INTEROPERABLE SMART HEALTHCARE MANAGEMENT APPLICATION USING MHEALTH AND DIGITAL TECHNOLOGIES SPECIALISED FOR EMERGENCY HEALTHCARE PROVIDERS

A THESIS SUBMITTED TO AUCKLAND UNIVERSITY OF TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

Supervisor

Dr Roopak Sinha and Dr Reem Abbas

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By

Varsha Pai

School of Engineering, Computer and Mathematical Sciences

Abstract

In emergency settings, delayed communication and lack of access to accurate patient data can hinder medical procedures conducted by healthcare providers, therefore reducing the chances of positive medical outcomes among patients in emergency cases. Despite healthcare entities such as hospitals, ambulance service providers, specialists, and general practitioners adapting to independent digital healthcare applications, interoperable patient data exchange from one healthcare application to another is highlighted as a major challenge in both academic literature and real life. Moreover, decentralised healthcare databases storing redundant patient information cause more operational issues for both paramedics and emergency hospital staff when triaging urgent cases.

This study investigates the integration of digital health technologies, specifically mHealth applications, cloud computing and electronic health records, in improving operations such as emergency response triaging and patient administration conducted in emergency settings. Like many other global ambulance service providers, St John New Zealand experienced significant operational challenges during 2020-2022 due to the increase of emergency cases during coronavirus disease of 2019 (COVID-19). Paramedics experienced unprecedented circumstances of overrun hospital beds, a deficit of ambulance vehicles, staff burnout, and inaccurate patient data, which impeded positive patient outcomes.

The thesis explores the possibility of exchanging interoperable patient data between two crucial healthcare providers in emergency settings; paramedics and emergency department (ED) hospital units, using one mHealth application, a centralised cloud database and electronic health records. The capability was extended to include two additional healthcare providers, primary and secondary care to encompass less severe emergency outcome scenarios. The design-driven approach to support this thesis was implementing a prototype for smarter healthcare management in emergency settings. The prototype was named touchPoint to signify the point of interoperable patient data transfer between emergency healthcare providers. The development was accomplished using Xcode integrated development environment (IDE), Swift and Objective-C programming languages. Open Electronic Medical Records (OpenEMR) was used as a centralised database along with the international Fast Healthcare Interoperability Resources (FHIR) standards defining the rules and specifications of exchanging electronic health records between different systems. The results from the prototype showed the possibility of improving the data communication between emergency healthcare providers in real-life. The novelty lies in the ability to offer an efficient and convenient alternative approach to the current manual process.

This thesis does not include any references to personal patient information or questionnaire results conducted by humans. To test the prototype, open-source anonymised data sets in the form of application programming interfaces (APIs) were used from official healthcare development websites, including FHIR New Zealand and OpenEMR. Technical artifacts can be found in the Appendix and GitHub link provided in Chapter 4.

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Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the qualification of any other degree or diploma of a university or other institution of higher learning.

Varsha Pai

Signature of student

Acknowledgements

Writing this thesis has been a rather strenuous yet fulfilling journey. It has been a prominent milestone in my master's degree, spanning almost four years, enduring major life changes, including a career change, moving to a new country, and battling the impacts of the COVID-19 pandemic whilst working full-time.

Like many, the closed borders around New Zealand meant I was also locked out from obtaining on-ground support at AUT, especially face-to-face discussions with my supervisors and fellow students. Although this journey felt like a ship stranded at sea, I was fortunate to have experienced sailors onboard. Firstly, I would like to express my sincere gratitude to Dr Roopak Sinha, my primary supervisor, who agreed to help me complete my thesis from Australia during the pandemic. He carefully guided me through the process with a lot of patience. I want to acknowledge the valuable contribution made by my secondary supervisor, Dr Reem Abbas. Her subject matter expertise was instrumental in accelerating the final stages of my thesis. Despite hindrances like the three-hour time difference and travel commitments, I always received good support and rapid feedback throughout this journey. I am extremely grateful for your inputs, persistence, and composure, especially on days when I felt I wouldn't make it.

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Intellectual Property Rights

Chapter 1

Introduction

1.1 Rationale of the study

Since the COVID-19 Omicron outbreak, St John New Zealand stood down 758 operational and clinical staff members due to testing positive or being symptomatic (Tokalau, 2022). Therefore, fewer than 1,000 paramedics were available across New Zealand to respond to approximately 606,503 urgent medical incidents (Correspondence, 2022). Staff shortages amid the Omicron outbreak forced patients to use their private vehicles for quicker hospital transport rather than relying on St John ambulances (Newshub, 2022). There are four types of ambulance responses to patient callouts as shown in the Figure 1.1. The intricate details of each of these responses were found in (S. J. O. Website, 2022). Code red refers to life-threatening or time-critical cases where an ambulance is sent instantly with sirens. Life-threatening cases include cardiac arrest, unconsciousness, shock, and shortness of breath. However, time-critical cases refer to strokes that commenced within the last three hours of the callout. The patient is a potential candidate for thrombolysis or fractures with distal limb ischemia. Code orange signifies potential serious cases where the ambulance is dispatched at average speed. These cases include symptoms such as abdominal pain without other signs and meningitis with a moderate

level of consciousness. Code green defines non-urgent cases. In the event of a code red callout, the objective is to have the incident addressed within 15 seconds and for the ambulance to arrive at the location of the incident within eight minutes (Dicker, Davey, Smith & Beck, 2018).

Code colour	Work order status	Description
Code red	Status 1	Life-threatening or time-critical cases
Code orange	Status 2	Potential serious cases
Code green	Status 3 and 4	Non-urgent cases
Code white/black	Status 0	Dead

Figure 1.1: Ambulance responses and code statuses

However, during the omicron outbreak, code red callouts were subjected to over 40 minutes of wait time (Newshub, 2022) as observed in Figure 1.2. Similarly, code orange callouts were subjected to over 5 hours of wait time. Finally, code green callouts were subjected to 11 hours of wait time (Kronast, 2021). Due to the increased occurrence of code red and orange callouts, paramedics were subjected to wait times exceeding 20 hours before the ED hospital units triaged patients (Mahase, 2021).

Hospital	Average time (minutes)	Number of ambulances vehicles waiting ED units
Auckland City Hospital	48	7514
Middlemore Hospital	41	6461
Waikato Hospital	41	5843
Christchurch Hospital	33	4214
North Shore Hospital	39	4217
Waitakere Hospital	40	1917
Palmerston North Hospital	32	1548
Hawkes Bay Hospital	29	1066
Tauranga Hospital	24	602
Southland Hospital	30	655
Taranaki Base Hospital	25	413
Nelson Hospital	28	416
Dunedin Hospital	26	564
Rotorua Hospital	30	526
Whangarei Hospital	25	362
All Hospitals	*33*	*38948*

Figure 1.2: Wait times outside emergency department units at 15 hospitals around New Zealand.

One potential contributing factor to this time delay in ED units is the disintegration and "lack of interoperability creating completely isolated systems" between healthcare applications (Reddy et al., 2009; Ribeiro, de Jesus, Claro & Moura, 2021; Amr, Elgarej, Benmoussa, Mansouri & Qbadou, 2021; Thun, Lehne, Sass & Essenwanger, 2019a, p.1). This thesis explores the integration of digital health technologies such as mHealth technology, cloud computing and electronic health records to connect four crucial emergency healthcare providers; paramedics, ED hospital units, primary and secondary healthcare providers within in the New Zealand healthcare system. Specifically the exchange of patient data between the four healthcare providers, potentially improving challenges within emergency settings. The thesis explores the possibility of exchanging patient data between the four different emergency healthcare providers using digital health technologies in an interoperable manner.

The novelty lies in offering a new digital solution to improve the existing technical challenges related to patient data exchange between emergency healthcare providers

and potentially improve the current manual process within emergency settings in New Zealand.

1.2 Significance of the study

Smart healthcare management applications have proven to assist the medical industry in various aspects, including managing general health and medical administrative systems (Tunc, Gures & Shayea, 2021; Salahuddin, Al-Fuqaha, Guizani, Shuaib & Sallabi, 2018; Kute, Tyagi, Sahoo & Malik, 2022).

While numerous academic papers discuss utilising mHealth technology to help patients schedule medical appointments and prescriptions, the healthcare industry has yet to explore how to use this technology in emergency settings thoroughly and effectively in conjunction with other digital technologies (Price et al., 2014; Fiordelli, Diviani & Schulz, 2013; Rowland, Fitzgerald, Holme, Powell & McGregor, 2020; Byambasuren, Beller, Hoffmann, Glasziou et al., 2020). Clinicians currently conduct telehealth appointments and clinical Pilates consultations using independent applications (Osborn, Ajakaiye, Cooksley & Subbe, 2020; Ahmed, Gagnon, Hamelin-Brabant, Mbemba & Alami, 2017; Thirumalai et al., 2018). However, there is still "little guidance on best practices" hence the need to identify best approaches for integrating mHealth applications with other healthcare platforms that address technical challenges encountered in emergency settings (Genes, 2017, p.3).

1.3 Research aims and objectives

This research aims to improve the major technical challenges faced within emergency settings by utilising digital health technologies as integrated solutions.

The research objectives were first to understand common requirements of mHealth

applications across different healthcare areas. Secondly, investigate the technical implementation challenges of mHealth applications in emergency settings. Finally, suggest a possible approach to solving these technical challenges using digital health technologies into a solution for emergency settings.

A systematic literature review on mHealth applications analysing trends and challenges in emergency settings was one of the research contributions. And hence an academic, practical, design-based digital solution to obtain improvement within emergency settings.

1.4 Research questions

The research questions were developed to analyse common requirements of mHealth applications across different healthcare areas. Secondly, to determine which common requirements cause technical challenges when implemented in emergency settings. Finally, to show evidence derived from the practical and design-rich solution to explore the potential of digital health technologies in improving data communication within emergency settings.

1.4.1 Research question 1

RQ1: *What common requirements need to be considered when developing mHealth applications?*

This research question was created to investigate recent mHealth applications related to various healthcare areas specifically common requirements which need to be considered during the design and development phases. This research question is answered in Chapter 2.

1.4.2 Research question 2

RQ2: *Which of the technical requirements from **RQ1** represent major challenges in the implementation of mHealth applications in emergency settings?*

This research question filtered for technical challenges out of the common requirements found in RQ1, which demonstrated significant difficulties when implementing mHealth applications in emergency settings. The term technical in RQ2 refers to the technical facets of software development and maintenance, such as programming languages, user accessibility, data security and privacy, and data interoperability. This research question is also answered in Chapter 2.

1.4.3 Research question 3

RQ3: *How can the major challenges identified in **RQ2** be translated into a mHealth application design, which can be integrated into emergency settings?*

This question created the technical design required to overcome the major challenges identified in RQ2, while also considering the common requirements found in RQ1. The prototype design is covered in Chapter 4.

1.4.4 Research question 4

RQ4: *To what extent does the mHealth application design created in **RQ3** succeed in improving communication between healthcare providers in emergency settings?*

This last research question concluded and further highlighted the novelty of this thesis by developing and evaluating the newly built prototype. The results and evaluation are covered in Chapter 4.

1.5 Thesis Structure

The thesis is constructed in the following format which is also illustrated in the Figure 1.3; Chapter 1 introduces the common themes related to this research, rationale and significance of this study, concluding with the research aims and questions. Chapter 2 presents a systematic literature review (SLR) to identify common requirements of mHealth applications across different healthcare areas and technical challenges when implementing within emergency settings. This chapter also addresses the first two research questions. Followed by Chapter 3, which describes all intricate components of all the research methods undertaken to answer the four research questions. Chapter 4 illustrates how the findings from Chapter 2 were integrated into the newly built prototype's design and development phases. This chapter also presents the test results and hence evaluation of the prototype, proposing the potential improvement in emergency settings. An overview of all research findings, threats to validity and future work are summarised in Chapter 5.

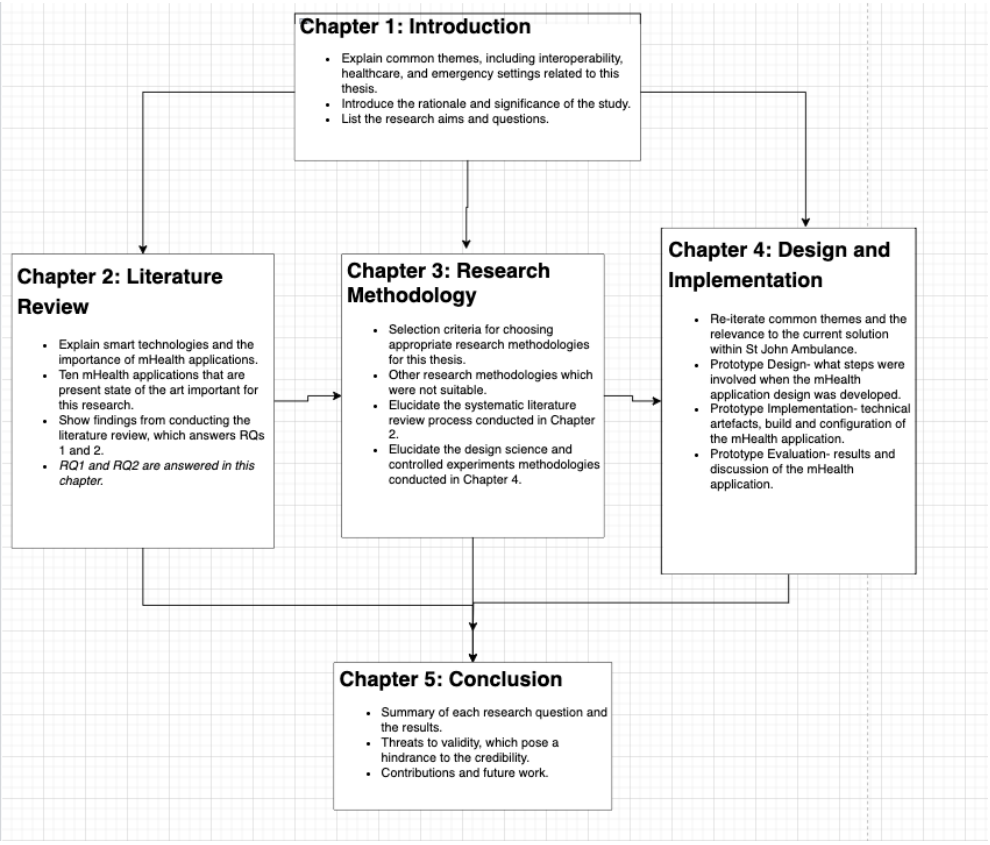

Figure 1.3: Visual diagram of the thesis structure

Chapter 2

Literature Review

The aim of this chapter is to answer research questions RQ1-RQ2 by identifying common requirements which need to be considered when building mHealth applications. Followed by technical challenges which can hinder the implementation of mHealth applications in emergency settings. A total of 43 papers were identified during the systematic literature review. Ten mHealth application papers were identified to determine the common requirements for developing mHealth applications. Meanwhile, 20 papers were researched in addition to the previous ten to understand each of the six common requirements further. Three additional papers were selected to understand the two major technical challenges- interoperability, security, and privacy. The SLR process is explained in detail in Chapter. 3

2.1 Background

This section explains the important terms used throughout the SLR and the subsequent chapters of the thesis.

2.1.1 Smart healthcare technologies

The concept of smart healthcare involves integrating advanced technologies into the traditional healthcare industry (Y. Chen, Zhang & Wei, 2022; Tian et al., 2019; Liu & Tao, 2022). This results in more personalized, flexible, and diversified healthcare services that are convenient for patients. Smart healthcare has revolutionized the way digital systems create value in the modern healthcare industry (Pan, Ding, Wu, Yang & Yang, 2019). Medical devices have been improved, treatment processes, disease diagnosis and management have become optimized. As a result, the organizational structure, ecosystem, and innovative model of modern healthcare services have also changed. (Su, Hou, Qi, Li & Ji, 2021; Sukkird & Shirahada, 2015). Elements of smart healthcare technologies include Electronic Health Records (EHR), Internet of Things (IoT), mobile internet, mobile health (mHealth) applications, Big Data, artificial intelligence (AI), 5G and cloud computing (Alshehri & Muhammad, 2020).

Smart healthcare services can contribute to improving the quality of healthcare in various ways. One major advantage is that it can reduce costs due to network externalities. Since smart healthcare services rely on network infrastructure, they benefit from network externalities. This means that the value of being connected to the network increases as more people join it (Miller & Tucker, 2014). Smart healthcare offers a reliable, efficient, and simple health monitoring system that can guarantee high-quality healthcare services while significantly reducing the expenses incurred by hospitals or assisted living centres (Nasr, Islam, Shehata, Karray & Quintana, 2021). By using smart healthcare systems, healthcare providers such as doctors, patients and surgeons can optimise connected healthcare systems (Kamruzzaman, 2021). This promotes the flow of interdependent relationships within the healthcare ecosystems (H.-L. Chu & Chiang, 2013). Utilizing information technology can enhance the bonds between healthcare organizations across different regions (Spanò, Di Paola, Bova &

Barbarino, 2018; Shirazi et al., 2021). Smart healthcare endeavours to link patients, doctors, hospitals, medical equipment, information systems, and intelligent systems via information and internet technologies. This facilitates the collection and integration of medical cloud data, forming medical cloud data centres, which allow for information sharing and interactions among patients and various healthcare providers (Su et al., 2021).

Mobile internet (network or data or broadband) is an internet connection delivered through a mobile network using a reception tower (Buchanan et al., 2001; Chae & Kim, 2003; Alshehri & Muhammad, 2020). It is from the reception tower that a mobile phone can access the internet. The use of mobile internet is crucial in smart healthcare technology as it enables people to access healthcare services through their smartphones and tablets. This enables healthcare providers, other stakeholders and patients to exchange health information and services regardless of their location. Mobile internet in smart healthcare technology provides timely access to healthcare services, promotes patient engagement, and ensures personalized care. It empowers individuals to manage their health and well-being while facilitating efficient and effective healthcare delivery.

Cloud Computing

Cloud computing is a modern approach to providing diverse computing services through networked media, such as the Internet (Sultan, 2014). This innovative methodology enables users to access a range of computing resources on demand without needing to maintain or invest in physical infrastructure. The benefits of cloud computing include scalability, cost-effectiveness, and flexibility, making it a popular choice in smart healthcare technology projects. Cloud computing offers a variety of computing services including servers, data analytics, databases, and software which can be accessed through the Internet (Dang, Piran, Han, Min & Moon, 2019). It also provides benefits of rapid

deployments, versatile resources and cost-effectiveness (Dang et al., 2019). Healthcare is experiencing rapid growth in cloud computing, which offers easy and widespread access to unlimited resources through a pay-per-use system. This innovative approach enables developing, delivering, and using services in new and creative ways (Griebel et al., 2015). More importantly, the healthcare sector has improved due to the integration of cloud computing (Dang et al., 2019). As a result, health professionals can offer faster, more efficient, and better healthcare services, resulting in a better patient experience. In addition, cloud computing technology improves healthcare services, enhances the patient experience, and reduces paperwork for health professionals.

2.1.2 Significance of mHealth applications in healthcare

Mobile health (mHealth) is a part of electronic health or eHealth and it is utilised to provide health services to consumers through mobile devices (Mechael, 2009). This refers to mobile and wireless technology and multimedia in healthcare systems that can be accessed remotely (R. Istepanian & Lacal, 2003). mHealth denotes the use of wireless technologies to transmit and collect various health-related data and services. With the aid of mHealth, patients can be monitored in real-time, and medical care can be directly administered through mobile (Latif et al., 2017). Robert Istepanian coined the term mHealth to describe the use of new mobile communication and network technology within the healthcare industry (Galetsi, Katsaliaki & Kumar, 2022). At the 2010 mHealth Summit held by the Foundation for the National Institutes of Health (FNIH), mHealth was defined as the provision of healthcare services using mobile communication devices such as mobile phones, smartphones, PDAs, laptops, and tablet PCs (Jameel, Valmaggia, Barnes & Cella, 2022).

A World Health Organization (WHO) report showed that higher-income countries have more mHealth activity than lower-income countries (Gauld et al., 2012). The

European Region had the highest activity, while the African Region had the lowest. The study also revealed a significant shortage of healthcare workers worldwide, with 57 countries having critical needs and a total deficit of 2.4 million health professionals (Naicker, Plange-Rhule, Tutt & Eastwood, 2009). The shortage of healthcare workers directly impacts the adaption of mHealth technology. In twelve African countries, the average density of physicians, nurses, and midwives per 1,000 population are only 0.64, compared to the United States 2.6. Although mHealth has potential in industrialised countries, it has primarily emerged as a solution for developed countries due to the rise of mobile phone use and adequate healthcare workforce. Mobile phones are better suited for providing healthcare services in developing countries due to their portability, low power consumption, small size, and ability to operate with limited infrastructure. mHealth is a practical approach to expanding healthcare access to more people in developing nations and enhancing the capabilities of their healthcare systems to deliver quality care (Kong, Fu, Hong, Liu & Luo, 2022; R. S. Istepanian, 2022).

mHealth applications use mobile communication technologies to deliver health information, services, and support programmes for a healthy lifestyle (Yaylacicegi et al., 2013). Mobile sensors, tablet computers, cellphones, and other devices that connect to cellular networks (3G or 4G), Wi-Fi, or Bluetooth are all examples of mobile communication devices. The capability includes text messaging (SMS), apps for smartphones and tablets, mobile web browsing, video calling, MMS/pxt, and enabling the mobile use of technologies like QR code scanning and GPS locating.

The usefulness of mHealth applications is determined by accessibility, functionality, usability, security and proof of effectiveness, confirming the user requirements and expected behaviour of the users are met (Palos-Sanchez, Saura, Rios Martin & Aguayo-Camacho, 2021; Vera, Nöel & Taramasco, 2019; Kopka et al., 2023). The usability of mHealth applications refers to how well specific users can use a system, product, or service to achieve their objectives effectively, efficiently, and satisfactorily. The

main factors which determine the usefulness of mHealth applications are usability, relevance, personalisation and interoperability. Usability and relevance offer user-friendly interfaces which are compatible with different mobile devices for different users. In contrast, personalisation caters to users' individual preferences. Interoperability assures the mHealth application can exchange patient data with different healthcare systems.

A substantial advantage in integrating mHealth applications into emergency settings is that healthcare providers, researchers, and patients can conveniently access patient data on their mobile devices to assist their work (Eberle, Loehnert & Stichling, 2021). This thesis focuses on the integration of mHealth applications into emergency settings. Hence, explicit details on how mHealth technology described in this section was utilised and integrated to solve technical challenges are covered in Chapter 4.

2.2 Present state of art

This section identifies and evaluates current mHealth applications selected as part of the SLR to answer the first two research questions:

RQ1: *What common requirements need to be considered when developing mHealth applications?*

RQ2: *Which of the technical requirements from **RQ1** represent major challenges in the implementation of mHealth applications in emergency settings?*

The subsections below provide an overview of each mHealth application's main features, software, technology, gaps and improvements. Considering mHealth technology raises several potential risks to users, including security and privacy issues among users (Schnall, Higgins, Brown, Carballo-Dieguez & Bakken, 2015), technology fragmentation challenges (Ndlovu, Scott & Mars, 2021) and ethical issues (Labrique, Kirk,

Westergaard & Merritt, 2013), each mHealth application was closely examined to identify the technical challenges which influenced the design and development inputs for the prototype named touchPoint. This prototype was built to provide a practical solution and support the findings of this thesis.

2.2.1 CMDigiHealth

CMDigiHealth is a mHealth application developed to serve as a mobile information management application on iOS and Android platforms (W. Boonchieng et al., 2021; E. Boonchieng, Boonchieng, Senaratana & Singkaew, 2014). Key features of CMDigi-Health included distributing health surveys to large groups of people within the Saraphi district of Chiang Mai Province in Thailand rapidly and efficiently. Although the Saraphi District Health Office and Saraphi District Hospital collected health information such as death rates and symptoms related to diagnosed medical conditions for preventive healthcare services in the district, the health information could not be cross-checked with other health information. *CMDigiHealth* was developed with the vision to correlate groups of people belonging to "governmental social services sources such as public schools and community health service providers" with underlying health determining factors such as "identities and jurisdictions of community leaders, availability and use of local natural resources, populations and demographics of incidence of disability and other direct or indirect health-related data from each household" (E. Boonchieng et al., 2014, p.350). The two main parts of the mHealth application consisted of "resident and individual data forms. The front-end technologies included PHP, HTML5 and MySQL as a database management system (DBMS). Mobile device issues and training non-technology savvy users prior to the release of the mHealth application in the community were the two improvement areas for the next iteration of this mHealth application. During the study, data collectors used mobile devices such as smartphones

and tablets with different operating systems (iOS or Android), versions, display sizes and features. The data technicians at call centres were responsible for fixing technical problems encountered by the data collectors. These technicians specialized in either iOS or Android systems and had to fix the same issue multiple times for different mobile devices. Since it was hard to anticipate these issues, technical expertise was needed throughout the study to ensure that compatibility problems were solved quickly. One recommendation for future iterations was recruiting developers with expertise in iOS and Android platforms to streamline fixing problems across both platforms. Also, it is beneficial to standardize smartphones/tablets among intended users to alleviate these compatibility issues. This is because some mobile devices were unsuitable during this CMDigiHealth study. Subsequently, a few smartphones did not support 3G SIM cards on the 850MHz frequency or could not locate GPS coordinates.

2.2.2 CoCoV vs NEMO

Two mHealth applications named *CoCoV* and *NEMO* were developed to create two different examples of exchanging sensitive clinical information (Schwab et al., 2021) in Netherlands. *CoCoV* features an online data transfer functionality for collecting inimical event reports following vaccination. In contrast, *NEMO* provides a straightforward visual data transfer functionality to aid, follow and control side effects in cancer patients undergoing oncological treatment. The *CoCoV* application was developed to track the events that transpire post-receiving a COVID-19 vaccination. In contrast, the *NEMO* application was designed to monitor any untoward incidents that raised during cancer treatment. Both mHealth applications utilized modern web technologies. *NEMO* was built into desktop HCP and mobile clients; using the Electron platform and NativeScript, respectively. *CoCoV* was developed using TypeScript, HTML5 and CSS. In order to assess and compare the mHealth applications, the results were allocated to the following

categories: data, structure, communication, security, and client. *CoCoV* focused on semantic interoperability as it replaced the current face-to-face data transfer in a doctors' clinic. A diary-like feature allowed individuals to record adverse events post-vaccination. However, the technology could not substitute general practitioners' duties; hence the diagnosis and treatment required a face-to-face discussion, specifically in emergencies. Both approaches required considerable modifications for safety measures. The *CoCoV* app used an online data transfer method to collect anonymous data on a central server. This anonymous data was wrapped into a JSON structured document, which was sent to a RESTful API (Representational State Transfer Application Programming Interface) endpoint, which allowed for the integration of established medical standards like HL7 (Health Level 7) and FHIR (Fast Healthcare Interoperability Resources). Healthcare professionals can develop easily maintainable software applications through these endpoints and established medical standards without additional hardware. This makes it easy to integrate the app into existing clinical IT systems. Despite all the benefits, semantic interoperability and data governance needed improvement from a development perspective for future iterations of *CoCoV*.

2.2.3 MGH STAT

Healthcare providers such as residents, interns, specialists and physicians did not have expansive knowledge and experience handling "low frequency, high acuity emergencies, such as those that might result from COVID-19" (A. L. Chu et al., 2021, p.4). These healthcare providers in conjunction with important stakeholders developed a plan to design and implement a mHealth application called *MGH STAT* to manage this situation. *MGH STAT* empowered emergency healthcare providers to quickly react to medical emergencies by accessing the latest clinical guidelines, and expert consultants in Massachusetts. The positive results derived from the surveys from 1,100 healthcare

providers regarding *MGH STAT* mHealth applications showed that mHealth applications can help emergency healthcare providers handle life-threatening emergency cases during the COVID-19 pandemic. The early engagement of emergency healthcare workers integrated into the development team guaranteed positive outcomes and adaptivity. The development team "mapped out the typical workflow, experiences, and challenges of responding to emergencies at the bedside" (Shanafelt, Ripp & Trockel, 2020, p.5). Almost all stakeholders voiced the opinion that emergencies were often fear-inducing and confusing. Thus, the integration of digital technologies in STAT further supported in completing their tasks and hence patient healthcare. The user experience and user interface UX/UI design were constantly improved through iterative changes based on feedback from healthcare professionals in the development team. Testing was conducted on every new iteration under strict conditions. The UX/UI was constantly improved to ensure ease of use by highly reducing the number of buttons, words and complex diagrams of medical information. Almost all surveys responded towards the recommendation of MGH STAT application to interns and residents as it was easy to use. 97.5% of the healthcare professionals surveyed agreed *MGH STAT* assisted in handling acute life-threatening emergencies, whereas 91.4% agreed *MGH STAT* improved patient outcomes for acute life-threatening emergencies. The significance of involving senior healthcare professionals and other important stakeholders throughout the development process, as their support is crucial for a successful launch and widespread acceptance of the initiative in the hospital. Moreover, these individuals can serve as advocates for the initiative among their colleagues. Similarly, clinicians who wish to create digital tools such as STAT during a crisis should present a persuasive case to their institutional leaders, such as Hospital Incident Command System (HICS), explaining how digital innovation deserves high priority within the institution, enabling them to access the necessary resources and expedite completion.

2.2.4 SaveMe

SaveMe was a project that used the combination of a smartphone application and GPS to secure users facing an emergency and connect to the associated emergency contact person set and nearby users, hence extending the capabilities to a mHealth application in Bangladesh (Tripti, Farhad, Iqbal & Zaman, 2018). The mHealth application used phpMyAdmin to securely store user data, whereas information about the incident location was stored in Firebase, a cloud server. The technical challenge found in this project were constant internet connection and Bluetooth capability. To send messages and receive notifications from other users, the internet connection needed to be on always. Additionally, the hardware button required mobile phones to have strong Bluetooth capability.

2.2.5 e-CoVig

All information about the *e-CoVig* application was found in (Raposo et al., 2021b). *e-CoVig* was a highly adaptable mHealth application developed for the remote monitoring of symptoms in COVID-19 patients, which was integrated with wearable sensing devices in Portugal. *e-CoVig* delivered fundamental features for patients required to report symptoms and essential clinical information to healthcare professionals. Patients sent heart rate, body temperature and blood oxygen saturation information using the specialised wearables integrated with the main application. The overall system was equipped with a mobile application, a web/cloud platform, and a specialised device that measured temperature and SpO2 at a low cost. The system's architecture was adaptable and adjusted to different operating conditions. This is because the mHealth application acted as an electronic diary, however, there were other features such as audio-based respiration and cough analysis and video-based heart rate information. The system had optical character recognition (OCR) functionality that allowed *e-CoVig*

to read data from commercial devices like oximeters and thermometers. The mobile application automatically sent data to the web/cloud application in real-time, making it easy for medical staff to monitor multiple users simultaneously without lengthy phone call interactions. The system was checked for feasibility and completed a primary deployment in a nursing home, which showed optimistic results.

2.2.6 Safe Delivery application- SDA

Rwanda is known to have the highest maternal and neonatal deaths, aside from frequent complications in post-partum haemorrhage (PPH) and newborn asphyxia amongst African countries. Hence, the integration of *SDA* facilitated "easy access to maternal and neonatal guidelines for routine and emergency obstetric and neonatal care" (Nishimwe, Ibisomi, Nyssen & Conco, 2022, p.2). Statistics highlighted 290 deaths per 100,000 live births in the maternal department and 20 deaths per 1000 live births in the neonatal department, despite 90% of the live births occurring in the presence of healthcare providers. This study investigated using a newly built mHealth application called *SDA* which acted as a clinical decision-support tool in basic emergency obstetric and newborn care (BEmONC).

The common contributing factors included healthcare providers lacking quick and timely access to clinical guidelines and pregnancy complications information during delivery care. The intervention of *SDA* in neonatal resuscitation showed a significant improvement as the stable outcome out of 213 newborn complications increased from 31% to 72% once the *SDA* was downloaded amongst healthcare providers. Similarly, unstable outcomes reduced from 62% to 28% after *SDA* intervention amongst healthcare providers. The deaths in neonatal resuscitation were recorded at 7%, which changed to zero deaths after the intervention of *SDA*. The *SDA* difference in PPH was similar to

neonatal, with a reduction from 3% to zero deaths after the *SDA* intervention.

The key factors in healthcare providers adapting to *SDA* quickly were the user-friendly design and multiple languages, including Global English, French and Arabic, and 18 national dialects. This mHealth application provided concise clinical guidance, making it easy to respond quickly to emergencies.

2.2.7 Cope 360

Cope360 is a mHealth application prototype built to support caregivers in tracking symptoms, preparing for emergencies and administrating medication among children with cancer (Mueller, Cochrane, Campbell, Nikkhah & Miller, 2022). Alpha testing consists of validating a new prototype and its performance (Mohd & Shahbodin, 2015). The limitation during the alpha testing was the users such as nurse coordinators and caregivers were from the same organisation. There was a lack of male participants and those from racial and ethnic backgrounds other than White, non-Hispanic. Although the interviews were transcribed, there was not enough opportunity to observe the user interaction in person due to the COVID-19 pandemic restrictions.

2.2.8 CVDs Self-Management Apps

Various mHealth applications are readily available to assist patients in managing cardiovascular diseases (CVDs) (Cruz-Ramos et al., 2022). Patients with heart conditions such as arrhythmia are recommended to use the RITMIA smartphone app, the mAF app, the KB app and PULSE-SMART mHealth applications (McManus et al., 2016; Guo et al., 2017; Bumgarner et al., 2018; Reverberi et al., 2019). The commonality between these mHealth applications is the medical recommendations and early arrhythmia detection. Applications for managing arrhythmia through mobile health technology typically prioritize prevention, diagnosis, and monitoring of the condition.

These mHealth applications can be used in conjunction with wearable ECG monitors, such as T-shirt-type devices and the AliveCor Kardia Mobile ECG. Patients with potential heart failure risk use mHealth applications like Healthy Heart, HeartMan, Heart Failure app (Heiney et al., 2020; Bohanec et al., 2021; Zisis et al., 2021). These mHealth applications concentrate on observing and treating heart failure by providing medical advice and managing medications. The most frequently used devices linked to these mHealth applications are oximeters and sensors for measuring blood pressure. Most mHealth applications built within the CVD healthcare field are linked to various devices and wearables, including heart rate monitors, the BioHarness Bluetooth sensor, portable ECG monitors, and T-shirts with sensors. 63.6% of the CVDs mHealth apps were built using the Android platform, whereas 13.6% were developed using the iOS platform, and 22.8% were constructed for both Android and iOS platforms. The main functionalities across mHealth applications for CVD self-management are adhering to medical regulations, simple user interface design, interoperable electronic health records, access to quick medical assistance and real-time data tracking. Four CVD mHealth applications allowed patients to access electronic health records inputted by healthcare providers in their clinical system, highlighting the lack of interoperability. Furthermore, 60% of the CVD mHealth applications do not disclose data security and privacy standards, making patient health data vulnerable to security threats. Application developers need to include privacy protection standards in future designs.

2.3 Findings

Ten mHealth applications of different healthcare needs were researched. These mHealth applications included a diverse range of healthcare sectors and geographic locations to collect comprehensive results in the literature review. Seven common requirements were found across the ten mHealth applications and thus, each common requirement is

explained in detail in this section 2.3.1. Furthermore, two requirements out of the seven listed in section 2.3.1 represented technical challenges in the implementation phase of mHealth applications, this is also explained in detail in section 2.3.2.

Table 2.1: Analysis of common requirements in the selected mHealth applications

mHealth application:	Common requirements:	Healthcare field:
CMDigiHealth	Usability	Public health
CoCoV and NEMO	Medical regulation, cost effectiveness, interoperability, usability, security and privacy	COVID-19
MGH STAT	Medical regulation and cost effectiveness	Public health
SaveMe	Usability, cost effectiveness	Public health
e-CoVig	Security and privacy	COVID-19
Safe Delivery application	Cost effectiveness	Obstetrics
Cope 360	Usability	Paediatric
CVDs Self-Management Apps	Interoperability, security and privacy	Cardiovascular
QuestExplore	Interoperability, security and privacy	Paediatric
PainApp for Chronic Pain	Interoperability, security and privacy, usability	Public health

2.3.1 Common requirements of mHealth applications

Medical regulation

Medical guidelines refer to quality and safety standards that must be integrated into a mHealth application intended for use within clinical and medical practice (C. Petersen & DeMuro, 2015). Adhering to the medical regulations and policies of the geographical location where the application is subjected to release is a key requirement for mHealth applications (Nyapwere, Dube & Makanga, 2020). However, this key requirement is still not defined at the global level and hence is a work in progress (Chatzipavlou, Christoforidou & Vlachopoulou, 2016). As an example, developers located in the United States of America (USA) have to abide by The US Food and Drug Administration (FDA) guidelines, which regulate all mHealth applications for therapeutic and diagnostic purposes before it is made available to users. This is because the FDA recognised a subset mHealth applications that pose a risk to patient security. THE FDA also plans to regulate mHealth applications that "transform a mobile platform into a regulated medical device by using display screens, sensors, or other methods" (Larson, 2018, p.3). The FDA guideline consists of thirteen standards the full list can be found in a document attached on the FDA government website (“Policy for Device Software Functions and Mobile Medical Applications”, 2022). The FDA also has the authority to enforce regulations on low-risk mHealth applications (Larson, 2018; C. Petersen & DeMuro, 2015).

End-user satisfaction

End user satisfaction is defined in the International Standard Organisation, ISO FDIS 9241-210 as "a person’s perceptions and responses that result from the use and/or anticipated use of a product, system or service" (Bevan, 2009; Lowe, Browne, Marsh & Morrissey, 2022; Alwashmi, Hawboldt, Davis & Fetters, 2019, p.8). Successful

adoption of a mHealth application is directly related to the users' satisfaction (Barnett, Harricharan, Fletcher, Gilchrist & Coughlan, 2015). Running questionnaires is a common method of gathering user feedback about a product or applications (Alanzi, 2022; Samsuri et al., 2022). The questionnaires focused on the users' satisfaction, application information and arrangement and usefulness. The first part of the questionnaire included eight questions regarding the users' demographic information, the second 24 questions about users' ease of use and satisfaction, system information arrangement and usefulness.

Cost effectiveness

Worldwide spending on healthcare is anticipated to reach $18.28 trillion in 2040 (Al-Jaroodi, Mohamed & Abukhousa, 2020). Therefore there exists a need to adopt innovative approaches to minimise the financial cost of developing and maintaining mHealth applications. Cost-effectiveness reduces in mHealth applications where there are multiple technologies integrated, hence it is advisable to create a simple mHealth application with one type of technology which will ensure user satisfaction and cost less (Rinaldi, Hijazi & Haghparast-Bidgoli, 2020). Another example of how cost-effectiveness can be achieved in mHealth applications is by using a Service-oriented Middleware framework (SOM). The SOM framework can be used to integrate data, systems and data analysis modules to provide information services (Jiang, Feng, Yi & Guo, 2022). It is a method "for integrated domain and business process modelling—which follows the service-oriented paradigm" (Reggio, Leotta & Ricca, 2021, p.8)

The middleware framework reduces the cost of developing mHealth applications by reducing the effort of building the application from scratch. Base functions that are required for a mHealth application are already developed and tested with high-quality standards. There are three main layers to the SOM framework, core services, value-added services (security, fault-tolerance, and context-aware services) and top layer

consists of specialised and advanced services to support specific healthcare applications (Al-Jaroodi et al., 2020). An independent platform framework was built to ensure cost-effectiveness in the QuestionSys project (Schobel, Probst, Reichert, Schickler & Pryss, 2019). The process model as well as the evaluation rules were mapped to XML documents. The XML documents were automatically sent to available smart mobile devices. Collected data, as well as execution information, were stored using an XML structure to allow for a subsequent evaluation. The entire communication relied on Web Services. Based on this automation, many challenging requirements of mobile data collection application projects are mitigated resulting in lower cost applications built from this framework. Another similar cost-effectiveness approach was found by using cloud computing consisting of a set of network-connected resources shared to maximise their utilisation resulting in reduced management and capital cost (Tawalbeh, Mehmood, Benkhlifa & Song, 2016).

Interoperability

According to The Healthcare Information and Management Systems Society (HIMSS), interoperability is defined as "the ability of different information systems, devices, and applications (’systems’) to access, exchange, integrate, and cooperatively use data in a coordinated manner, within and across organisational, regional, and national boundaries, to provide timely and seamless portability of information and optimise the health of individuals and populations globally" (*Interoperability in Healthcare*, 2022). More specifically, interoperability is the ability of digital healthcare technologies to communicate with each other while maintaining the integrity of the transmitted patient data. This allows healthcare professionals and organizations to share patient health information effectively (Nikchevska, 2019). Data interoperability facilitates healthcare data to be exchanged and compared across healthcare systems globally. Therefore, this requirement should be considered when developing mHealth applications. To effectively

address global health issues, it is crucial to exchange health data internationally as observed during the COVID-19 pandemic. In order to meet international standards for exchanging health data, it is important to prioritize interoperability when developing mHealth applications (Thun et al., 2019a). *Transport Interoperability* (TI) refers to the transfer of data from one system to another, disregarding the content and purpose of the data. For example, a fax machine is a primary communication technology for transferring documents. On the other hand, direct technology securely sends encrypted clinical data in healthcare by attaching it to a secure email. The email system transfers data regardless of its content or intended use (Braunstein, 2018). Whereas, *Structured Interoperability* (SI) can be advanced by placing specific data fields in positions that indicate their purpose. For example, when an Electronic Health Record (EHR) is received, the application can identify the specific field as the name of a laboratory test, its result, or a code for the test. SI assigns each piece of information to a designated field within the transported entity (Braunstein, 2018). More importantly, *Semantic Interoperability* (SEI) is the most advanced level of interoperability. It necessitates the presence of common standards, which allow the receiving system to utilize and store data obtained from the sending system as if it were generated in the receiving system (Braunstein, 2018). Clinical decision support utilizes patient data and "a rule or analytic-based approach" to provide personalized diagnostic and treatment recommendations. When semantic interoperability is present, clinical data from another EHR system can be relied upon and understood well enough to make informed decisions about patient care (Braunstein, 2018).

Usability

Usability is defined by the International Standard Organisation, ISO FDIS 9241-210 as "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of

use" (Bevan, 2009). This includes font style or size on the screen, size of mobile phone or tablet, combination of colors which should all be considered during the development on a mHealth application (Xue, Zeng, Zhang, Lee & Yan, 2021). There are myriads of attributes that are related to usability, however, the significant attributes which can apply across groups of children, adults and the elderly are efficiency, satisfaction, learn ability, memorability and simplicity (Wang et al., 2022). Efficiency refers to the "the ability of a user to complete a task with speed and accuracy" (Ghazizadeh & Vafadar, 2017). The duration spent on each screen, complete a task and number of user errors are all ways to measure the efficiency of an application (Weichbroth, 2020). Satisfaction refers to the "user's perceived level of comfort and ease, or a user's perceived level of fulfilment of his expectations and needs" (Ebrahimi & Fahmifar, 2019). Learn ability refers to a user's ability to become proficient with an application. In some cases, patients may require instructions or a manual to use the application, but the increase in application familiarity results in the ability to complete tasks such as uploading pictures with observations. To achieve this, the application should consider a simple design allowing users to easily remember the steps required to complete tasks (Alzahrani, Gay & Alturki, 2022). The memorability of an application determines how easily a user can remember to use it. To measure this attribute, one can use the eye-tracking technique mentioned in usability studies. It involves comparing the time it takes a user to perform a set of tasks initially to the time it takes to do the same tasks after a period of inactivity (Cho, Yen, Dowding, Merrill & Schnall, 2018). Simplicity refers to how many items are visible in the menu bar, the number of search results displayed, and the ease of scrolling through a page. Additionally, it can be determined by how comfortable the user feels navigating the interface (Mahapasuthanon, Kalantari & Motti, 2021).

Security and privacy

Majority of the applications researched as part of this literature review, mention patient data privacy. (Al-Jaroodi et al., 2020) reiterates that when "sensing devices collect private data that do not particularly pertain to application's needs, the middle-ware can provide features to anonymise this data". Middle ware-based approach is best when maintaining the privacy of patient data in scenarios where information is being transferred remotely using Io-HT devices. This method uses "personal gateways executing on fog nodes at the patient's side (Al-Jaroodi et al., 2020). This middleware approach is going to be applied in the SOM framework to avoid potential threats to patient data in this application.

CMDigiHealth application built using HTML5 and PHP, MySQL as the database management system(DBMS) is another example where patient data privacy needed to be improved. OpenNode, private cloud server could only be accessed from the IP address of the Hospital with authentication. Certain health professionals, project directors, and hospital directors had full assess to information. Privacy and other challenges not adequately addressed prior to the application implementation hampered the success of this application (W. Boonchieng et al., 2021).

Protecting users' personal data is imperative and should be considered as a fundamental requirement (Guo et al., 2018). Privacy is a major concern as applications using mobile cyber-physical systems (CBS) denote large number of sensitive patient data transferred on a daily basis. Information such as user's information should be treated anonymously like mentioned in (Al-Jaroodi et al., 2020). All studies mentioned in this section so far, suggest privacy of the user is crucial in ensuring a successful delivery of mHealth applications as it promises the user, the data provided as part of the

health service, medical treatment is safe and hence private. When building application designs, the effectiveness of the privacy of patient data outrivals the various methods of collecting data. Users can quickly reject the idea of providing sensitive medical data to applications knowing privacy has been comprised (Guo et al., 2018),(Al-Jaroodi et al., 2020).

Lack of privacy and data security which negatively impacts the delivery of an application in the mHealth field (Schwab et al., 2021). Particularly, CoCov, which is a mHealth application where individuals can record concerning events after COVID-19 vaccination to share with healthcare professionals. Personal information like age, and gender are collected as part of the individuals' daily report which can be retrieved from the server. This immediately poses privacy issues as CoCov follows an online data transfer approach, information accessible to various healthcare professionals and individuals using the mHealth application. To minimise the apprehension amongst users, the uploaded data was also anonymised as seen in (Guo et al., 2018) and (Al-Jaroodi et al., 2020), but in this mHealth application the anonymous component is using a random ID. This random ID is server-generated and unique to each client, which means each individual using a smartphone has a ID associated to it with a digitally signed consent. Future work includes patient-doctor communication with this privacy method further improved to increase user groups trust and therefore data privacy.

2.3.2 Implementation challenges of mHealth applications in emergency settings

Despite adhering to low cost, evidence-based health information standards and medical regulations at an international level, most mHealth applications have failed to deliver to the full potential and yield significant improvements due to the barriers including lack of interoperable data exchange between different health care systems (Thun et

al., 2019a; Albouq et al., 2022; Shull, 2019; Mehta, Grant & Ackery, 2020)and concerns around privacy and security aspects (Mehta et al., 2020). During the SLR process, there were several papers in sections 2.2 and 2.3.1 that highlighted the lack of data exchange interoperability between mHealth applications and other healthcare systems. This challenge restricted healthcare projects involving mHealth and other digital technologies in "improving national health care" and also "positively impact the health outcomes of patients" (Thun, Lehne, Sass & Essenwanger, 2019b). Additionally, security and privacy concerns were also identified as major technical challenges.

The following section provides the findings of RQ2; implementation challenges of mHealth applications in emergency settings:

Interoperability challenges

mHealth applications combine the usability and adaptability of smartphones with the high accuracy and dependability of medical equipment for home use. However, the challenge faced by patients is the struggle of how to link medical devices to their smartphones as observed in the e-CoVig and Cope 360 applications (Raposo et al., 2021b; Mueller et al., 2022). Various papers provided different standards of interoperability definitions however the following interoperability definitions can be applied to mHealth applications:

- Interoperability allows for seamless connectivity, sharing, and cooperation of data transfer and exchange without requiring any action from the end-user.
- Interoperability serves as a bridge between various platforms, enabling them to connect and share data. This results in the creation of a comprehensive database that facilitates the development of new services, while lowering costs and promoting open markets for data collaboration.

- Interoperability refers to the ability to transmit data from one context and interpret it in another context.
- Interoperability fosters collaboration among developers, allowing them to create healthcare applications that are widely accepted.

PHR project is one example where data interoperability has been outlined as a technical challenge and all details of this challenge are referenced from this paper(Bouri & Ravi, 2014). Personal health records (PHRs) are medical records in which information is accessible to both patients and doctors, whereas electronic health records are computer records that are generated and controlled by doctors (Taha, Czaja, Sharit & Morrow, 2013). In recent years, numerous technologies have made it feasible to access PHRs on mobile devices. Patients can access health information online or through telecommunications technologies like tablets, personal digital assistants, and cell phones by using mobile PHRs (mPHRs). mPHRs can help patients and clinicians detect medical issues and prescriptions from a variety of sources when EHRs are not available or when patients are seeing a new doctor, which may prevent medical errors and find methods to improve health behaviours. Despite mPHR application advantages, there are many obstacles preventing the acceptance and future development of mPHRs, including interoperability as well as issues with security and privacy (Bouri & Ravi, 2014).

Despite mPHR application advantages, data interoperability presents a significant challenge in the acceptance of mPHRs projects as most projects in this field run on noninteroperable and incompatible platforms, which makes it more difficult to acquire important medical data (Bouri & Ravi, 2014). The content that healthcare providers, including emergency healthcare workers can access, may be restricted if different EHR systems are not interoperable with one another because many PHR systems are connected with a particular EHR system. Users must enter data manually if PHR systems are standalone and are not connected with a larger EHR system.

PHRs will become "information islands" that are disconnected from other patient information repositories and offer little value to healthcare practitioners if they are unable to interchange data with other systems. This lack of interoperability between EHR and PHR systems restricts information flow, which could be essential in an emergency (Bouri & Ravi, 2014). Also, the lack of data interoperability between electronic health records and other IT tools results in inefficient patient monitoring. Weak interoperability is a system challenge when the coordination among providers and sharing information on real-time is crucial during patient treatment (Mohammadzadeh & Safdari, 2014).

The lack of interoperability between mHealth applications and eRecord systems based in Botswana also caused technical challenges throughout the project. Interoperability was not considered during the design phase despite the need to exchange health data between two different healthcare systems (Ndlovu et al., 2021). The main advantage of mHealth applications is the level of mobility, which allows healthcare capabilities to be accessed from any location with internet connectivity (Heart, Ben-Assuli & Shabtai, 2017). By connecting mHealth applications and eRecord systems, healthcare communities should potentially have the ability to exchange data seamlessly and benefit from this integration (Kitchenham, 2004b). However, despite the overall adoption and benefits of linking mHealth applications and eRecord systems, interoperability between the two technologies remains a major technical challenge (Ndlovu et al., 2021). Two main reasons for this challenge are the duplication of patient information and tests stored in silo databases and the lack of seamless data exchange between the mHealth application and eRecord systems (McCann, 2019; Heart et al., 2017).

Security and Privacy

The use of electronic health records (EHR) has revolutionized healthcare delivery and enhanced patient care. EHRs have facilitated decision-making, improved public health,

and reduced expenses, resulting in better health outcomes. However, the lack of data security between EHR systems has hindered the achievement of these objectives (Li, Clarke, Ashrafian, Darzi & Neves, 2022).

2.4 Conclusion and limitations

Following medical regulations of a country where a mHealth application is intended to be used as well as end-user satisfaction are key enablers of building the basic requirements which need to be considered when developing mHealth applications, as observed in section 2.4. However, without the use of interoperability which ensures seamless data exchange channels between different healthcare systems, mHealth application can quickly fail to meet the expectation healthcare service being provided via mHealth application. It is only through the use of interoperability that mHealth applications can share patient information with healthcare workers and interact efficiently without compromising the integrity of the transferred data (Gruson, 2021) as observed while answering RQ2. This is a key lead to answering RQ3, data interoperability between multiple healthcare systems and overall security and privacy are both technical requirements but also represent major challenges in the implementation phase of mHealth application.

Chapter 3

Research Methodology

This chapter outlines the research methodology followed in answering the research questions, including the SLR for RQ1-2, design science research methodology for RQ3 and controlled experiments for RQ4. First, section 3.1 elucidates the selection criteria behind choosing the appropriate research methods for RQ1-RQ4, including the justification for choosing mixed methods. Next, section 3.2 covers potential research methodologies that were not selected including a detailed explanation for each research method. Section 3.3 presents the systematic literature review process, including the planning, conducting and reporting phases. Finally, sections 3.4 and 3.5 cover specific details of other chosen research methods; Design Science Research Methodology (DSRM) and Controlled Experiments (CE), including a chapter summary in section 3.6.

The systematic literature review explained in section 3.3 was conducted to answer the following two research questions:

RQ1: *What common requirements need to be considered when developing mHealth applications?*

RQ2: *Which of the technical requirements from **RQ1** represent major challenges in the implementation of mHealth applications in emergency settings?*

SLRs are used to "synthesise existing work in a manner that is fair and seen to be fair"; however, it was necessary to be "undertaken in accordance with a predefined search strategy" (Keele et al., 2007, p.3). Triangulation is the process of examining the same phenomenon using various techniques, primarily qualitative and quantitative, to strengthen the validity of research (Hussein, 2009). It was essential to use alternative methods beyond solely relying on literature review for the remaining RQs because integrating multiple research methods hence triangulation, is known to improve "the generalizability of findings and presented a panoramic view of a particular phenomenon" (Hageman, 2008, p.1). The two remaining RQs are listed below:

- **RQ3:** How can the major challenges identified in *RQ2* be translated into an mHealth application design, which can be integrated into emergency settings?
- **RQ4:** To what extent does the mHealth application design created in *RQ3* succeed in improving communication between healthcare providers in emergency settings?

3.1 Selection criteria

There are different methodologies for academic research, such as; qualitative, quantitative and mixed methods (Mertens, 2019). Choosing a particular methodology depends on the purpose of the research and whether it is conducted using words, numbers or both. For example, the qualitative methodology aims to comprehend a complex reality and the significance of actions within a particular context. Conversely, the quantitative methodology endeavours to obtain accurate and reliable measurements that facilitate statistical analysis (Queirós, Faria & Almeida, 2017). Qualitative research is built on collecting and analysing words, concepts, and descriptions, whereas quantitative research is number based, focusing on statistics, measurements and numerical values.

Qualitative study becomes significant when the research involves body language and visual elements, as quantitative studies cannot measure this data (MacDonald, 2012). For example, when human nature plays a prominent role in research studies, it makes sense to use qualitative methodologies to understand people's perceptions about an event and their reaction time to a notification popup. In contrast, quantitative methodologies are conventionally selected when the research objective is affirmative about the relationship between two or many variables under research (Easterbrook, Singer, Storey & Damian, 2008).

Two variables can be measured using a quantitative methodology, including testing a hypothesis and finding a common relationship and pattern (Jansen & Rautenbach, 2021). When the research question requires an objective approach, quantitative research is the optimum method to choose, whereas the qualitative research method is most useful when the research question requires a more open and flexible approach. The rationale for selecting the qualitative method is usually subjective, whereas choosing the quantitative method is objective.

In the event that a mixed method is conducted, the strengths from both qualitative and quantitative methods merge, thus providing theoretical, methodological findings and observations across the research topic (Pluye, Gagnon, Griffiths & Johnson-Lafleur, 2009). RQ3 involved creating a technical design to overcome the technical challenges in implementing mHealth applications in emergency settings found in RQ2 hence, design science research methodology (DSRM), a qualitative method, was selected. In contrast, RQ4 required testing of a prototype created from the technical design constructed as part of RQ3, hence controlled experiment, a quantitative method, was chosen. DSRM fundamentally involved three stages; "an imperative or prescriptive logic, a search for alternatives, and the evaluation of design" (Pries-Heje, Baskerville & Venable, 2008, p.1). It was crucial to maneuver through the three essential and beneficial stages to address RQ3. The technical challenges identified in RQ2 had to be overcome in the

prototype, making the DSRM stages extremely crucial. Furthermore, to ensure the elimination of the two technical challenges from RQ2, the design needed to be robust to avoid the lack of interoperability in patient data exchange and overall security and privacy issues throughout the technical design. By conducting DSRM, the two technical challenges were carefully eliminated at each stage of the design creation. The critical components when conducting the DSRM consist of evaluating design documents which can then provide a skeleton for developing a solution (Venable, Pries-Heje & Baskerville, 2016). On the contrary, CE (RQ4 research method) bought the practice of carrying out experiments in almost real scenarios. Renowned companies, including Facebook, LinkedIn, Microsoft, eBay, Netflix, Amazon and Shop Direct, use online controlled experiments to "guide product development and accelerate innovation" (Kohavi et al., 2013). One approach to test the extent of improvements (if any) in communication between healthcare providers in emergency settings was a controlled experiment. The purpose of creating the prototype was to find both qualitative and quantitative results to support the thesis. When Bing conducted CEs on Facebook, LinkedIn, Microsoft, eBay, Netflix, Amazon and Shop Direct, it quoted the increase in annual revenue was because of the focus on evaluating new ideas through the CEs. Even a 1% increase in revenue equated to approximately US$10M annually (Gupta et al., 2019). If this prototype was to integrate within the NZ Health system to help support Ambulance Officers and Emergency Department Unit, continuous CEs conducted throughout the year could help increase patient outcomes in reaching hospitals, hence improving the overall revenue, which is currently lacking and causing many operational difficulties for the charity organisation (Newshub, 2022). In recent years, DSRM conducted in the Information Systems area gained recognition as an equally integral research methodology alongside behavioural science research. This recognition reflects the importance of design in creating effective information systems (Peffers, Tuunanen, Rothenberger & Chatterjee, 2007a; March & Storey, 2008). The selection of DSRM was for an additional purpose;

this method is uniquely known for demonstrating whether an existing IT artifact is adequate to solve a problem (March & Storey, 2008; Weber, Mutschler & Reichert, 2010).

3.2 Potential research methods

Incorporating multiple research methods enhanced the validity and reliability of the results by addressing any potential weaknesses inherent in the selected methodologies (Nusair & Hua, 2010). These methods encompassed the systematic collection, examination, and analysis of empirical data in an organised and methodical manner (Easterbrook et al., 2008). Alternative research methods were evaluated based on appropriateness, relevance, time constraints, and resource requirements. Research methods are specific data collection tools and techniques such as questionnaires, interviews and group discussions (Sakyi, Musona & Mweshi, 2020). In contrast, research methodology refers to the overall approach, framework, or strategy that guides the researcher's investigation. The section presents research methods and methodologies that were considered but not chosen.

Survey research

Survey research can be a method of gathering quantitative data from a large number of participants through a standardised questionnaire, which is then utilised to determine the traits of a large group of people. It is most closely associated with using questionnaires to gather information about a specific population's attitudes, beliefs, behaviours, or experiences (Fowler Jr, 2013). However, given the workforce challenges of paramedics, it would have been complicated to engage paramedics for questionnaires amidst patient work orders. The environment within the emergency department can be very hectic and

sensitive, so potential disruptions from survey research would have led to delays and disturbances. Therefore, the testing environment explained in Chapter 4 was closely matched to a real emergency-like setting to avoid all potential disruptions. Emergency Ambulance services in New Zealand and Australia collect and store patient data in similar ways (Andrew, Cox & Smith, 2022; Gray, MacDonald, Becker & Johnston, 2022; Reuter-Oppermann & Richards, 2019). There are multiple legislative, executive and judicial approval streams by bodies such as the Clinical Audit and Research Team in St John New Zealand and the Health Privacy Act at local, state and national levels in Australia which are required when research questionnaires entail patient information or precisely personal opinions of paramedics related to specific work orders (Al-Shaqsi, 2010). The initial prototype testing strategy involved conducting surveys among paramedics within the ambulance workforce. However, this approach was eliminated and discontinued due to the intricate approval process and data privacy laws in both Australia and New Zealand. For example, The National Ambulance Surveillance System (NASS) in Australia, an established and internationally unique multi-jurisdictional surveillance system, researched electronic patient care records provided by Australian states and territory-based ambulance services, multiple degrees of approvals and "strict protocols for data de-identification, confidentiality, storage, access and reporting" were required (Lubman et al., 2020). Conducting survey research was eliminated to avoid complexity in privacy legislation surrounding patient and paramedic input and focus solely on the technical outputs and quantitative improvements of the prototype built as part of RQ4. Otherwise, patient data could have included sensitive subjects such as self-harm and mental health variables among paramedics and patients, requiring another level of approval (Taylor et al., 2011).

Case studies

Case study research is utilized in investigating natural disasters (Grynszpan, Murray & Llosa, 2011). Therefore, this case study method was irrelevant because RQ3-4 pertains to technical design and patient data communication methods. Phenomena refer to measurable occurrences or events that can be studied to understand underlying causes and predict future behaviour (De Chardin, 2018). This phenomenon may be natural or man-made, requiring multiple approaches and methods to study effectively (Zainal, 2007). As a result, case study research is a widely accepted methodology for in-depth insights into complex phenomena. These phenomena may arise from individuals, organizations, or social groups. The method entails an in-depth examination of a single case or a small number of cases, with data collected through various sources such as observations, interviews, and archival records (Yin, 2009). Case study research is instrumental when seeking to understand a particular phenomenon's context or when the phenomenon in question is rare and challenging to observe hence unsuitable for this thesis.

Ethnographies

Ethnography is a research methodology widely operated in the social sciences and humanities research to investigate human communities and cultures (Zalta, Nodelman, Allen & Perry, 1995). This research method requires thoroughly investigating a particular cultural group through extended fieldwork and close observation, which was unsuitable for RQ3-4. RQ3 required a technical design, integrating the technical challenges found in RQ2. In comparison, RQ4 needed quantifiable results to measure whether the design from RQ3 resulted in any improvements. Ethnography also aims to comprehend the social structures, cultural customs, and worldviews of the group being researched and how they relate to and perceive their surroundings. Researchers engage

in the research study's culture or community, observing and participating in everyday activities and collecting data through various methods such as field notes, interviews, and observations. Ethnography seeks to understand individuals' experiences, beliefs, and perspectives within a cultural group and to provide a rich, detailed description of their way of life. This research method was not considered as RQ3-4 were unrelated to any social culture.

Action Research

Action Research is a research method where researchers aim to solve real-world issues while studying the experience of solving the issue. It is a collective and participatory research method used in educational, social, and organizational settings. The ultimate goal of action research is to enhance practices by comprehending real-world issues systematically and iteratively.

The researcher in action research collaborates closely with stakeholders and members of a society to determine an issue, gather data, and use it to improve practices. This iterative research process involves several stages, including planning, acting, observing, and reflecting. The process is repeated until the problem is fully addressed, or a satisfactory solution is found (Reason & Bradbury, 2001).

Grounded theory

Grounded theory is a research methodology used in social science research to develop views grounded in data collected through qualitative methods such as observation, interviews, and document analysis (Noble & Mitchell, 2016). The objective is to generate a theory grounded in the data and explain the phenomenon being studied (Khan, 2014).

There are three key points that need to be considered when choosing this research method:

1. Grounded theory is defined by its iterative approach. Researchers collect data, analyze it, and use the results of that analysis to generate new questions and hypotheses. This process is repeated until a theory has emerged that can explain the phenomenon being studied (Chun Tie, Birks & Francis, 2019).

2. Grounded theory has several vital features, including using a theoretical sampling strategy to select participants, focusing on data coding and categorization, and a constant comparative analysis that compares new data with existing data and theories.

3. Grounded theory has been used in various fields, including sociology, psychology, nursing, and management. It is particularly well-suited for studying complex, multi-faceted issues that are difficult to understand using more structured, quantitative methods.

The grounded theory method is predominantly qualitative, focusing on human interaction and actions. Conversely, RQ4 required a quantitative approach to measure how the technical design built as part of RQ3 has improved communication between healthcare providers in emergency settings.

3.3 Systematic Literature Review Process (RQ1-RQ2)

Systematic literature reviews (SLR) are regarded as the most reliable type of medical evidence and are highly ranked in research (Jahan, Naveed, Zeshan & Tahir, 2016b). Medical practitioners find SLRs helpful as it provides a comprehensive summary of the latest literature on a specific research topic. SLR offers a valuable understanding of a specific academic subject by compiling "published research on a topic, surveys different research sources, and critically examining these sources" (Jahan et al., 2016b). This thesis required research on the "breadth and depth of the existing body of work"

conducted on mHealth applications within the healthcare industry to "identify gaps to explore" in the form of technical challenges (Xiao & Watson, 2019). Given SLRs "are claimed to be a standardised method for literature reviews" it ensured the findings in Chapter 2 are "replicable, transparent, objective, unbiased and rigorous, and thus superior to other approaches for conducting literature reviews" (Boell & Cecez-Kecmanovic, 2015). A literature review of some kind is the typical first step in research. However, it has little scientific value if it is not complete and objective, as this is the primary justification behind conducting systematic reviews (Kitchenham & Charters, 2007a). A systematic review fairly synthesises previous research. Systematic reviews must be conducted in line with a predetermined search strategy. The search approach must make it possible to gauge how the search was conducted. Researchers are responsible for reporting research that does not support their preferred research hypothesis and research that does simultaneously (Kitchenham, 2004a).

3.3.1 Planning the SLR

During this research phase, it was imperative to develop research questions grounded in the area of mHealth applications. In addition, it was crucial to ensure that the research questions formulated are answerable, as this was crucial to achieving a successful and informative review. In order to formulate practical research questions, it was imperative to ascertain the problem definition first. This can be discerned by analyzing areas of unresolved challenges, which are delineated below:

Problem: mHealth applications are often developed to administrate and monitor a particular body condition through self-management tasks or educate patients on preventative care (Rowland et al., 2020). Researchers also proposed mHealth applications for health conditions such as "dementia, autism, dysarthria, Parkinson's disease" (Zapata, Fernández-Alemán, Idri & Toval, 2015). However, there were minimal guidelines on a

list of technical and common requirements that every mHealth application could use as a foundation or skeleton to support the design phase of the development process.

Few papers suggested usability takes priority as a "key factor in the adoption of mHealth applications" because users often "have problems when using mobile devices and have a limited experience of technology" and hence should be considered while creating a mHealth application design (Zapata et al., 2015; Sannino, De Pietro & Verde, 2020; L. Zhou et al., 2019). Meanwhile, other papers suggested that "the privacy and security of users' data have been the subject of concern and controversy", therefore, should be carefully integrated into the requirement phase (Nurgalieva, O'Callaghan & Doherty, 2020), (Plachkinova, Andrés & Chatterjee, 2015). Inadequate consideration for privacy and security concerns in the requirement phase of mHealth applications has led to "the potential to carry substantial risks to the security and privacy" of the mHealth application users, "despite the potential of mHealth applications to improve the availability, affordability and effectiveness of delivering healthcare services" (Hussain et al., 2018).

This led to the formation of the first research question:

- **RQ 1:** What common requirements need to be considered when developing mHealth applications?

The first question, RQ1, covered various common requirements for mHealth applications, both technical and functional. On the other hand, the second research question needed to focus on narrowing the common requirements to specific technical challenges that could cause issues in a mHealth application used within the emergency settings.

This directed to the composition of the second research question:

- **RQ 2:** Which of the technical requirements from RQ1 represent major challenges in the implementation of mHealth applications in emergency settings?

Novices often make the mistake of choosing a research question that is too broad. This is because when the research question is too broad, it can lead to an overwhelming amount of data to review, making it difficult to manage (Xiao & Watson, 2019). Consequently, RQ2 was further refined to focus on a healthcare subtopic of emergency settings within the original area of mHealth applications.

Literature mapping can assist in identifying subtopics within research questions and finding similar literature to review potential flaws, errors and areas of improvement (Brereton, Kitchenham, Budgen, Turner & Khalil, 2007). Hence, a literature mapping was conducted on terms such as mHealth applications in combination with various technologies, however, most papers concluded on improvements needed in areas of privacy, security and lack of data interoperability.

Despite the plethora of existing literature and proposed solutions addressing research questions on mHealth applications, it was clear that there remains potential for further improvements. Two papers suggested that a research question should be looked into from three viewpoints: the population (the people affected by the research topic), the interventions (comparison between two or more alternative technologies) and the outcomes (factors that will compare the interventions). RQ1 required comprehensive results regarding common requirements related to mHealth applications from a software development perspective.

The research questions were also analyzed and separated into individual search terms, including inclusion and exclusion criteria, to generate relevant research papers. The finer details of search terms, inclusion and exclusion criteria and conducting the SLR are covered in the next section.

3.3.2 Conducting the SLR

To address RQ1-2, it was necessary to break down and translate the question into a series of search terms. The search terms were gathered using different search strategies, such as synonyms, narrower and broader words, and standard classification of terms used in different databases. The search terms used on various research databases were *smart healthcare, mHealth application, patient management, disease management, requirements gathering, general requirements, digital mobile technology, digital mobile communication, emergency settings, software development, technical challenges*. The results of the literature review were obtained using the search engine of the Auckland University of Technology library. This library database was integrated with resources from other databases such as Springer, Scopus, Science Direct, IEEExplore, and ACM Digital Library. To ensure the sources were comprehensive, Google Scholar was also utilized. Search strategies such as boolean operators of AND and OR and truncation on like terms were used in the search string to gather "more focused and productive results" (Jahan, Naveed, Zeshan & Tahir, 2016a). Boolean operators AND found papers with a combination of search terms, whereas OR broadened the search to include papers with at least one of the search terms; however NOT was not used in the search string (Atkinson & Cipriani, 2018). Truncation was also used to make the search more focused and comprehensive (Gusenbauer & Haddaway, 2020). Publication bias is the tendency to publish positive outcomes more often than adverse outcomes. The interpretation of results as positive or negative can vary depending on the researcher's perspective (Mlinarić, Horvat & Šupak Smolčić, 2017). To prevent this problem, the SLR was conducted using search strategies that included grey literature and conference proceedings, as recommended in the Dwan et al. (2008)'s paper. Approximately 46 other papers were manually hand-picked, sources including grey literature, google scholar and domain experts (secondary supervisor and research assistant) to avoid

publication bias and include additional research sources to the SLR. This is because initial searches for preliminary studies using electronic databases are not sufficient (Kitchenham & Charters, 2007b; Kitchenham, 2004a). The results from the search terms applied to the various library databases were approximately 386 papers, including 46 articles handpicked with the assistance of grey literature, domain expert and research assistant. After using the inclusion and exclusion criteria described in the section, 43 papers were studied to conduct the literature review.

Inclusion and exclusion criteria

When conducting SLR, inclusion and exclusion of papers "determine the scope and validity of systematic review results" (Meline, 2006). The purpose of incorporating inclusion and exclusion criteria is to ensure the quality of the results is high and set the appropriate boundaries for the SLR (). When the selection criteria are too narrow, it limits the results causing an over-exclusion threat. On the other hand, selection criteria that are too broad lead to an over-inclusion threat making the synthesis of the study difficult and biased ().

Inclusion and exclusion criteria were used to find the most relevant studies related to mHealth applications and associated common requirements and technical challenges in emergency settings.

The Figure 3.1 presents the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) hence the database search flow of this SLR. Exclusion criteria included eliminating papers published before 2012; papers published between 2012-2022 were included, specifically, 2019-2022. The papers that did not have a mHealth prototype or application references were excluded. Most importantly, papers with insufficient details of the associated research topic that did not match the objective of this thesis were also not included.

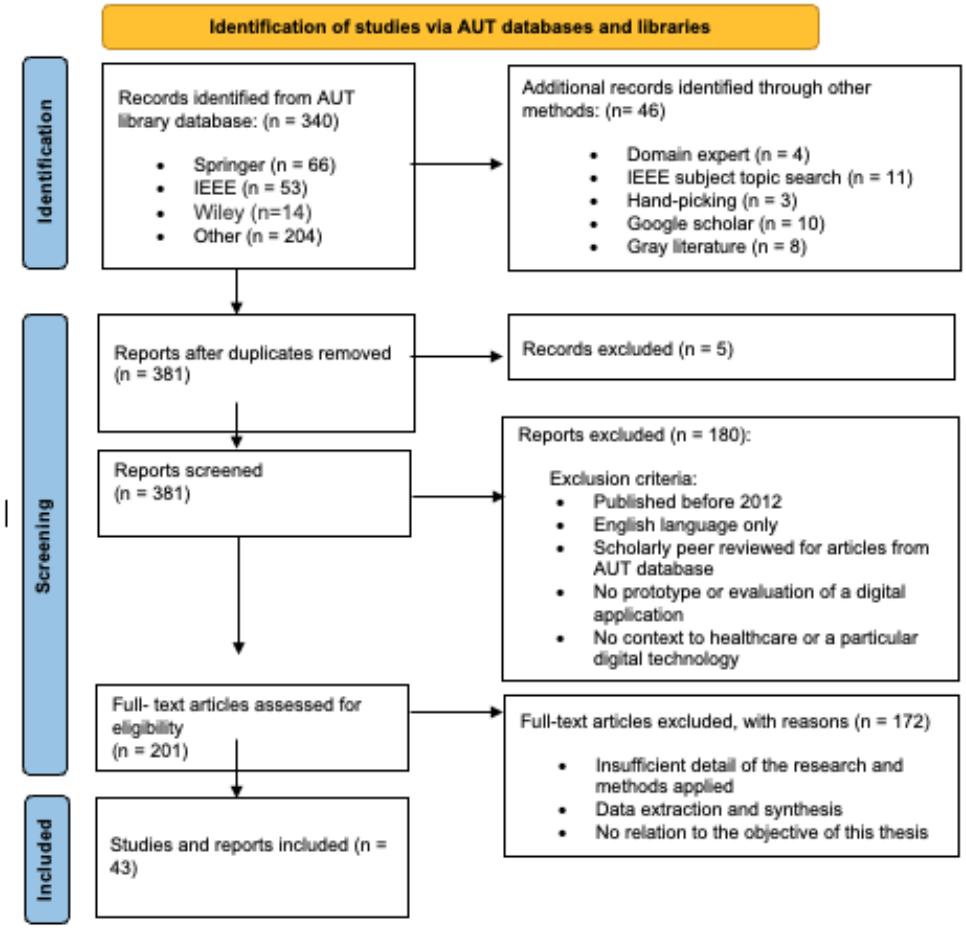

Figure 3.1: The flow diagram for the database search of publications for systematic review.

Quality Assessment

Quality assessment is a crucial process that involves evaluating primary studies relevant to answering research questions. This helps to establish detailed inclusion and exclusion criteria, as well as determine the weight of individual studies when incorporating data. The quality of papers used to conduct the SLR determines the quality of the SLR (Y. Zhou et al., 2015). Through critical review, bias is minimized, while internal and external validity is maximized. To determine whether the research questions were sufficiently addressed, a series of questions were used to assess the quality of the research.

These questions were scored with either "Yes," "No," or "Partly."

Table 3.1: Research question quality assessment

Criteria:	Score:
Criteria 1: Are the review's inclusion and exclusion criteria described and appropriate?	Yes- due to the inclusion and exclusion criteria, the SLR included many relevant resources to find out common requirements in mHealth applications and technical challenges in emergency settings.
Criteria 2: Is the literature search likely to have covered all relevant studies?	Yes - The AUT database was integrated with resources from other databases such as Springer, Scopus, Science Direct, IEEExplore, and ACM Digital Library. To ensure the sources were comprehensive, Google Scholar was also utilized. Additionally search strategies such as AND and OR were also utilised.
Criteria 3: Did the reviewers assess the quality/validity of the included studies?	Partially- Initially the title and abstract were given the first priorities. For papers which showed valuable evidence to support the thesis and hence RQs, methodology, limitations, conclusion and future work was closely examined.
Criteria 4: Were the basic data/studies adequately described?	An overview of aspects that the RQs required was adequately described.

Data Extraction

Data extraction is conducted to obtain necessary data from primary studies and accurately document the information researchers need to answer the SLR (Mengist, Soromessa & Legese, 2020a). The data extraction process is a critical phase because the form should include the "name of the reviewer, date of data extraction, title, authors, journal, publication details and additional notes". It is recommended to perform a second extraction on random preliminary studies and cross-check it with the first extraction. The data extraction for this SLR were; the name of the mHealth application, author, year, strengths and weaknesses, software development details, common requirements and technical challenges, and other technical evidence.

Data Synthesis

Data synthesis includes summarising the literature findings using qualitative and quantitative synthesis (Han, Xu & Chen, 2018). This stage aims to create extraction forms that can precisely document the details gathered from the chosen papers. When the literature review consists of quantitative data, the data collected is usually numerical and presented as a meta-analysis. This statistical method merges several papers' findings into a single summary. In contrast, qualitative synthesis is the process of researching a topic and gathering results from individual papers together. This is usually conducted through integrated reviews or interpretative reviews (Seers, 2012).

3.3.3 Reporting the SLR

The final step of the SLR is presenting the search process followed throughout the SLR and the results from all the literature (Mengist, Soromessa & Legese, 2020b). This includes two phases; describing the procedure and reporting the findings from the systematic literature review (Hermosillo, 2022). The procedure has been explained

using the PRISMA flowchart in Figure 3.1 and further detail in section 3.3.2. The second step is reporting the systematic literature review results, which has been done in Chapter 2.

3.4 Design Science Research Methodology (RQ3)

Design Science Research (DSRM) is a methodology used to study and create design solutions in the field of information technology and related disciplines. The focus of DSRM is to develop new theories, artifacts, and practices to solve real-world problems (A. Hevner, Chatterjee, Hevner & Chatterjee, 2010). This methodology is particularly useful to answer RQ3 because as seen in the paper (Ferreira, Pereira, Bianchi & da Silva, 2021) it allows the following:

- DSRM is commonly known to create answers for problems that exist in the real world.
- DSRM-developed solutions are made to be applied in actual situations.

Considering this thesis aims to close a significant gap in the current real-life scenario, both points mentioned above is vital and hence in answering RQ3. Additionally the list of advantages and disadvantages listed in the table below shows appropriateness in choosing DSRM to answer RQ3:

Table 3.2: Advantages and Disadvantages of DSRM research method

List of DSRM advantages and disadvantages.	
Advantages:	Disadvantages:
1. Relevance: DSRM places a strong emphasis on developing useful answers to everyday issues. It is therefore very pertinent and beneficial to researchers.	***1. Inability to generalise:*** DSRM solutions are frequently created to solve particular issues and might not be transferable to other circumstances. The solutions' scope of use is thus constrained.
2. Multidisciplinary strategy: DSRM uses a range of disciplines derived by subject matter experts to create solutions that are all-encompassing and holistic. This might lead to better solutions.	***2. Empirical validation limited:*** Due to the emphasis on creativity and the design process, DSRM solutions may not have empirical support. The solutions' credibility may be hampered as a result.
3. Iterative design procedure: DSRM uses an iterative design procedure that enables solution improvement and refinement over time. This may result in more sensible and practical answers.	***3. Dependency on resources:*** Due to the requirement for interdisciplinary knowledge, iterative design procedures, and strict evaluation methodologies, DSRM can be resource-intensive. This may reduce the approach's viability for some research initiatives.
4. Rigorous assessment: DSRM uses rigors evaluation techniques to make sure the solutions are successful and satisfy the required standards. This improves the results' validity and dependability.	***4. Limited stakeholder engagement:*** DSRM solutions could have limited usability and acceptance if all pertinent stakeholders were not included in the design process.
5. Knowledge contribution: By developing fresh ideas and new information, DSRM can increase our understanding in the pertinent topic.	.

As established in earlier chapters, the significance of finding a possible solution to the existing gap in data interoperability between the two healthcare systems is the driving factor in choosing this research method. DSRM underlines practical relevance, which attempts to develop solutions that are usable and valuable to researchers. This is a key advantage and hence the logic in choosing this method to answer RQ3. DSRM also combines a variety of fields of study and areas of experience to produce thorough and efficient answers. Additionally, the DSRM's rigorous evaluation techniques and iterative design process might result in the creation of more practical and successful solutions than expected.

However, there are also several disadvantages to DSRM. One potential limitation is the lack of generalizability of the solutions developed, as they are often tailored to specific problems and contexts. Additionally, the resource-intensive nature of DSRM may limit its feasibility for some research projects. Furthermore, the focus on innovation and design may result in limited empirical validation, which can reduce the credibility of the solutions.

DSRM may also require a high level of expertise and skills in design, development, and evaluation methods, which may be a barrier for some researchers. The involvement of stakeholders, such as users and practitioners, is also critical in DSRM, but this can be challenging due to their limited availability and conflicting interests.

Nonetheless, in accessing both pros and cons of this research method, the disadvantages did not have a negative effect on the solution for RQ3. The drawbacks of this research method did not undermine the validity of the solution.

The answer for RQ3 required a specific non-generalised solution due to the nature of the problem, the design was based of the practical empirical situation occurring in emergency setting.

3.4.1 Design Science Methodology Procedure

Activity 1: Problem identification and motivation: The identification of the problem definition during the initial phase of the DSRM for a number of reasons, including: defining and determining the problem area may support in designing and developing related artefacts which in turn would effectively provide a solution (Peffers, Tuunanen, Rothenberger & Chatterjee, 2007b). This proves useful during the conceptual atomization of the problem thus providing a solution that can capture relative complexities. The accomplishment of two additional aspects, including the supply of motivation to the researcher, audience, and stakeholders in relation to the research, may be involved in this phase. Also, this stage would include adequate justifications, findings, information, and necessary resources to let the researcher as well as the reader comprehend the severity of the issue and the significance of the solution.

Scientific research concerning information system design has led to the development of targeted information technology solutions for critical organisational problem, as observed in the work industry. However, the targeted solutions must be effectively represent the work industry in order to be put into practice and utilised in the right field (A. R. Hevner, March, Park & Ram, 2004). This thesis surrounds around providing a targeted solution within the emergency setting. A prototype representing usage within the emergency setting. Chapters 4 introduces the design, which includes the fundamental requirements, technical considerations, and quality attributes.

Activity 2: Define the objectives for a solution: The second phase entails the identification and specification of objectives, which covers the problem definition as indicated in Chapter 4. The practical and potential solutions resolving the problem definition are also acknowledged at this stage of the research methodology design scientific procedure (Peffers et al., 2007b). Additionally, the design science research methodology emphasises a multi-disciplinary approach that strengthens both design

and development activities.

The prototype in this thesis is designed and developed to achieve numerous objectives as mentioned below:

- Identify and resolve the issue of lack of interoperability when integrating patient data information from St John ambulance technical application into various hospital systems.
- Enhance the usability, user-friendliness, and understandability in the user interface aspect of the prototype. This is important because the prototype main users are emergency setting health professional, the user interface must consist of simple interface which eases their work rather than add complexity.

Activity 3: Design and development: The creation of a prototype, model, or system that can be tested and assessed is a common task during the design and development process. Creating new technologies, software programmes, or other forms of solutions may be necessary. The goal is to provide a solution that is both workable and efficient. A real-life example of design and development in DSRM can be seen in the development of new medical technologies. For example, a research team may identify a problem in the field of oncology, such as the need for more accurate and reliable cancer diagnosis tools. The team would then develop a research question focused on developing a solution to this problem, such as "How can we design a more accurate and reliable cancer diagnosis tool?"

The team would subsequently start the design and development stage, which can entail developing a brand new medical instrument or software programme that makes use of cutting-edge imaging methods or other modern technology to enhance cancer diagnostics. In order to determine the solution's effectiveness, efficiency, and usability, the team would first endeavour to develop a prototype or model of the proposed approach.

If the solution proves to be successful, it might be improved upon before being put on the market. New technologies and solutions that significantly impact society may be developed as a result of this design and development process in DSRM. Ultimately, the DSRM design and development phase is essential because it enables researchers to generate useful and efficient answers to real-world issues.

Similarly, the prototype which will help answer RQ3 and RQ4 requires the steps mentioned in the real life medical project example used above. Specific details on the design and development will be discussed in Chapter 4.

Activity 4: Demonstration: In DSRM, the demonstration phase is vital because it allows the generated artefact to be showcased and assessed for its applicability and efficiency in real life scenarios (A. Hevner et al., 2010). The demonstration phase's primary goal is to demonstrate that the proposed solution is workable, efficient, and capable of resolving the identified issue. Considering the newly developed three-tier prototype is to be used ideally used in a emergency setting, a similar scenario was conducted to test and provide results which is highlighted in Chapter 5. This demonstration phase empowers this thesis to present proof that the proposed prototype is workable, efficient, and capable of resolving the stated issue. More importantly, by putting the prototype to the test in almost real-life situation, it also aids in bridging the gap between theory and practice.

Activity 5: Evaluation After the prototype was created, testing procedure started. The prototype was first thoroughly tested using Controlled Experiment methodology, details discussed in Chapter 5. The proposed prototype could be expanded and improved upon if the evaluation phase is effective.

Activity 6. Communication Communication phase entails the dissemination of the issue and its relative significance, the creation of the artefact and prototypes, its relative usefulness and uniqueness in terms of the research methodology used, and the accuracy of the design work completed (Peffers et al., 2007b). New ideas and facts were discussed

with both supervisors with regard to all aspects considered throughout this thesis. Specifically, communicating the research done during the design and development of the prototype. These aspects include the problem identification, research methodology used, technical design and development practices.

3.5 Controlled Experiments (RQ4)

A controlled experiment is an investigation of a testable hypothesis where one or more independent variables are manipulated to measure their effect on one or more dependent variables (Kohavi, Tang & Xu, 2020; Bianchi, Marzi & Guerini, 2020). Controlled experiments are a widely used research method in the natural and social sciences to test causal relationships between variables. The goal of a controlled experiment is to determine the effect of an independent variable on a dependent variable while controlling for extraneous variables that may influence the relationship. To conduct a controlled experiment, the researcher manipulates an independent variable and measures the effect on a dependent variable. Participants are randomly assigned to either the experimental group or the control group. The experimental group receives the treatment (manipulation of the independent variable), while the control group serves as a comparison group and does not receive the treatment. Both groups are then observed and compared to see if the independent variable had an effect on the dependent variable (Campbell & Stanley, 2015). Controlled experiments are useful to show the cause-and-effect relationship between variables hence it was considered to help answer RQ4.

If RQ3 required analysis on the adoption and use of mobile healthcare applications by different populations, such as older adults, low-income populations, and people with chronic conditions, ideally multiple research methods listed in section 3.2 should have been looked into. Nonetheless, RQ3 explored the intricate area of how a mHealth application can minimise the current lack of interoperability between the systems used

by paramedics and emergency department staff. Firstly, the design of the prototype which would help eliminate the gap of interoperability needed to be created. Secondly, how the prototype has improved the communication between healthcare providers in emergency settings from a technology perspective needed to be evaluated. Hence, design science and controlled experiment research methodologies were selected respectively.

In Chapter 2, the common requirements and major challenges in the implementation of mHealth applications in emergency settings were identified. The key themes derived in Chapter 2 through the SLR also set the building blocks for the prototype requirements built as part of RQ3. The last research question was added to find out whether digital healthcare technologies can provide an improvement in data communication within emergency settings. It can be assumed from (Chan, Killeen, Griswold & Lenert, 2004) the use of technology in emergency departments (EDs) can have both positive and negative impacts on patient flow and wait times. Technology can improve patient triage, diagnosis, and treatment, leading to faster and more efficient care. For example, electronic medical records (EMRs) can provide immediate access to patient information and medical history, reducing the time spent on paper-based record keeping.

However, technology can also introduce new challenges and delays in emergency departments. For instance, the integration of new technology can be complex and time-consuming, and technical problems can arise that need to be addressed before the technology can be used effectively. Additionally, the use of technology in emergency departments can increase the workload of healthcare providers, leading to increased stress and fatigue and potentially affecting patient care.

In conclusion, the impact of technology on wait times and patient flow in emergency departments can be both positive and negative. RQ3 ensured the validity of the prototype in the context of real emergency setting scenarios.

3.6 Summary

This chapter describes the research methodology and methods conducted to find literature evidence and findings for RQ1-2. Additionally, it also includes DSRM and CE research methods used to design, create and test the touchPoint prototype, which was used to answer RQ3 and RQ4. While DSRM assisted the research in creating a technical design to build a prototype led by the findings from RQ2, CE assisted the research by evaluating the prototype using quantitative measures to show clear improvements. However, the design and development entails several more minor phases, including the creation of the prototype design and development and results (see Chapter 4), and finally conclusion (see Chapter 5).

Chapter 4

Design and Implementation

This chapter summarises details about the design and implementation phases of the prototype. Section 4.1 recapitulates relevant information such as patient journey, healthcare roles, ePRF tablet and the introduction to the prototype. Section 4.2 outlines the two research questions which will be answered in this chapter. Section 4.3 covers the prototype design, including refinement of requirements and planning of sequence diagrams and user journey pathways. Section 4.4 covers the prototype implementation, including the development approach, application architecture and the main components of the touchPoint prototype. Finally, section 4.5 summarises the prototype results and discusses the findings of RQ3-4.

4.1 Relevant information

This section explains the critical concepts necessary to comprehend the scope of the thesis and the potential contribution of the thesis to the healthcare system in New Zealand. These concepts encompass interoperability in healthcare applications, ePRF tablet, smart healthcare, mHealth technology, touchPoint prototype, and the healthcare providers' roles and hierarchy. All the information stated in this section was derived

from a combination of grey and white literature. The grey literature is from reputed official websites, including but not limited to: Hato Hone St John - St John New Zealand, Te Whatu Ora - Health New Zealand, Manatū Hauora - Ministry of Health, Te Anamata O Te Oranga - Future of Health, Te Aka Whai Ora - Maori Health Authority, Waipapa Taumata Rau - University of Auckland, Te Wānanga Aronui o Tāmaki Makau Rau - Auckland University of Technology and Stuff NZ (news media).

Figure 4.1 on page 73 illustrates a typical patient's journey from the emergency incident location to the hospital's emergency unit. In this mock-up example, a 7-year-old student named Ryan from ABC Primary School located in Christchurch slips while playing in the school playground and is unresponsive (Image 1 in Figure 4.1). School teachers at the site immediately call the St John Ambulance services, where the St John Ambulance call handler dispatches a code status two Ambulance service to the playground located in ABC Primary School. The next step in the patient journey is when a Paramedic crew are allocated to the 'Ryan playground accident' work order (Image 2 in Figure 4.1). Meanwhile, the Paramedic crew can view his medical and allergic information on an (Electronic Patient Report Form) ePRF tablet, if there has been a successful connection to Ryan's National Health Index (NHI) number during the call taking process. Upon the arrival of the Paramedic crew, Ryan is first assessed for injuries and other medical conditions. Then safely transferred into an Ambulance using a scoop stretcher (Image 3 in Figure 4.1) while maintaining a responsive medical condition and transported to the Emergency and Trauma Department (ED) of Christchurch Hospital (Image 4 in Figure 4.1). During the drive to the hospital, the Paramedic crew input patient information about Ryan's playground accident, the cause and location of the injury and any administered medications and procedures into the ePRF tablet. An experienced emergency nurse from the hospital is assigned to the 'Ryan playground accident' case and verbally receives the latest updates from the Paramedic crew at the main entrance. Ryan is officially handed over to the ED unit and taken inside for further medical

assistance (Image 5 in Figure 4.1). Alongside, the paramedic crew are responsible for printing out a physical copy of the patient information gathered from the 'Ryan playground incident' using a local printer and handing this to the clerical officer at the admin desk of the ED. This physical copy is shared between emergency nurses and primary and secondary care personnel via digital scan and email. This thesis studies the exploration of mHealth applications in this specific scenario explained above, where there is a lack of interoperability between the ePRF tablet and emergency hospital systems.

Figure 4.1: Typical patient journey from the location of the emergency incident to the emergency unit of a hospital.

Below is a list of key concepts found on the St John New Zealand website which are essential to be taken into consideration:

- All calls are either answered by the Auckland or Christchurch communication call centres depending on the availability and supply of ambulances.
- It is uncommon that the ePRF tablet patient information gathered prior to reaching

the emergency incident location is reliable and accurate due to the inconsistency of NHI numbers (Todd et al., 2022).

- This lack of reliability is also because onlookers or strangers usually misspell the patient's name, the NHI number is not associated with the patient's other names and, notable lack of interoperability between the NHI system and the St John Ambulance database.

4.1.1 Healthcare Roles

Paramedics

The role of a paramedic involves promptly responding to emergency incidents and providing essential medical care outside of the hospital setting to patients suffering from various conditions and injuries (O'Meara & Duthie, 2018).

Duties include:

- Attend to patients suffering from accidents and medical emergencies – such as a car crash, a heart attack, or an injury.
- Evaluate and treat patients on-site or during transportation to the hospital via ambulance.
- Ensure that ambulances have an adequate medical equipment supply and that all equipment functions correctly.
- Create reports on patients and the medication or treatment administered.

Clerical Officer (Emergency Department Unit)

The Emergency Department (ED) unit depends on the Clerical Officers to provide crucial initial support to patients and their families upon arrival. They are an integral part of the medical team, providing essential administrative assistance to ensure smooth

operations. Based on the readings of a few grey literature on healthcare, this is a list of duties assigned to Clerical Officers in ED units:

- Administrative tasks and handling telephone inquiries.
- Gathering patient information from paramedics and other medical professionals
- Medical billing
- Scheduling appointments
- Patient enrollment and liaising with varied medical professionals

Emergency Nurse

The role of Emergency Nurses is the responsibility of caring for patients who have experienced trauma, illness, or injury. Unlike other hospital units, ED units require nurses to be present all hours of the day and night 7 days a week (Osman, Al-Hinai & Piya, 2019).

4.1.2 ePRF Tablet

Electronic Patient Report Form (ePRF) officially released in 2015, is a electronic form stored in an Android tablet replacing the previous hand-written patient record document filled by Paramedics in New Zealand (S. J. Website, 2019), shown in Figure 4.2. All patient information is securely captured and stored electronically in one place for easy access and reliability using a local cloud server. It also consists of relevant clinical information for St John ambulance officers. Each ambulance that responds to emergency incidents reserves an ePRF tablet. The ePRF system operates on a tablet that connects to a St John server through the Internet. Any data logged onto the tablet is expeditiously transmitted to the server in the presence of an internet connection. When no internet is available, the tablet stores the information and transfers it once connectivity is restored.

The ePRF system stores essential information about patients, including their identity, the details of their medical concerns and the treatments received, and the outcome of their case. In addition, the information provided may consist of pictures, such as those of accident scenes or injuries. There is currently no technical solution in production where the patient information gathered in the ePRF tablet by paramedics is directly and digitally transferred to the ED unit of a hospital and associated primary and secondary care. Thus, a new prototype was created to investigate the possible integration of digital health technologies to provide a technical solution to replace the current manual process. The prototype created to support this thesis is named touchPoint. This naming convention's significance was creating a point of interoperable patient data transfer between the paramedics and the ED unit during patient handover at the hospital.

Figure 4.2: Screenshot of an ePRF tablet used by Paramedics - provided by the domain expert

The current manual process as shown in Figure 4.3 comprises of four main steps (*Clinical Communications Centres*, 2023):

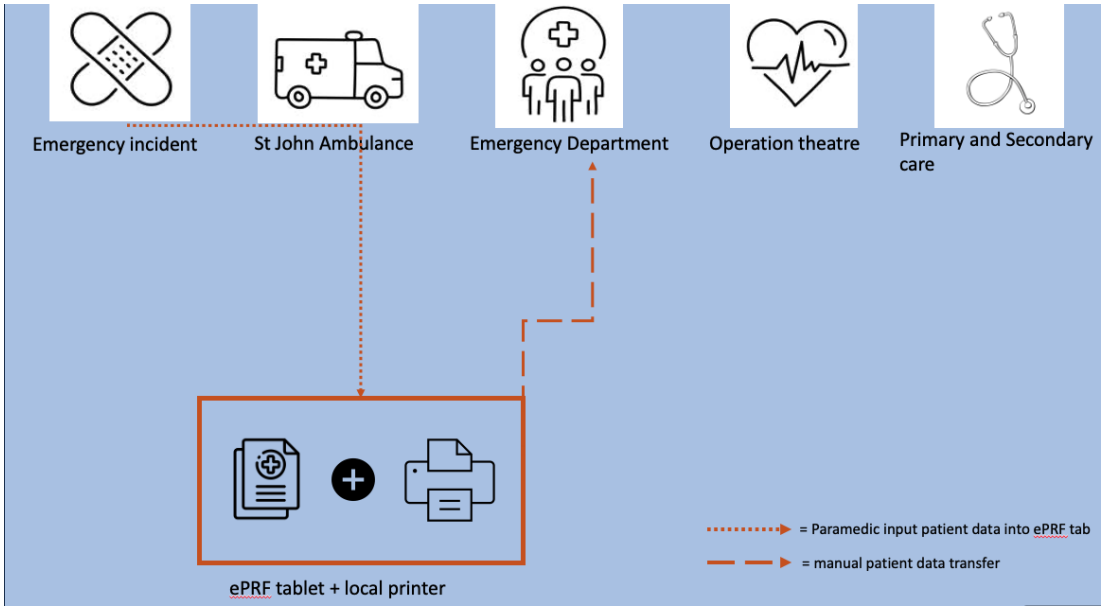

Figure 4.3: Current manual process using ePRF

Step 1: When an emergency call is made to the St John ambulance call centre, the call handler creates a work order in the call centre system and evaluates the emergency incident based on metrics described in Figure 1.1.

Step 2: This work order information is sent to the call dispatcher in the St John call centre, who then assigns a paramedic to the work order based on ambulance vehicle availability and location.

Step 3: The paramedic is notified about the emergency incident via the ePRF tablet.

Step 4: The paramedic uses ePRF tablet to collect all the patient information at the emergency incident location.

Step 5: When the patient is transferred to a hospital, the paramedic must manually print the information collected in step 4 using a local printer and hand it to the ER department's clerical staff.

touchPoint prototype firstly eliminates the manual task explained in step 5 and, more

importantly, extends the capability to connect emergency healthcare providers, including hospital, primary and secondary care to share interoperable patient data. The prototype offers four main portals for the different emergency healthcare providers and uses OpenEMR as a centralised database to send information adhering to FHIR standards between the four main portals.

4.2 Research questions

A comprehensive overview of the current method for transferring patient data to clerical administrators at hospitals following submission to the hospital is outlined in section 4.1. In the last step of Figure 4.1 the paramedic crew are responsible for printing out a physical copy of the patient information gathered from the 'Ryan playground incident' using a local printer and handing this to the clerical officer at the admin desk of the ED. This physical copy is shared between hospital emergency staff, primary and secondary care personnel via local print, digital scan and email services. Thus, this prototype aims at utlising mHealth in improving data interoperability by facilitating data flow between the ePRF and emergency department hospital systems.

The following two RQs which will be answered throughout this chapter and more specifically in sections 4.3 and 4.5.

- *RQ4: How can the major challenges identified in RQ2 be translated into a mHealth application design, which can be integrated into emergency settings?*
  This question conjoins the technical design required to overcome the major challenges such as data interoperability and security identified in RQ2, along with the medical regulation, end-user, satisfaction and cost effectiveness requirements found in RQ2. The mHealth application design is covered in section 4.3.

- *RQ4: To what extent can the mHealth application design created in RQ3 succeed in improving communication between healthcare providers in emergency settings?* This last research question evaluates the prototype created to use in a mock emergency settings and providing results found through the conducted experiments. The findings of this RQ is briefly covered in section 4.4 and more precisely in section 4.5.

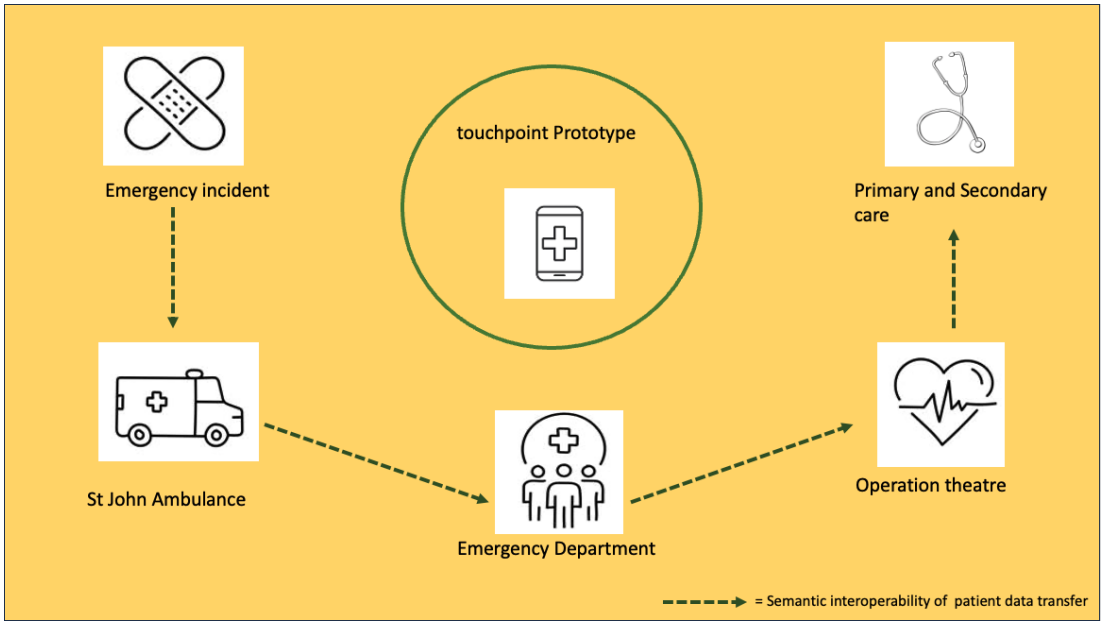

Figure 4.4: New process using touchPoint prototype

4.3 Prototype Design

The touchPoint prototype aims to demonstrate the exchange of patient data between various healthcare entities using mHealth and other digital technologies. touchPoint comprised several functional requirements (FRs) found when conducting the SLR to answer RQ1. These FRs are based on the problem definition specified in section 3.3.1 of chapter 2. The problem definition summarised that the mHealth application papers researched as part of the SLR in 2, there were minimal guidelines on a list of

requirements that every mHealth application could use as a foundation or skeleton to support the design phase of the development process, which led to the formation of RQ1. After reviewing the results from RQ1, as outlined in section 2.3.1 of chapter 2, the requirements for the touchPoint prototype were corroborated.
The most important functional requirements have been listed below:

1. **FR1) Medical regulation:** Ability to adhere to the standard medical regulations that concern this prototype in emergency settings.

   This requirement was crucial because medical guidelines refer to a set of regulations that ensure newly built mHealth applications are complaint and use recent healthcare data standards. However, there are limited medical regulations that address the experimental context for software engineering research projects (Davenport & Kalakota, 2019; Kitchenham et al., 2002). The prototype adhered to global medical regulations by incorporating HL7, FHIR healthcare standards.

2. **FR2) End user satisfaction:** Ability to ensure end-user satisfaction while using the touchPoint prototype.

   This requirement was paramount because end-user satisfaction is essential in measuring a software product's success (Zviran & Erlich, 2003). More importantly, this requirement is crucial to measure the success of any technical solution based on the capability and ease of use amongst the intended users (Mahmood, Burn, Gemoets & Jacquez, 2000).

3. **FR3) Cost effectiveness:** Ability to develop touchPoint prototype using cost-effective methods.

   This requirement was essential cost-effectiveness is the ability to sell your software products at prices that will engage customers and generate a high return on investment quickly (Al-Rousan, 2015). The technology development tools used to develop the prototype were open-source technologies and data payloads hence

reducing extra costs (Rodriguez-Martinez, Seguel & Greer, 2010).

4. **FR4) Interoperability:** Ability to link healthcare systems where patient data is sent and received using interoperable data exchange standards.
   This requirement was important because many healthcare systems are built in separate functional, organizational, and technical "silos" which makes it difficult for them to interact with each other effectively (Weber-Jahnke, Peyton & Topaloglou, 2012). The lack of interoperability is a severe issue that hinders the ability to connect various aspects of healthcare through technology. Achieving interoperability is challenging due to the complexity of healthcare information and the presence of multiple technical, socio-political, and legal problems.

5. **FR5) Usability:** Ability to cater to all users that will potentially use this prototype, explicitly meeting the general accessibility guidelines in software development.
   This requirement was necessary because software usability is crucial, especially in a work setting (Anderson, Fleak, Garrity & Drake, 2001). Poor usability and other risks associated with software and computers can lead to health problems, making it essential to prioritize usability. This requirement is also crucial because "focusing on the user early in the development process goes a long way toward improving product quality and eliminating rework" (Boivie, Åborg, Persson & Löfberg, 2003)

6. **FR6) Security and Privacy:** Ability to guarantee the patient data collected and exchanged to and from healthcare systems protect patients' privacy and security.
   This requirement was vital because "data security and privacy in the healthcare sector is an issue of growing importance" (Appari & Johnson, 2010). As digital patient records become more widespread and regulations increase, there is a growing need for improved information security.

4.3.1 White-board Session

During the early stages of design, developers utilise various methods to stay organised and attentive, including whiteboard sessions. Collaboration is crucial during the early stages of design for software professionals. Discussing ambiguous issues helps to clarify them, and reaching a consensus on how to solve problems is especially beneficial for group projects (Rooksby & Ikeya, 2012). The purpose of white boarding the overall design of touchPoint is similar to the goals found in (Socha, Frever & Zhang, 2015), continuous improvement and visualisation of the technical design. By drawing individual boxes and arrows representing every relationship and thus communication between different screens and healthcare systems, there was visual clarity of the technical design found in Figure 4.5. Furthermore, the whiteboard session in Figure 4.5 shows the proposed prototype's overall strategy and specifies screens and application programming interfaces (APIs). The following sections of Chapter 4 will provide detailed explanations of each component of the prototype.

4.3.2 Process View - Sequence Diagrams

Software engineering is a field in which Unified Modeling Language (UML) diagrams as a standard to represent object-oriented design models. A UML diagram is helpful for software projects as it provides visual models that assist in identifying system and application requirements and scopes (Koç, Erdoğan, Barjakly & Peker, 2021). It is a visual tool used to showcase the features of a product or application. The graphics within the UML diagram represent the functions and events of the software (Torre, Labiche, Genero & Elaasar, 2018). An Activity diagram which is a fragment of a UML diagram, comprises various diagram subsets, as shown in Figure 4.6 where the sequence of activities for a user when logging into touchPoint is exhibited. The activity diagram depicted in Figure 4.6 on 84 shows the logic behind the login process and user account

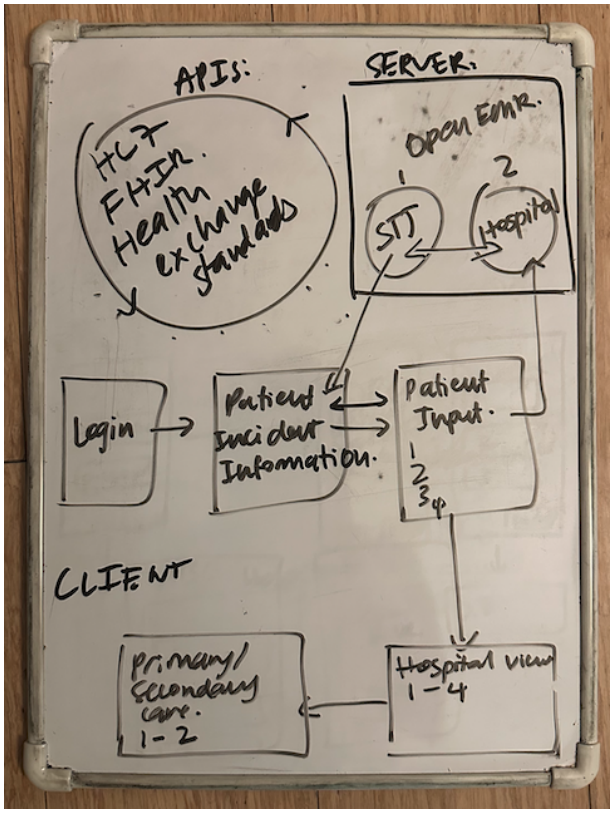

Figure 4.5: touchPoint whiteboard session conducted in September 2023

creation. All activities in the activity diagram are interconnected; thus, user registration and validation are crucial.

First, the user must enter login credentials; unless the user is not previously registered, creating a new account sequence should be followed. Secondly, once user credentials have been entered, touchPoint differentiates between the healthcare users; paramedics, hospital emergency staff and primary/secondary care staff. Depending on the type of healthcare user and validation, the ensuing activity diagrams shown in Figures 1-4 symbolise the user journeys and subsequent visual flows of all three healthcare users.

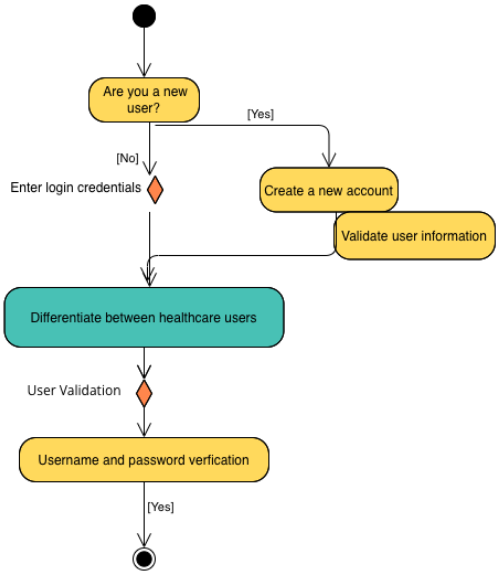

Figure 4.6: touchPoint mHealth Activity Diagram for User Login

4.4 Prototype Implementation

4.4.1 Development Approach

The Software Development Life Cycle (SDLC) builds and maintains software products. This process involves different phases, starting with preliminary development analysis and ending with post-development software testing and evaluation. The development teams use various models and methodologies to create the software systems, and these methodologies serve as the framework for planning and controlling the entire development process (Leau, Loo, Tham & Tan, 2012). The Waterfall model shown in Figure 4.7 on page 85, first proposed by Winston Royce in 1970, is a linear sequential model for software development (McCormick, 2012). It involves various phases, including "requirements analysis, design, coding, testing, and implementation" (Rather & Bhatnagar, 2015). It is crucial to complete each step of this SDLC model before proceeding to the next one (Sabale & Dani, 2012). One major drawback of this waterfall

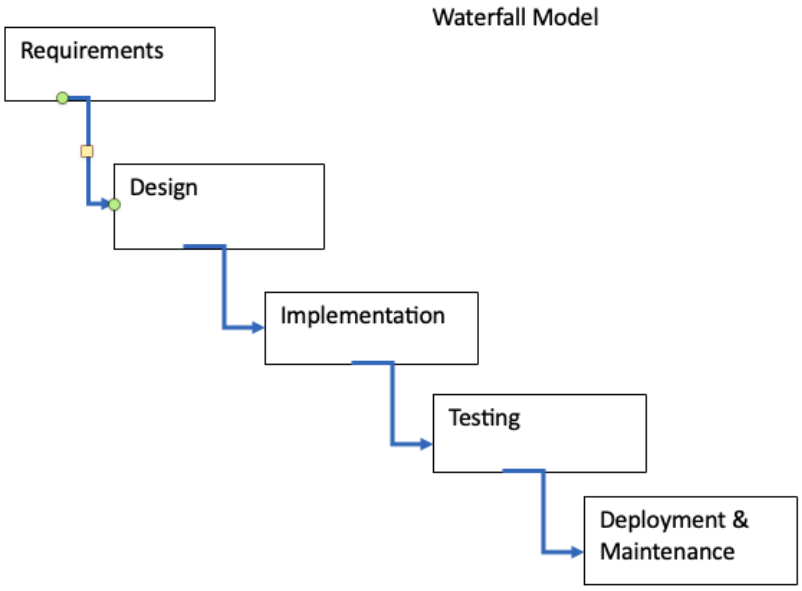

Figure 4.7: SDLC Waterfall Model

model approach is that it is irreversible, "once a stage is complete meaning it is locked" (Amlani, 2012). The SDLC approach for the touchPoint prototype required a more dynamic, iterative and recurring development model due to the complex requirements; hence this waterfall approach was unsuitable as "it is not very useful when the project requirements are dynamic in nature" (Mishra & Dubey, 2013). A new iterative SDLC approach was developed, as illustrated in Figure 4.8 on page 86, to address the need to reform and revise touchPoint by repeating the implementation phase of SDLC on multiple iterative cycles. Iteration refers to the concept of repeating a process until a desired outcome or sequence is achieved for an artifact (Schuh, Rudolf & Diels, 2015; Kneuper, 2017). Three advantages of adapting this new iterative model for this thesis were inborn variation, fast turnaround and easy adaptability Okesola et al. (2020).

1. **Inborn Variation:** It is common for software development to include variations, particularly during the deployment phase. However, the new iterative model simplified this process by gradually improving upon previous versions with newer

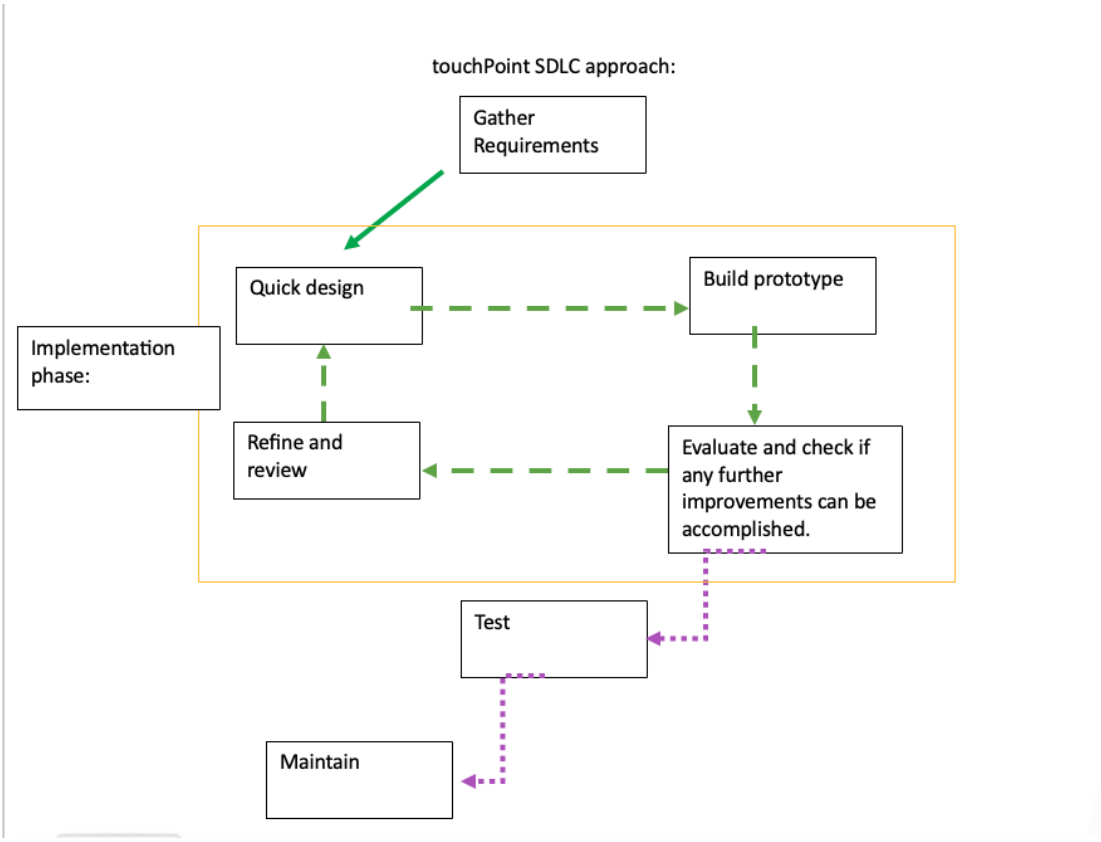

Figure 4.8: touchPoint prototype development model

and better iterations. This made the entire process easier and more efficient.

2. **Fast Turnaround:** Although the phases of the new iterative model are similar to those of a traditional model like the waterfall model, the new iterative process allowed each stage to be broken down into smaller periods as needed to meet the thesis requirements. This allowed for greater flexibility and efficiency in the process.

3. **Easy Adaptability:** The new iterative model enabled quick adaptation to any changes during the development phase, such as coding changes, a new UI screen, a new button, replacing a health information exchange standard. The new iterative model enabled essential code structure or implementation changes to be made quickly when required.

Table 4.1 details the new iterative SDLC model created for the touchPoint prototype.

Table 4.1: New iterative SDLC model

Detail	**Iterative cycle 1**	**Iterative cycle 2**
Gather requirements	Listed all the vital functional requirements needed to test data exchange between the prototype and OpenEMR database.	Added new requirements, screens and code when required.
Quick design	Mocked up a quick UI design using Xcode and Swift language view controllers	Added more view controllers for new functionalities.
Build prototype	Code swift controller classes, adding important functions	Any changes made to during the previous two steps reflected in this phase and the next iterative cycle.
Evaluation	Test the prototype built so far and check if refinement is reviewed.	Evaluate all the features.
Refine and review	Refine and review existing features	NA
Test and Maintain	Testing user journeys for all three healthcare roles	NA

The new iterative SDLC model created for touchPoint combined "elements of the waterfall model in an iterative fashion" (Alshamrani & Bahattab, 2015). Each round of the implementation cycle produced deliverable increments of the prototype. The model gradually added more features by starting with a partial implementation and building upon it in subsequent implementation cycles. As each implementation cycle progressed, additional features were integrated into the existing version until all planned functionalities were incorporated into the prototype. The following table outlines the various stages involved in the iterative SDLC model utilized to develop touchPoint:

4.4.2 Application Architecture

During the process of conducting the systematic literature review (SLR), it was observed that many mobile applications rely on the traditional client-server architecture. A mobile or desktop workstation collaborates with internet servers to offer users the necessary functionality (Oluwatosin, 2014). World Wide Web (WWW) is a prime example of a client-server architecture model where documents are retrieved from servers or clients which connect to File Transfer Protocol (FTP) servers to download or upload documents. mHealth applications are also based on this traditional architecture of the client-server model. Digital technologies like cloud computing are easily accessible for mobile application development. As a result, it is often integrated into the mobile application architecture (Gurupur & Wan, 2017). Correspondingly, a mHealth application called Freeband Awareness created by Broens, Van Halteren, Van Sinderen and Wac (2007) exemplifies a three-layered architecture framework. The first layer is the application layer, where the application framework is located. It contains an application container that supports the execution of application components and gives access to general and domain-specific functions. The container also provides access to the service infrastructure. The second layer is the service infrastructure layer, providing a platform for mobile services. It manages the service life-cycle, discovery, and security mechanisms. The bottom layer is the network infrastructure layer, which ensures smooth mobile connectivity through different means, such as General Packet Radio Service (GPRS), Universal Mobile Telecommunications System (UMTS), and Wireless Fidelity (WiFi) (Wegdam, 2005). While this application architecture is helpful for mHealth applications requiring connectivity to network and service infrastructure to optimise multiple communication devices, wearbles and sensors, the touchPoint prototype required an application architecture to support data exchange between different healthcare entities.

Coincidentally, the open mHealth application architecture discussed in (Estrin &

Sim, 2010) was about shared data standards that are "already in place to support interoperable voice and data transfer", which can "promote the scaling, coherence, and power of mHealth" technology. This type of application architecture model was bound to complement the touchPoint application architecture due to its dependency on health information standards such as FHIR and HL7 (covered in the next section). Various papers studied as part of the SLR, focused on adapting architecture models to support the development of scalable and sustainable health information systems. mHealth Applications are commonly known to be "an information source for clinical information or documents" or sufficient enough to be integrated into healthcare practices solely when there is a presence of healthcare data and information exchanges standards incorporated into the application architecture (Marceglia, Fontelo, Rossi & Ackerman, 2015). This was an important factor in considering a three layered architecture similar to (Estrin & Sim, 2010; Marceglia et al., 2015) where healthcare data standards such as HL7 and FHIR could be easily integrated into the touchPoint application architecture model.

The application architecture model for the touchPoint prototype shown in Figure 4.9 incorporated several entities, including Xcode, Swift programming language, OpenEMR, and healthcare data information standard APIs. The rest of this section presents the reasoning for selecting each of the components in the touchPoint architecture, and how each component contributed to the prototype architecture as a whole.

Xcode and Swift

Apple Inc's integrated development environment (IDE), Xcode, is widely used in mHealth applications to develop software for macOS, iOS, watchOS, and tvOS (Jordan et al., 2018; López, López, de la Torre Díez, Jimeno & López-Coronado, 2017). Xcode uses Apple's Cocoa Touch software framework, the application programming interface

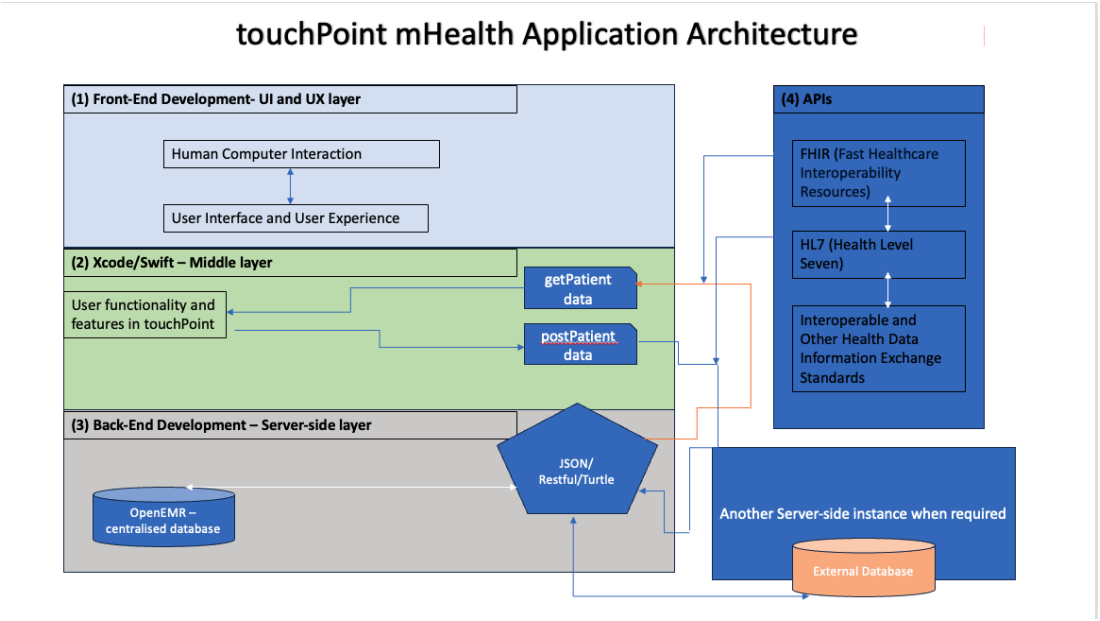

Figure 4.9: touchPoint mHealth Application Architecture

(API) used for the iOS, watchOS, and tvOS operating systems. The main reason for selecting Xcode IDE to develop touchPoint was due to its easy integration of compliance and graphic framework in the user interface of the prototype. The requirements for compiling and coding a mHealth application can be complex and vary between different platform vendors, as stated in a study on platform vendor requirements and compliance (Ouhbi et al., 2015). To meet the strict code signing standards for app store submissions, building iPhone applications using Xcode is recommended (C. L. Petersen, Gorges, Dunsmuir, Ansermino & Dumont, 2013). The Figure 4.10 displays how Xcode allowed the application interface to be threaded seamlessly (left hand side) with the design principles, icons, buttons and navigation between the screens of the iOS platform. The choice of "contrasting colours and sans serif fonts" (right hand side) was highly beneficial "to ensure readability among aging adult users", as observed in the paper (Ratnanather et al., 2021).

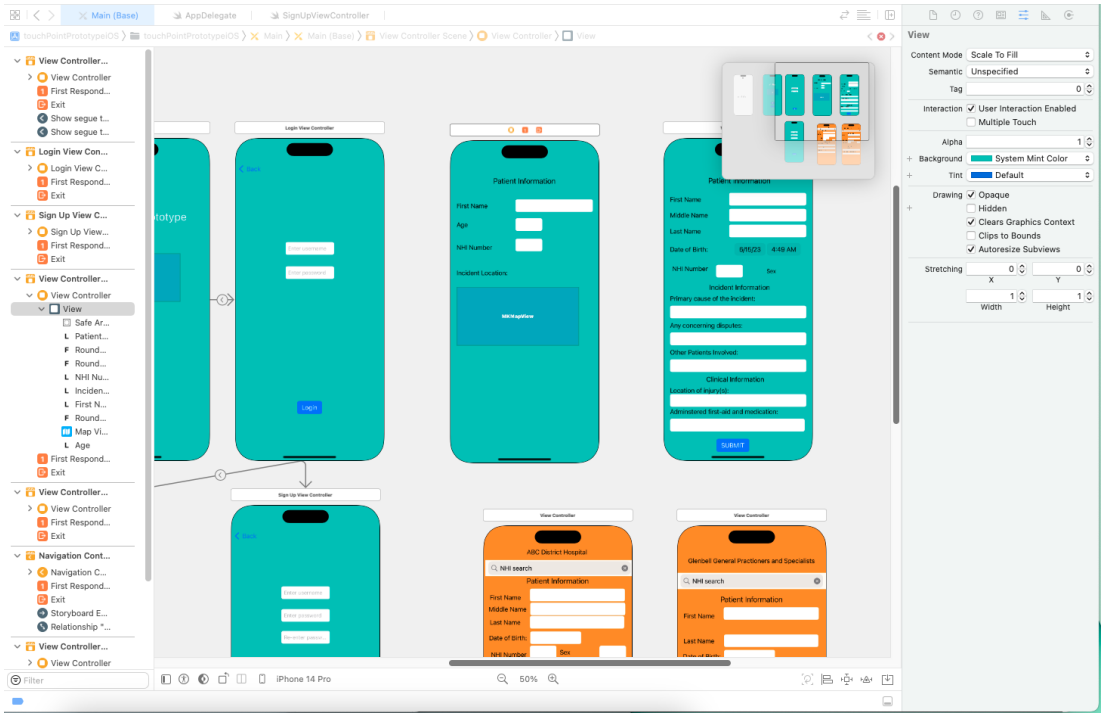

Figure 4.10: Xcode snippet

FHIR and HL7

Health Level Seven (HL7) is a set of guidelines governing information exchange between healthcare systems. Meanwhile, SNOMED CT is a coded classification system that defines healthcare concepts such as diseases, procedures, and findings (Benson, 2012). In 2020, the U.S. Centers for Medicare & Medicaid Services (CMS) announced the healthcare IT interoperability rules requiring all CMS-regulated parties, such as hospitals, health insurers and healthcare IT developers, to adopt new standards and reach the ultimate clinical interoperability due to the increase in telehealth, internet-of-things (IoT) and other digital technologies introduced into the healthcare system (Zhang, Saltman et al., 2022). The two critical new standards included FHIR (Fast Healthcare Interoperability Resources) and US Core Data for Interoperability (USCDI) (Schreiber, Krauss, Blake, Boone & Almonte, 2021). Evaluating the findings from RQ2 which defined that semantic data interoperability is a significant challenge to

implement within a mHealth application design; the decision to incorporate FHIR was obvious and logical. This is because FHIR as shown in Figure 4.11 dictates the precise data exchange method to ensure mutual understanding among all parties involved. Also, the three significant advantages of incorporating FHIR into the prototype were the automated data structure facility, improved data management (Mandel, Kreda, Mandl, Kohane & Ramoni, 2016) and most importantly, FHIR resources were uniquely adapted for emergency clinical settings in the prototype. FHIR and HL7 are healthcare

Figure 4.11: FHIR diagram

standards for exchanging healthcare data, but FHIR has some distinct advantages. FHIR uses web technologies like XML, JSON, and RDF, whereas HL7 solely supports XML. Additionally, FHIR was easier to use and more versatile because it is a iterative improvement from previous healthcare standards, including HL7 (Bender & Sartipi, 2013). FHIR also has more options for exchanging data between systems. It uses a RESTful API approach, which allows for one-to-many interfaces instead of point-to-point interfaces (Gøeg & Hummeluhr, 2018). FHIR allowed the patient data exchange to be seamless, which was critical for the touchPoint prototype.

OpenEMR

OpenEMR, through modular architecture, allows data collection through HTML-based UI forms and storage of that data in a database with a structure that is based on its information model and data records. Encryption is used to protect some sensitive information. The database structure is constantly changing to meet expanding requirements. OpenEMR can be used with a XAMP stack and is mostly based on the PHP programming language. OpenEMR also offers a restricted mapping between HL7 FHIR resources and the OpenEMR data model (Noll, Beecham & Seichter, 2011). The fundamental reason for choosing OpenEMR as the server side component is because the open-source medical practice management software has been used in many mHealth application papers where healthcare data interoperability is a challenge to incorporate in the design (de Abajo & Ballestero, 2012). Also incorporating OpenEMR with the use of RESTful API and FHIR has shown that it "was successful since it contributed to lowering the implementation expense and, simultaneously, increasing interoperability between organizations" (Sujudi & Heryawan, 2022). Also, OpenEMR was free of cost as compared to other cloud-based solutions. OpenEMR supports data encryption through all data exchange pathways and is compliant to the Health Insurance Portability and Accountability Act (HIPAA) which sets the standards for protecting patients' electronic health information.

Overall, choosing Xcode, swift programming language assisted in ensuring common requirements such as usability, end-user satisfaction and cost-effectiveness were attained. Whereas digital health innovations like FHIR, HL7 and OpenEMR assisted in translating the data interoperability and security challenges identified in RQ2 into a mHealth application for emergency settings.

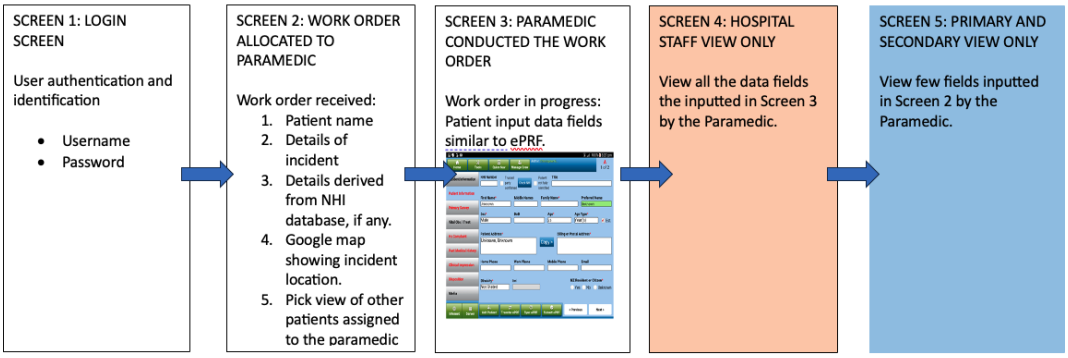

Figure 4.12: Prototype screens

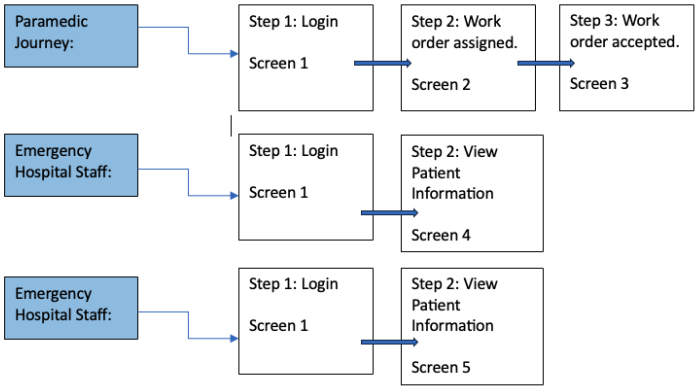

Figure 4.13: Prototype user journeys

4.4.3 Main Components and Portals

Component 1 - Login Screen

Upon opening the application for the first time, the user is directed to the login screen (refer to Figure 4.14). Here, the user can sign in to the application using the login credentials; username, and password. After successfully signing in, the user unlocks the application and is directed to the appropriate healthcare portals associated to their roles, the various portal screens are discussed in the next sections. This form of user authentication and identification was common amongst most mHealth applications researched during the SLR. On the contrary, e-CoVig application uses the QR code procedure to login "for patients less proficient in smartphone use". This feature allows

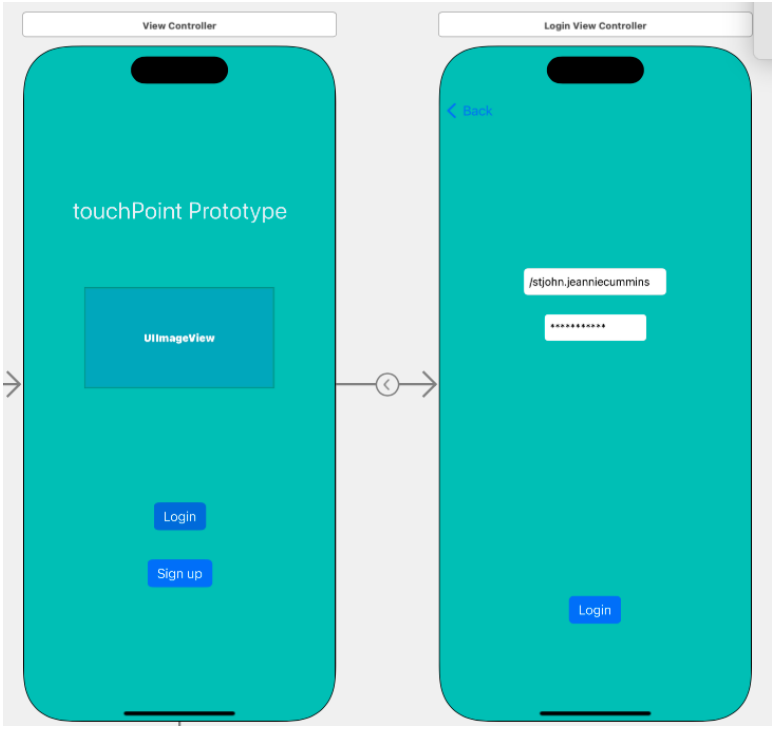

Figure 4.14: Login and Signup Screen Simulator Snippet

for the processing of multiple patients at once in facilities like nursing homes or prisons where it may be beneficial to monitor groups of patients in sequence (Raposo et al., 2021a). Considering this prototype was targeted at three main user groups, paramedics, emergency, and other healthcare professionals, a simple username and password procedure was developed using Firebase. Firebase is a platform for developing web and mobile applications provisioned by Google (Nigam, Narang, Chaurasia & Nanda, 2020). Many mHealth applications researched during this thesis used Firebase to authenticate the various users logging into the application such as (Fazio et al., 2022; Saha, Tahora, Barek & Shahriar, 2023). Firebase was used as the user authentication tool to store the username and password of the healthcare users such as paramedics, hospital staff, and primary and secondary care users, who needed to login into the prototype. As illustrated in Figure 4.14, paramedic user; Jeannie Cummins enters username and password to navigate to the incident portal (covered in the next section). Firebase

platform is a Back-end-as-a-service (BaaS), which links applications to back-end cloud storage and APIs provided by back-end applications (Sharma & Dand, 2019).

As observed Firebase Authentication is a secure and user-friendly service that allows users to authenticate themselves in the application easily. It offers fast implementation and supports various authentication methods, such as passwords, email, phone numbers, and popular federated identity providers like Facebook, Google, and Twitter. To ensure proof of concept of the prototype, a simple authentication of username and password was developed. Firebase Authentication service encrypts data in transit using HTTPS and logically isolates user data ensuring a secure authentication method for touchPoint.

Component 2 - Emergency Incident Portal

After successfully logging in, Paramedics will be directed to the "Emergency Incident Portal" screen, as illustrated in Figure 4.15. This screen comprises three crucial components. The initial element displays three text fields at the top of the screen; patient's first name, age, and NHI number. The second component is a map view that pinpoints the emergency incident's location. Lastly, there is a dropdown menu that lists all the patient work orders assigned to the Paramedic within a ten-kilometer radius of the incident location.

Healthcare data exchange procedure:

First data communication procedure:

- A call handler from St. John receives a call about an emergency incident.
- The patient's details provided during the call are cross-checked with their National Health Index (NHI) number, which is stored in OpenEMR. This is a centralized healthcare database.
- The exchange of healthcare data occurs using three components - HTTPs, Restful, and FHIR message format.

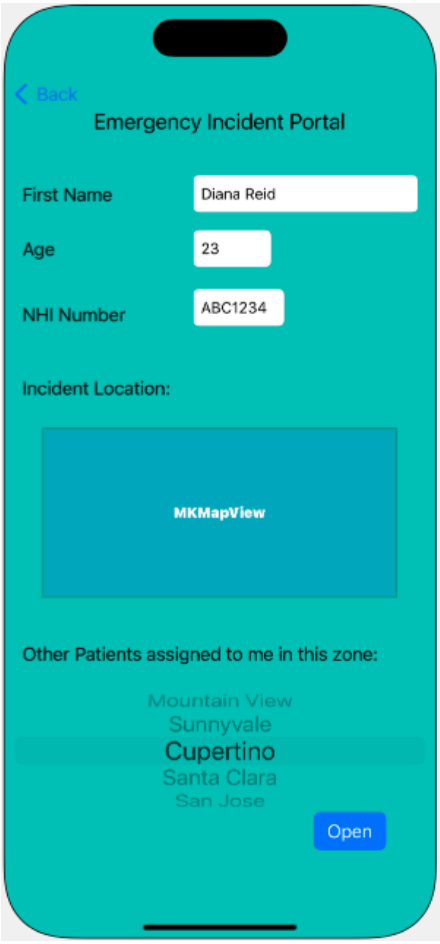

Figure 4.15: Emergency Incident Portal Simulator Snippet

Second data communication procedure: The patient information matched and established using the OpenEMR database explained during the first data communication procedure is sent to Emergency Incident Portal in touchPoint. This healthcare data communication is also conducted using HTTPS, Restful, and FHIR message format.

It is due to these three components that assure both the data communication procedures in this emergency incident portal are secure and adheres to healthcare interoperability standards. This form of data communication has the potential to overcome the data interoperability challenge found in RQ2.

Component 3 - Paramedic Portal

The paramedic portal on touchPoint, as seen in Figure 4.16, displays all the necessary patient information that must be collected and shared with hospitals or other healthcare agencies. The text fields have emanated from the text fields available in ePRF. Four crucial text fields related to the incident and clinical information are required for the patient's admission and subsequent medical procedures at the hospital, if necessary. Therefore, it is essential Paramedics fill in all text fields in this portal. After submitting

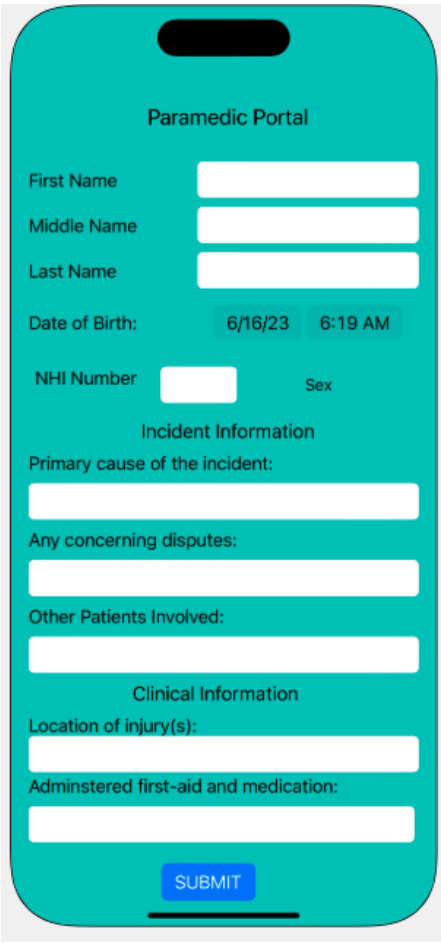

Figure 4.16: Paramedic Portal Simulator Snippet

patient, incident, and clinical information to OpenEMR, the healthcare data exchange procedures follow the same process as the emergency incident portal, hence also assuring technical challenges are minimized.

Component 4 - Emergency Hospital Staff Portal and Component 5 - Other Healthcare Staff Portal

The Emergency Hospital and the Other Healthcare Staff Portals are paramount in representing the findings of touchPoint. These portals provide a digital solution that could replace hospitals' current physical handover of ePRF documents described in the background section. Security and Data interoperability are crucial aspects of this solution. Once Paramedics input the patient, incident, and clinical information in the Paramedic portal, this data is enveloped and sent to OpenEMR via RESTful, FHIR message format. OpenEMR sends patient, incident, and clinical information to the Emergency Hospital Staff and Other Healthcare Staff Portals via HTTP POST request.

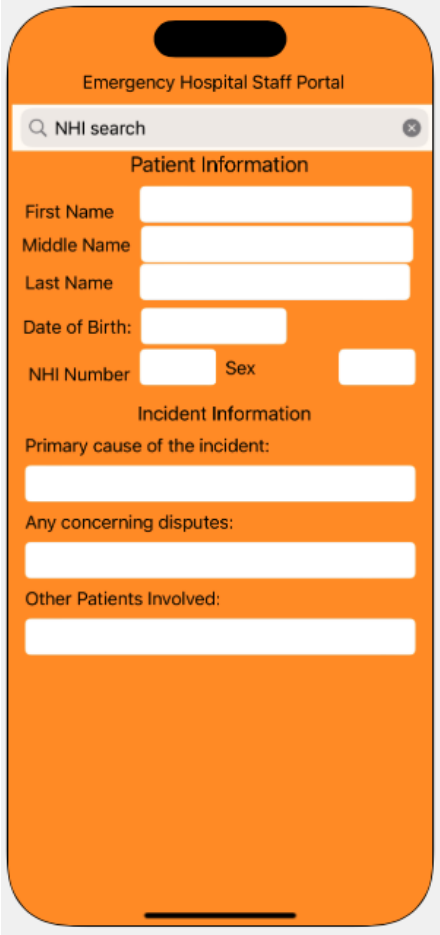

Figure 4.17: Emergency Hospital Staff Portal Simulator Snippet

All important technical artefacts are attached to the Appendix. Code bases and other information about the prototype can be found on https://github.com/varshapai-digital/touchPoint.

Figure 4.18: Other Healthcare Staff Portal Simulator Snippet

4.5 Prototype Evaluation

4.5.1 Results

To test the prototype, a mock test setup was created as seen in Figure 4.19. This test setup consisted of three data exchange pathways. The first data exchange pathway was the emergency incident information sent for a paramedic from the ambulance call centre

to view within the emergency incident portal as seen in Figure 4.15. Upon receiving this incident information, the paramedic inputs incident and clinical patient information in the paramedic portal as seen in Figure 4.16 and submits it to the associated hospital or primary/secondary healthcare providers depending on the patient's condition. The emergency hospital staff portal in Figure 4.17 displayed patient and incident information for the hospital ER healthcare providers to view, whereas the other healthcare staff portal in Figure 4.18 showed patient and clinical information for primary and secondary healthcare staff to view. The testing of the prototype was conducted across 11 iterations. Each iteration consisted of the end-to-end user journey pathway as illustrated in Figure 4.12. Six iterations followed the patient data being sent to the hospital, whereas five iterations followed the patient data being sent to the other healthcare provider portal.

Table 4.2: Test results from the prototype

	Task description	**Expected behaviour**	**Time take**
1	Open the prototype on the phone	Appearance of login page	Less than 1 second
2	Enter user name	Username is entered by the user	Less than 1 second
3	Enter password	Password is entered by the user	Less than 1 second
4	Username and password correct	If the username and password are correct, user is taken to ambulance officer portal/emergency care unit portal	8 seconds
5	Username and password not correct	If the username and password are incorrect then show login details incorrect	2 seconds
6	Ambulance officer navigates to patient information portal	If the username matches with ambulance officer ID then ambulance officer portal is displayed	6 seconds

7	Emergency unit clerical staff	If the username matches with clerical staff ID then clerical staff portal is displayed	6 seconds
8	Ambulance officer inputs all information regarding the patient	All mandatory patient data is filled	5-10 minutes (one person test)
9	Ambulance officer after inputting all patient information, they click submit	All mandatory patient data is filled and submitted	3 seconds
10	Corresponding emergency care unit can view this information	Fields inputted by the ambulance officer can be viewed by the emergency care unit	Out of 11 tests the range is between 6 milliseconds -11 seconds

Across both of the portals, patient data was received by the corresponding healthcare provider within an average of 11 seconds across the 11 iterations. This results showed a significant improvement in data communication as compared to the current 25 minutes time taken for the paramedic to manually provide a hard copy of patient information to the ER clerical staff as confirmed by the domain expert at St John New Zealand. A major reason for this time reduction is due to the insertion of mHealth technology. Thus, it is important to note that the credibility of this improvement is subject to adequate mobile data coverage. Poor mobile network coverage in rural and underprivileged areas is an immense challenge highlighted in healthcare, educational and business projects (Thapaliya, 2023). Access to adequate mobile data coverage has resulted in positive outcomes for projects across educational, environmental and most importantly

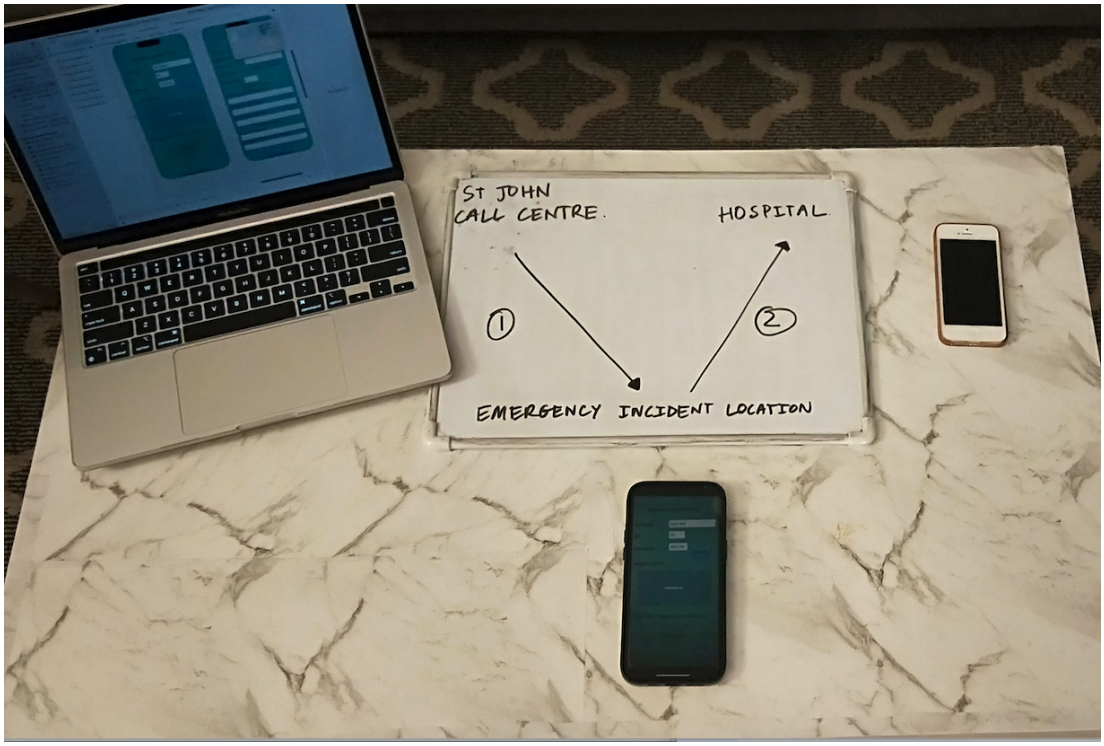

Figure 4.19: touchPoint test setup environment

healthcare (Arnold et al., 2020). To cover the scenario of low mobile data coverage incident locations such as mountains or remote areas, one extra test iteration was conducted in the basement of a building where the mobile data signal on both iPhones were minimal. The data exchange was observed with a delay of 20 seconds, hence it is vital to note adequate mobile data coverage has to be set as a perquisite for this prototype to provide improvements within emergency settings. Rural Broadband Initiative (RBI) conducted by the New Zealand government invested 400 million New Zealand dollars to facilitate 50 Mbps mobile network coverage to 99% of the country's population and 10 Mbps to the remaining 1% (Xiang et al., 2022). Since the completion of stage 1 there is proven evidence of better mobile network usage and proficiency, hence the requirement of adequate mobile network is imperative for paramedics to be aware of in New Zealand (Milner, 2020). This section covered the quantitative aspect of answering RQ4, the next section discusses how the interoperability, security and privacy challenges

were overcome in detail and hence the extent of data communication improvement introduced by the prototype.

4.5.2 Discussion

Security and Privacy Improvement

Patient data security is imperative when healthcare providers and individual users consider mHealth applications to be integrated into their healthcare practice or lives (Mia et al., 2022). In this thesis, mHealth application technology was extensively studied to potentially integrate into emergency settings to improve data communication. Thus, it was crucial to maintain and transmit patient data securely. This section discusses the decision to develop the prototype on an iOS platform in comparison to Android due to the security concerns found in existing Android mHealth application literature. iOS is considered more secure because it is a closed ecosystem as compared to the open-source Android platform, reducing the chances of malicious attacks (Adekotujo, Odumabo, Adedokun & Aiyeniko, 2020; Garg & Baliyan, 2021). Also, Apple's strict policies during application review eliminate potential harmful applications available to users in the app store. Apple's regular software updates and quick security patch deployments ensure iOS devices are less vulnerable to attackers than Android devices. Health Insurance Portability and Accountability Act (HIPPA) offers a set of guidelines for developers to ensure the mHealth applications built are in accordance with the required and addressable technical safeguards and hence are compliant (Zubaydi, Saleh, Aloul & Sagahyroon, 2015). However, the HIPPA guidelines are not widely known amongst development teams, causing more security issues in mHealth applications built on the Android platform (Mia et al., 2022; Sataloff, 2008). Android is a mobile operating system that is open-source and created by Google (Developers, 2011). A report by a global cyber security and privacy company named F-secure8 indicated

Android gets significantly higher malware attacks than the iOS platform (Sayfullina et al., 2015). Android is a Linux-based system providing an application framework for developers to build applications using Java (He, Naveed, Gunter & Nahrstedt, 2014). Activity, service, content provider and broadcast receiver are the four main components in the Android application framework (Developers, 2011). In Android, Intents are utilized to communicate between different components. These intents include starting an Activity, initiating a Service, or sending a Broadcast message. Developers can create an Intent Filter using action strings to specify the specific types of Intents a component wants to receive. Android also offers a permission system to control admission to system resources and limit inter-component communication (Enck, Octeau, McDaniel & Chaudhuri, 2011; He et al., 2014).

Interoperability Challenges

Interoperability refers to the capacity of two or more systems to share data and utilise common functionalities (Ducq & Chen, 2008). The definition of interoperability in healthcare is the ability of a system or product to exchange data, both within and between systems or products without the user exerting extra effort (*Digital Health Australia- Interoperability and data quality*, 2023). By putting standards into practise, interoperability is made possible. The use of technology to support healthcare providers assists in boosting communications promptly and securely and improving patient outcomes. Assessing many mHealth applications and other digital health technology based applications during the SLR, these are conclusions which determines why interoperability in healthcare systems is important:

- Interoperability in healthcare allows for better care coordination by making sharing patient data between different healthcare settings easier. This ensures that healthcare providers have access to complete and current patient data, resulting

in improved care coordination and continuity (Vest & Gamm, 2010).

- Interoperability in healthcare facilitates easy access to complete patient information, such as medical history, test results, and medication details. It leads to informed decision-making, reduces unnecessary tests, and enhances patient safety (Kawamoto et al., 2012).

- Interoperability gives patients the ability to access and communicate their health data with multiple healthcare providers, which helps them engage in their own healthcare decisions, manage their health conditions, and make informed choices (Vest, Campion, Kaushal & investigators, 2013).

Metrics and measurements must be created in order to improve interoperability and assess the level of interoperability (Ducq & Chen, 2008). Measuring interoperability is crucial for improving healthcare delivery, enhancing patient outcomes, and supporting effective collaboration and information exchange among healthcare stakeholders (Dolin & Alschuler, 2011). Well-known notable examples of interoperability frameworks are ATHENA Interoperability Framework (AIF), The European Interoperability Framework (EIF) and Framework for Enterprise Interoperability (FEI).

Table 4.3: Types of interoperability framework

Interoperability frameworks	
Type of interoperability framework	Description
ATHENA Interoperability Framework (AIF)	The AIF offers a composite framework and related reference architecture for encapsulating research components and comprehensive solutions to interoperability problems. Along with reference standards for the implementation of the reference architecture, the AIF also offers a methodological framework that outlines the approach to interoperability from the choice to consider collaboration to solution maintenance (Berre et al., 2007).
The European Interoperability Framework (EIF)	The various levels of interoperability and the emphasis on interoperability between public institutions from various governments throughout Europe. Additionally, it offers a number of suggestions for strengthening communication between national and international public administrations (da Silva Serapião Leal, Guédria & Panetto, 2019)
Framework for Enterprise Interoperability (FEI)	Illustrates the potential obstacles that could arise from the enterprise interoperability concerns (D. Chen, 2006), originally introduced through the INTEROP Network of Excellence (INTEROP NoE) project (Ducq & Chen, 2008), now known as the become ISO 11354:1 standard (da Silva Serapião Leal et al., 2019)

ATHENA Interoperability Framework (AIF) was selected to measure the interoperability developed in the prototype, to show interability improvements due to the integration of digital health technologies. By measuring interoperability, healthcare providers

can pinpoint areas where communication and collaboration are lacking (Lupşe, Vida, Stoicu-Tivadar et al., 2012). Improving interoperability in healthcare communication and collaboration can be achieved by measuring it. This identification of gaps can lead to better coordination and continuity among healthcare providers.

Figure 4.20 shows the matrix results of interoperability within the prototype. Interoperability barriers are identified as obstacles to interoperability within a system among three categories; conceptual, technological, and organisational. Conceptual compatibil-

Prototype component/Barriers	Barriers					
	Conceptual		Organisational		Technology	
	Syntactic	Semantic	Persons	Organisation	Platform	Communication
Emergency incident portal	0	0	0	1	0	0
Paramedic portal	0	0	0	1	0	0
Emergency Hospital Staff Portal	0	0	0	1	0	0
Other Health-care Staff Portal	0	0	1	1	0	0

Figure 4.20: AIF framework measurement matrix results

ity refers to the arrangement and alignment of concepts, semantics, and interconnection among various systems or entities involved in data exchange (Motta, de Oliveira & Travassos, 2019). This compatibility guarantees that the shared information's meaning and interpretation are consistent and properly understood by all parties. Semantic and syntactic mapping are the two aspects of conceptual compatibility. Semantic mapping involves establishing relationships between different terminologies to bridge the semantic gap. Interoperability frameworks, such as HL7 FHIR, provided guidance and standards for achieving semantic compatibility in the touchPoint. In comparison, syntactic mapping refers to the exchange of information using the same syntax. Organizational compatibility in interoperability refers to the alignment of policies, processes, and practices among different organizations involved in data exchange (Shirowzhan, Sepasgozar, Edwards, Li & Wang, 2020). It encompasses the organizational aspects

that enable effective collaboration and information sharing. Technology compatibility in interoperability refers to the ability of different technological systems, platforms, and software applications to seamlessly exchange and communicate data (Hazra, Adhikari, Amgoth & Srirama, 2021; Belchior, Riley, Hardjono, Vasconcelos & Correia, 2023). It involves ensuring that the technical components and infrastructure used by various systems are compatible and can effectively interact with each other.

The coefficient one (1) was assigned to the portal component and the barrier if an incompatibility was detected. Contrarily, the coefficient zero (0) was assigned when zero incompatibilities were found. The following questions were used to assign either zero or one against the portal and interoperability barrier (Ducq & Chen, 2008):

- Syntactic: Is the information exchanged between two different portals using the same syntax?
- Semantic: Does the information exchanged between portals have the same meaning?
- Persons: Are the roles and responsibilities clearly defined at both ends of the system?
- Organisation: Are the institution structures consistent?
- Platform: Are the digital health technologies used in this prototype able to exchange data?
- Communication: Does the digital health technologies use the same rules of data exchange?

By measuring the interoperability of a mHealth application at regular intervals, stakeholders can assess its strengths and weaknesses to interoperate and hence prioritize any actions to further improve it (Kasunic, 2001). The interoperability between

systems needs to be continually improved to prevent potential issues and to better support enterprise cooperation (?, ?). Statistics show the U.S. Department of Commerce Technology Administration in 2004 estimates a cost of US$15.8 billion related to the inadequate interoperability between systems in the U.S. Capital Facilities Industry. The West Health Institute estimated in 2013 a potential of US$30 billion waste per year related to the lack of interoperability across segments of healthcare in the U.S. Whereas, PwC, commissioned by the Global System for Mobile Communications Association (GSMA) estimates that digital health could save US$99 billion in healthcare costs to the European Union Gross Domestic Product due to interoperability improvements.

Overall based on the matrix, the incompatibility lies in the organisational which can easily be improved in future works. Thus, the conceptual and technology interoperability aspects of the prototype remain intact and compatible.

Communication improvement between healthcare providers in emergency settings

RQ4: To what extent does the mHealth application design created in RQ3 succeed in improving communication between healthcare providers in emergency settings?

The measure the success of the mHealth application designed in RQ3 in improving communication between healthcare providers in emergency settings depends on various factors. This section discusses the various factors which need to be considered to determine how successfully this mHealth application can potentially improve communication in emergency settings. The terms successfully, succeed and success in this discussion all refer to the ease that this mHealth application prototype provides which is beneficiary for all emergency health providers in emergency settings while conducting emergency response triaging and patient administration (Green et al., 2022). Also, the term communication refers to the patient data communication and exchange between healthcare providers who can access different portals within the prototype as seen as in

Figures 4.15, 4.16 and 4.18.

- *Usability:* By adhering to user interface guidelines from Xcode this mHealth application has been developed to be user-friendly and intuitive, allowing emergency healthcare providers to easily navigate and utilize its features even in stressful situations. A well-designed user interface and clear workflows in an mHealth application can contribute to improved communication (Coughlin et al., 2021).

- *Integration with existing systems:* The mHealth application is designed to integrate with a centralised database using OpenEMR. Thus, seamless data exchange between the centralised database and the prototype has enhanced data communication by providing access to relevant patient information to both Paramedics and healthcare providers in emergency, primary and secondary care.

- *Security and privacy:* In emergency settings, the confidentiality and security of patient data are of utmost importance (El Zouka & Hosni, 2021; Pramanik, Pareek & Nayyar, 2019). The mHealth application incorporated robust security measures, such as encryption, user authentication, and access controls to all portals, to ensure that sensitive patient information remains protected.

- *Compatibility and device availability:* The application's design should be compatible with various devices, including smartphones, tablets, and potentially wearable devices (Vijayan, Connolly, Condell, McKelvey & Gardiner, 2021). Considering the availability of these devices among healthcare providers can ensure broader accessibility and adoption. The prototype was tested on different versions of iPhones.

- *Data interoperability:* This mHealth application supports seamless data exchange and interoperability between the prototype and OpenEMR database. This is important to ensure that critical patient information is readily accessible and

can be shared among providers (Abu-Elezz, Hassan, Nazeemudeen, Househ & Abd-Alrazaq, 2020).

- *Healthcare standards:* Adherence to data standards, such as HL7, FHIR, or other relevant interoperability standards facilitated effective data communication. Standardized data formats and protocols enable consistent data exchange and interpretation across different systems, enhancing the compatibility and integration of the mHealth application with existing healthcare infrastructure.

- *Data transmission:* Given the sensitivity of patient data the prototype prioritized data security and privacy. Compliance with relevant privacy regulations within OpenEMR such as HIPAA was crucial for maintaining patient confidentiality.

To evaluate the extent to which the mHealth application design created in RQ3 can succeed in improving data communication; it would be necessary to assess the various factors discussed in this section. Most of these factors have been adequately developed in the prototype, ensuring a robust mHealth application to improve communication in emergency settings. While this prototype provides primary proof of concept to improve communication in emergency settings, a few major limitations need alignment to further enhance mHealth application integration in emergency settings. These include conducting user testing, questionnaires and gathering feedback from healthcare providers in emergency settings. Real-world implementation and iterative improvements based on user experiences can further enhance the long-term effectiveness of the application in facilitating data communication among providers.

Chapter 5

Conclusion

This chapter summarises the thesis and highlights how the research questions were addressed. It also acknowledges the limitations of the proposed solution and suggests future work. The chapter concludes by summarizing the results achieved by implementing a mHealth application focused on providing data interoperability between healthcare systems. Section 5.1 refers back to the research questions answered during the systematic literature review in Chapter 2 and the design and implementation of the prototype in Chapter 4. Section 5.2 highlights the potential gaps, limitations and threats to validity. Future work has been discussed, along with potential improvements that will provide better results. Section 5.3 lists the contributions made by the thesis and discusses how the mHealth application prototype can be practically implemented within ambulance and emergency settings.

Chapter 1 introduced the research topic, including the rationale of the study, the research aims and objectives, the research questions, the significance of the study and the thesis structure. Chapter 2 delved into the systematic literature review to identify common requirements and technical challenges from a diverse range of mHealth applications. It also explained important terms such as smart healthcare technologies and significance of mHealth applications in healthcare. Chapter 3 presented the three

research methodologies used to answer RQ1-4; systematic literature review, design science research methodology and controlled experiments. Chapter 4 illustrated the software development lifecycle journey of the prototype, starting with the design derived through the design science research methodology, implementation and testing using controlled experiments. The design, implementation and findings demonstrated how the prototype included all the common requirements and, most importantly, attempted to solve the technical challenges found during the systematic literature review.

5.1 Summary

RQ1: *What common requirements need to be considered when developing mHealth applications?*

This research question was created to investigate recent mHealth applications related to various healthcare areas, specifically common requirements which need to be considered during the design and development phases. RQ1 was summarised in Chapter 2 with the aid of a systematic literature review. Six common requirements were identified to be imperative during the design and development of mHealth applications. Medical regulation, end-user satisfaction, cost-effectiveness, interoperability, usability, security and privacy are key components which construct a solid foundation for mHealth applications.

RQ2: *Which of the technical requirements from **RQ1** represent major challenges in the implementation of mHealth applications in emergency settings?*

This research question filtered for technical challenges out of the six common requirements found in RQ1, which demonstrated significant difficulties in implementing

within emergency applications. The reference to the term technical was the facets of software development and maintenance such as programming languages, user accessibility, data security and privacy, and data interoperability. Out of the six common requirements from RQ1, interoperability (data) and security and privacy proved to be the major challenges in implementing mHealth applications in emergency settings.

RQ3: *How can the major challenges identified in **RQ2** be translated into a mHealth application design, which can be integrated into emergency settings?*

FHIR, OpenEMR and HL7 open-source healthcare standards were the main components in overcoming and hence translating the data interoperability, security and privacy technical challenges into a mHealth application design for emergency settings.

RQ4: *To what extent does the mHealth application design created in **RQ3** succeed in improving communication between healthcare providers in emergency settings?*

The touchPoint prototype demonstrated a realistic solution to exemplify how digital health technologies, especially mHealth, can improve data communication in emergency settings. While there is a notable improvement in the time reduction as compared to the current manual process, there are limitations which are covered in the next section.

5.2 Threats to validity

Addressing the threats to validity in a thesis is crucial because it explains the possible aspects of the research that could compromise the credibility of the findings (Zapata et al., 2015; X. Zhou, Jin, Zhang, Li & Huang, 2016). The four main categories of threats to validity include construct, internal, external and conclusion. Table 5.1 explains each

of these categories.

Table 5.1: Threats to validity definitions

Category:	Definition:
Construct validity	To ensure accuracy, identify appropriate operational measures for the concepts being studied.
Internal validity	Aim to demonstrate a causal relationship between specific conditions, instead of false relationships.
External validity	Clearly specify the domain to which the research findings can be generally applied.
Conclusion validity	Demonstrate the proper implementation of the research operations, including the data collection method.

Assumption of completeness

Most papers researched as part of the systematic literature review did not mention quantitative improvements from the development of mHealth applications; therefore, an assumption was made that each mHealth application examined delivered substantial improvement.

No questionnaires conducted

In this thesis, no questionnaires were conducted among emergency healthcare providers. In hindsight, emergency healthcare providers could have tested the prototype with a questionnaire to provide insights and personal experiences. However, resourcing emergency healthcare providers for this thesis would have proven difficult due to the staff shortages and increased emergency cases during COVID-19. Questionnaires or

feedback forms could have strengthened the validity and credibility of the practical aspects of this thesis. Also, involving emergency healthcare providers in testing the prototype would have required an ethical approval from the AUT Ethics Committee. Due to the complexity and time constraints, this was not conducted.

Lack of real-time data and experiment

The prototype was not tested using real-time data and experiments. A mock testing structure was used to test the prototype. It is imperative to assess the testing of this prototype within an emergency setting to gather context to real-time data in future.

5.3 Contributions

The touchPoint prototype is the main contribution from this thesis. As observed the time reduction from 25 minutes (current manual process) to 11 seconds to exchange interoperable patient data between emergency healthcare providers, is a notable improvement in data communication. This was possible by integrating digital health technologies to create one robust technical solution. Consequently, the implications of these results, when practically implemented in the real world include interoperable connected healthcare systems in New Zealand, particularly between St John ambulance services and emergency departments in hospitals. Future work should also consider the use of additional smart healthcare technologies such as artificial intelligence and big data to solve other major challenges such as staff burnout or mental health management among emergency healthcare providers. From a technical solution perspective, the importance of mHealth, cloud computing and electronic health records digital health technologies improving data communication by facilitating seamless patient data exchange has been highlighted in this study.

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&quot;code&quot;: &quot;M&quot;,
&quot;display&quot;: &quot;Married&quot;
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{
&quot;relationship&quot;: [
{
&quot;coding&quot;: [
{
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&quot;code&quot;: &quot;C&quot;
}
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]
}
],
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&quot;use&quot;: &quot;usual&quot;,
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&quot;given&quot;: [
&quot;Sarah&quot;
]
},
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{
&quot;system&quot;: &quot;phone&quot;,
&quot;value&quot;: &quot;0690383372&quot;,
&quot;use&quot;: &quot;mobile&quot;
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]
}
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&quot;display&quot;: &quot;Dutch&quot;
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&quot;text&quot;: &quot;Nederlands&quot;
},
&quot;preferred&quot;: true
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],
&quot;managingOrganization&quot;: {
&quot;reference&quot;: &quot;Organization/f001&quot;,
&quot;display&quot;: &quot;Burgers University Medical Centre&quot;
}

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&quot;id&quot;: &quot;example&quot;,
&quot;meta&quot;: {
&quot;versionId&quot;: &quot;1&quot;
},
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{
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"display": "Appendectomy (Procedure)"
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},
"subject": {
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"recorder": {
"reference": "Practitioner/example",
"display": "Dr Cecil Surgeon"
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"reportedReference": {
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"display": "Dr Cecil Surgeon"
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"performer": [
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"actor": {
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"display": "Dr Cecil Surgeon"
}
}
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"reason": [
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"concept": {
"text": "Generalized abdominal pain 24 hours. Locali
guarding"

}
}
],
"followUp": [
{
"text": "ROS 5 days - 2013-04-10"
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],
"note": [
{
"text": "Routine Appendectomy. Appendix was inflamed
}
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"supportingInfo": [
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"reference": "ImagingStudy/example"
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