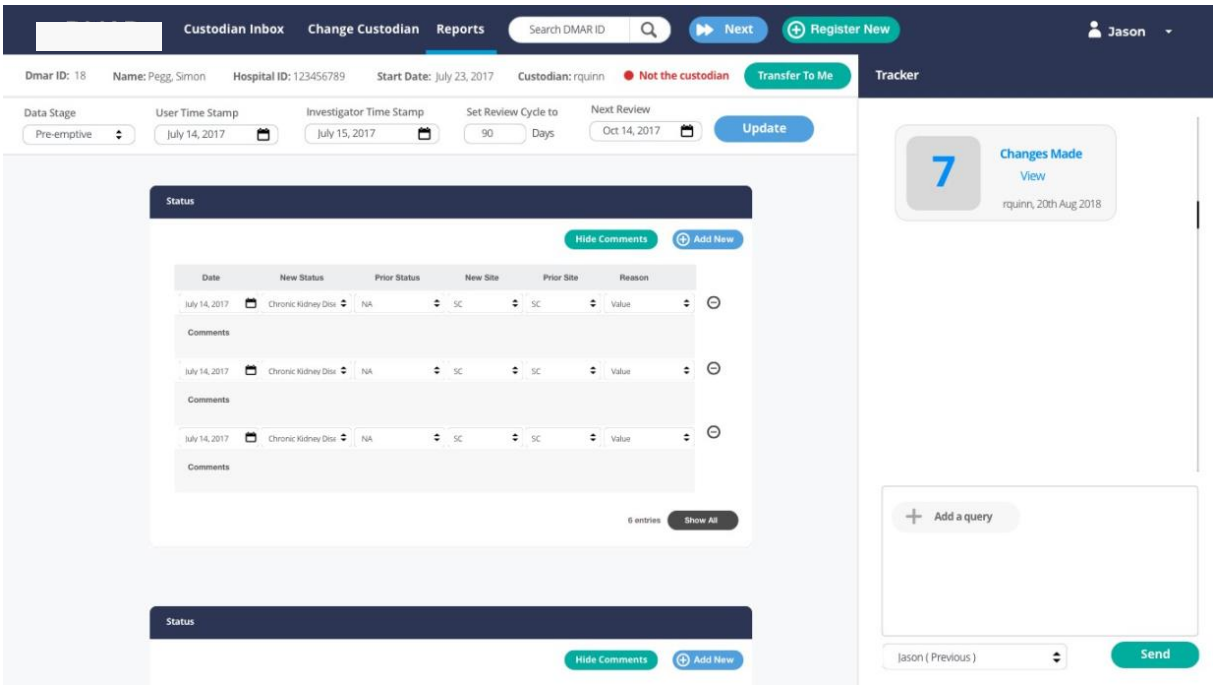

Figure 8.11: Final Design

By the end of the high-fidelity prototyping stage, all the design requirements established during the user research phase and the updates requested at the end of the low fidelity prototyping phase were addressed by the new design. The approved final design, as shown in figure 8.11, was shared with the technical implementation team.

A summary of the design requirements and associated solution established at the end of the design research is presented in table 8.1.

Requirement #	Design Requirement	Approved Design Solutions
Req#3	System System should have consistency and standards	• **Design System**
Req#4	System should aid user's memory (Recognition instead of recall)	• **Patient info bar** Present all the frequently accessed variables • **All custodian messages presented** • **Layout Reorganisation** 1) Move the baseline data submission to patient info section 2)Move the outcomes date stamp to the patient info section
Req#5	System should support coders education	• **Messaging module**
Req#6	Should make comments easily accessible	• **Show all comments button**
Req#7	Should reduce unnecessary pop-up and click interactions	• **Messaging Module** • **Inline Table Editing** Inline form elements editing, deletion
Req#8	System should provide visibility of the changes made	**Changes Preview :** • Present the coders with summary of changes made by the reviewer
Req#9	System should support faster navigation and review workflow	• **Single page layout** Consolidated the forms and tracker and messaging section into one page. • **Embedded Messaging Module** allows the reviewer to compose messages on the same page and forward the case to the reviewer. • **Accelerators:** 1) Next patient button to navigate to the next patient record in the custodian inbox. 2) Transfer to myself button, for quick custodian change 3) Search and transfer patient record from the review screen
Req#10	System should support easier communication	• **Embedded messaging module**
Req#11	System should be aesthetic and minimal	• **Design System**
Req#12	System should improve the custodian inbox	• Search and tab option implemented to quickly change between custodian list
Req#13	System should provide information about the primary custodian	• Messenger section dropdown indicates primary custodian

Table 8.1: Design Requirements and Associated Solutions

Chapter 9

Summative Analysis

The involvement of the reviewers throughout the design development process ensured that the new design was continually assessed and evaluated qualitatively against the design requirements **(Req #3, #4, #5, #6, #7, #8, #10, #11, #12, #13).** The reviewer's approval for implementation of the design at the end of the high-fidelity prototyping phase confirmed that the qualitative requirements were met satisfactorily.

As the last step of the research, summative analysis was conducted for the quantitative assessment of the new design. In this step, Keystroke Level Model (KLM) [32] was employed to assess the improvements in the workflow of the SYSTEM X review process (Req#9) by comparing the task execution times of the new design with the old design. In this research KLM was chosen since it overcomes the following challenges:

1. The new design interface was not yet implemented in the SYSTEM X software and therefore actual reviewer testing could not be performed.

2. Since the reviewers were involved in the design development process, it could potentially bias their performance on the new system.

9.1 Procedure

To perform keystroke-level modeling, the first step is to determine the task scenarios for comparison. Once these task scenarios are established, they are broken down into sequence of actions required to complete the task. These are actions such as moving the mouse, pressing the keyboard keys and not abstract instructions such as Logout of the system, etc. These actions are also called operators.

After the task is broken into individual actions/operators, standard timings associated with each of these operators (figure 9.1) are added to calculate the task execution time.

	Operator	Time (ms)	Required	Information	Associated with
Visual	Look	550	-	Looking at item at a known position	NGOMSL | CPM
	Perceptual_processor	100	-	One cycle of perceptual processor	HIP
	Proofread	330	-	Time to carefully read one word.	NGOMSL
	Read	260	-	Time to read one word.	NGOMSL
	Search	1250	-	Search for item at an unknown position	NGOMSL
	Saccade	30	-	One saccade (rapid eye movement)	CPM-GOMS
Audition	Hear	400	label	Listen to someone speak	NGOMSL | CPM
& Speech	Say	400	label	Speak	NGOMSL | CPM
Cognition	Attend	50	-	Shifting of attention to stimuli	CPM-GOMS
	Cognitive_processor	70	-	One cycle of the cognitive processor	HIP
	Ignore	50	-	Remove item from working memory	NGOMSL | CPM
	Initiate	50	-	Initiate motor process	CPM-GOMS
	Recall	550	-	Retrieve information from memory	NGOMSL | CPM
	Store	50	label	Place item in working memory	NGOMSL | CPM
	Think	1250	-	Generic operator for thinking	NGOMSL
	Verify	1250	-	Generic operator for thinking	NGOMSL
Motor	Click	320	-	Click of a mouse	NGOMSL | CPM
	Drag	230	-	Drag item across touchscreen	
	Grasp	750	-	Reach and grasp an object with hand	NGOMSL
	Hands	450	-	Move hands to mouse or keyboard	NGOMSL | CPM
	Keystroke	280	-	Pressing a single key (e.g., Enter or Esc)	NGOMSL | CPM
	Motor_processor	70	-	One cycle of motor processor	HIP
	Point	950	-	Movement of cursor via a mouse	NGOMSL | CPM
	Write	2000	label	Handwriting (2 seconds per word in label)	NGOMSL
	Swipe	170	-	Swipe or flick touchscreen gesture	NGOMSL
	Tap	450	-	Touch a series of touchscreen buttons	NGOMSL
	Turn	800	-	One turn of a knob or dial	NGOMSL
	Touch	490	-	Press a touchscreen button	NGOMSL
	Type	280	label	Typing a series of keys	NGOMSL | CPM
System	Wait	1000	-	Movement of cursor via a mouse	NGOMSL | CPM

Figure 9.1: Operator timing look-up table

9.2 Methods

For conducting KLM analysis, the author spent 1 week analyzing the notes gathered during the task analysis and user interview phase, to identify and establish the scenarios that incorporated the most frequent tasks carried out by the reviewers on SYSTEM X. At the end of the analysis, 7 scenarios representative of the review process were generated.

These scenarios were then broken down into individual actions/operators required to complete the task on both the old and the new design. The task execution time was then calculated using the execution time lookup table, as shown in figure 9.1. Lastly, the task execution times of individual scenario on the old and new design were compared and analyzed.

9.2.1 Test Scenarios

The 7 scenarios developed for KLM analysis are discussed below:

Scenario 1: Complete baseline review:

This scenario emulated baseline patient record review process demonstrated by the reviewer during the video walkthrough (user research). The assumption for this scenario was that the reviewer started at the login screen, and then selected the first baseline case in the custodian inbox. Lastly, after checking all the forms, the reviewer typed a message for the next custodian and completed the review of the record. This scenario quantified the performance of the new layout design developed to address Req#9.

Scenario 2: Add comments/query to the messaging section:

This scenario emulated the task in which the user goes through 3 different forms, and makes a drop-down change, identifies 3 corrections required and inputs these correction requests into the forwarding window/messaging module section. The assumption was that the reviewer had selected the case to be reviewed and is on the review screen. This scenario quantified the efficiency of the messaging module designed to address Req#10.

Scenario 3: Search for a case and transfer to yourself:

This scenario emulated the task in which the user searches for a specific patient record and then transfers the record to themselves. The assumption in the scenario was that the reviewer already knows the SYSTEM X ID of the case they are searching for. This scenario quantified the performance of the accelerator designed to address the Req#9.

The scenarios 4-6 below, emulate a situation where the reviewer adds, deletes, or updates a form entry in either the Status, Visits, Access Interventions, and Hospitalization forms. These scenarios quantified the performance of the table design established to address the Req #6, #7.

Scenario 4: Adding a new status entry to the patient record:

The assumption in this scenario was that the reviewer had clicked or scrolled to the Status form, and the reviewer knew the details of the status entry to be added.

Scenario 5: Delete a status entry:

The assumption in the scenario was that the reviewer had clicked or scrolled to the Status form, and the reviewer knew the status entry to be deleted.

Scenario 6: Update a status entry:

The assumption in this scenario was that the reviewer had clicked or scrolled to the Status form and knew the status entry to be updated, as well as the details about the information to be updated.

Scenario 7: View comments for individual status entry:

The last scenario emulated the reviewer checking the individual comments associated with status entries. The assumption was that the reviewer had clicked or scrolled to the status form and had the intent of investigating the entries for the comments. This scenario evaluated the performance of “show all comments” button designed to address Req#6

9.3 Results and Discussion

The results of the keystroke-level model are presented in Table 9.1 below. The table presents the task execution times of the scenarios for old and new SYSTEM X design, along with the time saved and the percentage time saved. Figure 9.2 presents the comparison of the task execution times on the old and new system.

Scenario #	Old Design (seconds)	New Design (seconds)	Time Difference	% Time saved
Scenario 1	135.4	96.8	38.6	28.51%
Scenario 2	142.4	112.5	29.9	21.00%
Scenario 3	24.1	6.9	17.2	71.37%
Scenario 4	46.6	40	6.6	14.16%
Scenario 5	7.8	4.2	3.6	46.15%
Scenario 6	11.8	6.9	4.9	41.53%
Scenario 7	16.4	6.1	10.3	62.80%

Table 9.1: KLM task execution time comparison results

Scenario 1: Complete baseline review process: In scenario 1, the new design was able to achieve a significant reduction in the execution time. The new design reduced the task execution time by 28.51%, saving 38.6 seconds of the reviewer's time. This was attributed to the new design allowing the user to scroll through the data forms instead of clicking and switching between the forms required in the old design.

Scenario 2: Add comments/query to the messaging section: In scenario 2, a 21% reduction was observed in the task execution time. This saved 29.9 seconds of the reviewer's time in entering the message into the messaging/forwarding window. The reduction in task execution time was attributed to the new design of the messaging module, which was embedded in the review screen and eliminated the need for the reviewer to switch between the forwarding screen and the form screen to compose messages.

Scenario 3: Search for a case and transfer to yourself: In scenario 3, task execution time was reduced from 24 seconds to 7 seconds and thereby achieving a 71% reduction in task execution time. The saving in execution time was attributed to the search bar(accelerator) designed to address the Req#9. Search bar allowed the user to search and assign custodianship of the patient records to themselves without the need to navigate away from the review screen.

Figure 9.2: KLM results

Scenario 4,5,6: Add, update, or delete a new status entry to the case:

In scenario 4, 5, and 6, the new design showed 14.16%, 46.15%, and 41.53% reduction in execution time, respectively. The reduction in execution time was attributed to the new table designed (Req#6,#7) for the status form. It allowed the user to change the input entries inline without the use of a pop-up window, as needed in the previous design.

Scenario 7: View comments for individual status entry: In scenario 7, 62.80% reduction in execution time was observed. This was attributed to “show all comments” button introduced in the new design to address the Req#7. The “show all comments button” allowed the reviewers to view all the comments associated with individual entries in the table simultaneously, whereas the previous design required the user to click on individual entries and view the comments in a pop-up window.

9.4 Conclusion

The keystroke level model was used to quantitatively assess and compare the performance of the new design with the old design of SYSTEM X.

The results substantiated and quantified the improvement in the workflow achieved with the new design. The new design was able to reduce the time it took for the reviewers to complete a baseline review task (Req#9) by 28.51%, thereby saving 38.6 seconds of the reviewer’s time in each review.

Assuming that on an average, a reviewer checks 700 patient records in a month (based on insight from user interviews), implementation of the new interface design would result in saving of 7.5 hours of reviewer’s time, thus reducing their workload immensely.

9.5 Limitations

There were some limitations to this analysis. Firstly, KLM assumes that no errors occur during task execution. Secondly, KLM assumes that the users show expert behavior. Thus, the usability of the new system should be tested with actual users to accurately determine the performance improvement achieved by the new design.

Chapter 10

Conclusion and Future Work

This thesis explored the application of user-centered design methodology, in understanding and developing a new interface design for SYSTEM X, an electronic medical record. SYSTEM X employs a data review process which ensures high data quality by involving experts-in-the-loop (clinicians) to periodically assess, validate, and correct the data entered into the system by the coders (data entry professionals). The focus of the research was to reduce the workload for the clinicians by developing a new interface that caters to their specific workflow needs.

The user-centered design process started with the user research phase, where heuristic evaluation of the SYSTEM X interface was conducted to identify usability issues. Next, video walkthrough approach was used to get an initial understanding of the data review process and the reviewer's workflow. User interviews were conducted with reviewers and coders, to further our understanding of the review workflow and to identify the pain-points and bottlenecks experienced by them. Design requirements were established based on these insights at the end of the user research phase.

These design requirements were then used to develop low and high fidelity prototypes. The involvement of the reviewers and their continuous feedback throughout the user research and design development phase ensured that the new design was continually assessed for qualitative requirements. The designs were improved until reviewers were satisfied.

Lastly, the Keystroke Level Model (KLM) was used to quantitatively assess the improvements achieved by the new design in the review workflow. The results showed that the new design was able to reduce the time required for the baseline

case review task by 28.51%, thereby substantiating workflow improvement and successfully achieving the design objective.

Though the constraints on the design and the user group made this a challenging research project, user-centered methods applied creatively and in new ways helped us address the problem of improving medical data review workflow while reducing clinician workload.

It is recommended that similar user-centered design studies be conducted with other EMR systems to understand and improve methods that ensure high data quality in healthcare by focusing on the specific needs of the users involved in the process. It is also be interesting to design a study understand the impact on medical data quality through the implementation of the new SYSTEM X design.

References

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Appendices

Appendix A

Structured Interview Questions

General Questions:

- Who are the users ?
- How much time do you spend on system ?
- Who are the reviewers ?
- Who is a custodian ?
- Why do you call them users ?
- Do all data entries have a comments associated with it ?

Inclusion:

- What is inclusion criteria ?
- Why is it important ?

Baseline Start:

- What is start date ?
- What is access ?
- Is it possible to have two access at the same time ?
- Why do you use 0,1 or 2 as mode of data entry ?

Baseline-Comorbidities

- What are comorbidities ?
- What do you use comorbities for ?
- Lab values origin?

Baseline-Comorbidities

- What are comorbidities ?
- What do you use comorbities for ?

Outcomes – Hospitalization, Status and Visits ?

- What does hospitalization mean ?
- What is status form ?
- What is visits form ?
- What is the relevance of each form ?

Tracker Section:

- What are delay days ?
- What is forwarding ?
- Are all messages limited to the users ?
- What is investigator time stamp ?
- What is the point of delay days if the example shown is 456 days overdue?
- “Location” is missing from for Access Intervention, would you still like it to be displayed?
- The “Visits” page is missing, would you still like it to be included in the interface for the reviewers

HD and PD Assessment

- What is PD ?
- What is HD ?
- How do you coduct the assessment ?
- Are “Were you able to determine if the patient was eligible for PD?” and “Assessed for PD” the same thing?

Access Intervention

- What is intervention ?
- What are the procedures ?
- How long are the comments?
- Intervention comments: scroll over, click and fill a text box, all visible at all times
- How many interventions are there usually ?
- Do you have add delete or edit multiple interventions at the same time?