

DESIGN AND USABILITY TESTING OF A NEAR FIELD
COMMUNICATION-BASED BEDSIDE MEDICATION
ADMINISTRATION AND CLINICAL COMMUNICATION SYSTEM

by

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Submitted in partial fulfilment of the requirements
for the degree of Doctor of Philosophy

at

Dalhousie University
Halifax, Nova Scotia
August 2018

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Dedication

This dissertation and all of my academic achievements are dedicated to my parents.

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Abstract

Medication administration errors are a critical issue that can lead to significant clinical consequences. In nursing practice, the three major causes of medication errors in the administration stage are failure to confirm the ‘five rights’ of medication administration, failure to verify contraindications, and failure to effectively communicate with other healthcare providers. The purpose of this research is to design a prototype NFC-based Medication Administration and Clinical Communication (NFC-MACC) system to reduce the medication errors and streamline the processes of bedside medication administration, and to understand nurses’ perception regarding its usability. NFC (Near Field Communication) is an effective short-range wireless technology that has been used to securely identify objects. While many healthcare domains have benefited from the use of NFC, it is currently in limited use in bedside medication administration in hospitals.

The research study is divided into three sequential phases. The first phase is a preliminary study, in which we apply a mixed-method approach and aim to explore whether the idea of using an NFC technology is acceptable and usable for nurses during the medication administration stage. We test the usability of an initial prototype design of two functions of the NFC-MACC system, namely, to verify drug allergy and to verify drug interactions. The findings indicate positive feedback concerning the usability and acceptance of the NFC technology, and provide recommendations for improvements. The recommendations are then used as design guidelines for the NFC-MACC system.

The second phase uses a descriptive qualitative approach and aims to understand the bedside medication administration procedure to help us in designing the system. The findings provide us a better understanding of the required data and sources used in nursing practice to verify medications and to contact healthcare providers, and assisted us to define the essential functional guidelines for the NFC-MACC system.

The design and functional guidelines obtained from Phase 1 and Phase 2 were utilized to design the prototype NFC-MACC system. We designed the system to reduce the major causes of medication errors by: (1) identifying the patient and the medication; (2) confirming the five rights of medication administration; (3) verifying allergies; (4) verifying drug interactions; (5) verifying contraindications; (6) alerting nurses and providing sufficient alert information; (7) providing real-time communication between nurses and other healthcare providers; and (8) documenting the administered medication.

The third phase aims to understand the nurses’ perception regarding the usability of the NFC-MACC system. A mixed-method approach to test the usability of the system is employed. The findings show that the system was well received by the nurses and offers promise to ease the steps required to verify medications and improve clinical communication efficiency and mobility.

Overall, this thesis presents a comprehensive research study that emphasizes the use of NFC technology at the bedside medication administration stage. Evidence derived from user studies of nurses shows the benefits of NFC technology over the existing wireless medication administration systems. Participants expressed their interest in using the NFC-MACC system in a clinical setting and believed it would enhance nursing practice and increase patient safety.

List of Abbreviations Used

NFC	Near Field Communication
RFID	Radio Frequency Identification
MAE	Medication Administration Errors
BMA	Bedside Medication Administration
BCMA	Barcode Medication Administration
NFCMA	Near Field Communication Medication Administration
ADE	Adverse Drug Event
MAR	Medication Administration Record
E-MAR	Electronic Medication Administration Record
EMR	Electronic Medical Record
EHR	Electronic Health Record
MRN	Medical Record Number
ISRM	Information System Research Model
HITUEM	Health Information Technology Usability Evaluation Model
HITUES	Health IT Usability Evaluation Scale

Acknowledgements

First and foremost, I would like to express my sincere gratitude to my supervisor Dr. Srinivas Sampalli for the continuous support of my Ph.D. study, for his patience, encouragement, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I also appreciate his understanding and moral support during the times when I was down due to health issues.

My sincere thanks also go to my thesis committee: Dr. David Zitner and Dr. Bonnie MacKay for their insightful feedback which incited me to widen my research from various perspectives. I would also like to thank Dr. Tara Sampalli, Dr. Edwin Hanada, the School of Nursing, Dalhousie University and the IWK hospital for supporting me in recruiting participants throughout my Ph.D. study.

Very special thanks to my family. Words can not express how grateful I am to my father for all the sacrifices he made to help me start this amazing journey. I am grateful to my mother who believed in me and supported me in every step of my Ph.D. study, her prayer for me was what sustained me thus far. I would also like to thank my beloved husband for encouraging me throughout this experience and supporting me through all the difficulties. Last but not least, I would like to thank my sisters and brother for always cheering me up, and being constant source of strength and inspiration.

Chapter 1. Introduction

In Canada, medication errors are the third leading cause of death after cancer and heart disease. An estimated 70,000 preventable medication errors occur annually, causing up to 23,750 deaths [1]. Medication errors happen either in the prescribing stage by physicians, the dispensing stage by pharmacists, or the administration stage by nurses [2][3]. The percentage of medication errors is highest in the administration stage, exceeding 41% [4]. This can be attributed to the large number of medications administered by nurses per shift. According to a study on nurses' perceptions of medication errors, a single hospitalized patient can receive up to 18 medications per day, and a nurse can administer up to 50 medications per working shift [5]. Major causes of medication errors in the administration stage are: (1) failure to confirm the 'five rights' of medication administration; (2) failure to verify contraindications; and (3) failure to effectively communicate with other healthcare professionals [6][7][8].

During the administration of medication, accuracy and patient safety take priority in nursing practice [9]. Nurses follow the universal standard of medication administration by confirming the five rights before administering medication to the patient. The five rights are (1) right patient, (2) right medication, (3) right dose, (4) right time, and (5) right route [6]. In addition, nurses verify that the patient's condition does not contraindicate the medical treatment. Nevertheless, even though nurses adhere to the five rights and contraindication, there remains a chance for human error.

One way to reduce medication administration errors related to failure to verify the medication is to introduce wireless technology such as Barcode and Radio Frequency Identification (RFID) in healthcare to promote safe medication practice. Barcode and RFID technology replace manual documentation with electronic and wireless scanning of unique identifiers for the patient and the administered medication, helping nurses confirm the five rights of medication administration [10][11]. Although Barcode and RFID have been proven to enhance patient safety, there are some challenges associated with using them. The challenges for Barcode are malfunctioning scanners, scanning difficulty, unreadable barcodes, slow scanning, and the large size of the system [12]. The challenges associated

with using RFID include error alert, battery life, electromagnetic interference, tag readability problems, and the duplicated system's large size [13].

Near Field Communication (NFC) is a short-range wireless technology that has been used in various areas of healthcare such as identification, home monitoring, and medication management. However, there is limited literature on its application in the medication administration process. NFC can be integrated into smartphones and does not require extra devices (e.g., readers, antennas, computers on wheels) to operate, which increases its portability and decreases the cost [14][15]. It also reads passive tags from a very close proximity (tapping), which makes it secure and easy to use [14][16]. This helps NFC overcome some of the Barcode and RFID drawbacks and gives it the potential to be applied during medication administration.

In addition, another way of reducing medication errors related to failure to communicate with healthcare professionals is to provide an effective, efficient, and accessible method of communication. Effective communication between healthcare professionals is mainly affected by two factors: time and resources [6]. Because healthcare professionals have an intensive workload and everyone can be independently busy, finding the time to communicate properly is a serious issue [17][18]. Thus, communication between them often becomes ineffective (i.e., rushed or less interactive) [18]. Moreover, limited resources for communication cause delays in making proper decisions for patient safety [6]. An example of this is physician delays when responding to urgent nurse calls. Therefore, there is a significant need to find a sufficient and effective intervention to improve communication and collaboration between healthcare professionals [19][20].

Against this background, we designed a prototype NFC-based Medication Administration and Clinical Communication system (NFC-MACC) to streamline the process of bedside medication administration, and reduce the major causes of medication errors by: (1) identifying the patient and the medication; (2) confirming the five rights of medication administration; (3) verifying allergies; (4) verifying drug interactions; (5) verifying contraindication; (6) alerting nurses and providing sufficient alert information; (7) providing real-time communication between nurses and other healthcare professionals; and (8) documenting the administered medication.

1.1 Objectives and Research Questions

The overall purpose of this research was to design a prototype NFC-MACC system and understand the nurses' perception regarding its usability. We used the Information System Research (ISR) Framework by Hevner et al. (2007) to guide our research through the design, implementation and evaluation process of the NFC-MACC system [21].

The research study was divided into three sequential phases. Phase 1 was a mixed-method preliminary study to explore whether the idea of using an NFC-enabled smartphone application at the bedside is acceptable and usable to nurses during the medication administration stage. The objectives of this study were to:

- Assess the acceptability, usefulness, learnability, efficiency, and effectiveness and satisfaction of the NFC-enabled smartphone application for checking drug interactions and known allergies from the nurses' perspective.
- Identify the weaknesses and strengths of the wireless smartphone application.
- Provide recommendations for improvement.

Phase 2., motivated by the findings of Phase 1, was a qualitative study that aimed for understanding the bedside medication administration procedure. The objectives of this study were to:

- Determine the required data and sources used in nursing practice to verify the five rights of medication administration, allergy, drug interactions and contraindication.
- Determine the required data and sources used in nursing practice to document the administered medication.
- Define the type of information used to communicate with healthcare providers.
- Define the essential functional requirements for medication verification, documentation and communication.

The guidelines obtained from Phase 1 and Phase 2 were utilized in Phase 3 (part 1) to design the prototype NFC-MACC system. Phase 3 (part 2) aimed for evaluating the system and exploring the nurses' perception regarding its usability. The central research question of this study aims to explore *How do nurses perceive the usability of the NFC-MACC system?* We broke down the central question into six associated sub questions:

- *RQ1: To what extent is the NFC-MACC system efficient in terms of time spent completing tasks in comparison to optimum time?*
- *RQ2: To what extent is the NFC-MACC system effective in terms of completing the tasks with the least number of errors?*
- *RQ3: How do nurses perceive the usefulness of the NFC-MACC system in comparison with their current method used for bedside medication administration and clinical communication procedure?*
- *RQ4: How do nurses perceive the ease of use of the NFC-MACC system?*
- *RQ5: How do nurses perceive the usefulness of the NFC-MACC system for patients, and what do they believe the patients would think of the system?*
- *RQ6: What are the strengths and weaknesses of the NFC-MACC system from the nurses' points of view?*

1.2 Research Contributions

This research makes contributions in three areas: employment of NFC technology in healthcare, employment of mobile health in the medication administration stage, and usability of medication administration systems. First, while there has been increased interest in applying NFC technology in different contexts of healthcare, literature about its application at the bedside medication administration in hospitals is limited. This thesis presents a comprehensive research study that emphasizes the significant potential use of NFC technology at the bedside to identify the patient and medication. It adds evidence derived from the end users (nurses) of the NFC use benefits over the existing wireless medication administration systems, BCMA, used for identifying patients and medication at the bedside.

Second, it introduces an NFC-based novel solution (NFC-MACC system) to streamline the process of medication administration and reduces the major causes of medication errors (failure to confirm the 'five rights' of medication administration, failure to verify contraindications, and failure to effectively communicate with other healthcare providers). The existing wireless medication administration systems, BCMA and RFIDMA, focus on verifying the *five rights* of medication administration and allergies; however, they ignore the verification of drug interactions and contraindications which are among core nursing responsibilities. The introduced system in this research not only

overcomes the usability problems of the Barcode and RFID but it considers triggering alerts concerning drug interactions and contraindications. In addition, the system integrates the medication verification procedure (verifying the *five rights* of medication administration, allergy, drug interaction and contraindication) with the clinical communication, which to the best of our knowledge no medication administration systems had consider. Proposing a novel idea of customized communication that precisely fit the context of the medication administration stage is an important contribution. It draws the attention to the significance of the clinical communication content between the healthcare providers, and it introduces the potential of integrating the clinical communication with the medication administration systems.

Third, little attention has been paid to the adoption of NFC technology at the bedside, hence, the usability evaluations for the medication administration system integrated with NFC technology is limited. This research tested the usability of the NFC-MACC system and provided evidence of nurses' interest in the adoption of such technology in a clinical setting. Understanding the nurses' perception regarding the usability and acceptability of the system will be an important contribution to building health information systems integrated with NFC technology in similar (medication administration stage) or different contexts. In addition, the result of our study indicates how the customized communication to serve bedside medication administration is promising and can be applied to different contexts of healthcare.

1.3 Structure of the Thesis

The overall structure of the proposal takes the form of nine chapters, including this introductory chapter. Chapter 2 begins by giving an overview of the NFC technology and its role in healthcare. Then, discusses the importance of medication administration errors, and afterward reviews the existing solutions and their limitations. Chapter 3 presents the research methodology and design. It also discusses the followed theoretical framework to guide our research through the design, implementation and evaluation process of the NFC-MACC system. Chapter 4 explains Phase 1 of our research study, which is a preliminary study that explores the nurses' perception regarding the acceptability and usability of the NFC technology. It also presents set of design guidelines to be used when designing the NFC-MACC system. Chapter 5 discusses Phase 2 which focuses on understanding the

bedside medication administration procedure in order to determine the required data for medication verification. It also discusses the essential functional guidelines that used for designing the NFC-MACC system. Chapter 6 presents Phase 3 (part 1) which includes the design and implementation of the prototype NFC-MACC System and its main functions. Chapter 7 discusses Phase 3 (part 2) which focuses on evaluating the usability of the NFC-MACC from the nurses' perception. Chapter 8 includes the discussion of the findings and reviews the research questions and their answers. Finally, Chapter 9 concludes the study and highlights the research contribution, implication, limitations and future work.

Chapter 2. Background and Related Work

The overall structure of this chapter takes the form of three main sections. The first section gives an overview about the NFC technology and its application in healthcare. The second section discusses medication administration errors and current automated solution and their drawbacks. The third section discusses the importance of communication among healthcare professionals during medication administration, as well as the technologies used for that purpose and their limitations.

2.1 Near Field Communication

Near Field Communication (NFC) is a short-range wireless technology that operates on a 13.56 MHz frequency and allows communication between two NFC-enabled devices (e.g. NFC-enabled smartphones) or between an NFC-enabled device and a passive NFC tag with data transfers up to 242 kbit/s [16].

Recently, a wide range of mobile phone companies such as Nokia, Samsung, RIM, HTC, LG, Android, and Apple have integrated NFC technology in their smartphones. NFC-enabled smartphones have a built-in NFC reader as well as a built-in NFC smart card that enables them to function as a reader or as a contactless smart card [16]. In other words, operating as a reader and as a contactless smart card helps to transfer information from one smartphone to another, from a smartphone to an NFC reader, or from a smartphone to a tag. These functions give NFC-enabled smartphones significant potential in diverse areas such as marketing, payment, transportation, and healthcare [22].

2.1.1 NFC Modes of Operation

NFC-enabled smartphones can adapt their operation to any of the following modes:

Reader/Writer Mode

This mode is a one-way communication and includes an NFC-enabled smartphone and a passive tag. The NFC-enabled smartphone operates as a reader that can read data from a tag, or as a writer to write data to a tag [16]. An example of writing mode is writing a URL on an NFC tag for advertising purposes. An example of reading mode is reading the NFC tag to access the desired URL.

Peer-to-Peer Mode

This mode is a two-way communication method and includes two NFC-enabled

smartphones. The two smartphones exchange data with each other. In other words, the smartphone that sends the data works as a smart card, while the smartphone that receives the data works as a reader [16]. An example of peer-to-peer mode is sending games from one smartphone to another.

Card Emulation Mode

This mode includes an NFC-enabled smartphone and an NFC reader. The NFC smartphone operates as a contactless smartcard with the ability to send information to an NFC reader [16]. For example, the smartphone can be configured to operate as a credit card or a transportation ticket.

2.1.2 Earlier Forms of NFC: RFID

NFC is an extension of Radio Frequency Identification Technology (RFID), which is a wireless technology that allows one-way long-range communication between an RFID reader device and passive/active RFID Tag. RFID is popular for identification and tracking purposes. The main difference between NFC and RFID is the length of the communication range: RFID can read tags at distances up to 100 m due its high frequency, while NFC can read tags only up to 10 cm [16][23]. This difference makes NFC communication more secure than RFID, as short-range communication prevents eavesdropping on the tags [16].

2.1.3 NFC Role in Healthcare

NFC applications are currently an active research area in healthcare. Researchers are continuously developing and implementing NFC applications in various healthcare areas to improve patient safety and healthcare quality. It has been used for identification purposes, medication management, personal information management, and appointment and shift management.

Researchers have used NFC technology for nurses to identify their patients. In this application, a nurse uses an NFS-enabled phone to tap on a tagged hospital room (to identify who is occupying it), a tagged patient, and a tagged patient's bed [24]. Other studies have used NFC technology to obtain accurate identification for newborn babies. For instance, a physician will use an NFC-enabled phone to tap on the baby's NFC tag [25].

In addition, Eevasti et al. (2011) proposed an audio-based medication management

system called BlinedNFC to help vision-impaired older people manage their daily medication. It works by tapping an NFC-enabled PDA on a tagged medication in order to read the medication name and dosage information [26]. Also, NFC has been used to help physicians manage the medication prescription to avoid drug interaction errors. It works by simply tapping an NFC-enabled pocket PC on a tagged medication to retrieve information from a remote-knowledge based system. The retrieved information informs the physician about whether or not the prescribed medication would cause a drug interaction to the patient [27]. Furthermore, Engle et al. (2013) proposed an NFC-based system that streamlines the medication prescription process for physician, pharmacist, and patient. The physician creates a digital prescription and provides it in an NFC terminal, and the patient taps his/her NFC-enabled smartphone on the terminal to obtain the prescription and send it to the pharmacist for pre-ordering [28].

Furthermore, researchers have used the NFC technology to manage personal health information. Young-Joon et al. (2013) developed a U-Health system for personal health information management. This system uses Zigbee and NFC smartphones to collect a patient's health information, such as blood pressure and body temperature. The collected information is sent to a hospital database and then to a physician's smartphone in order to monitor the patient's health information [29]. Similarly, Zhang and Li (2011) use wireless sensors to collect a patient's health information and send it to an NFC-enabled device. Then the collected information is transferred to the patient's hospital for monitoring purposes [30]. Gune et al. (2013) also developed an NFC-based application to monitor a patient's health information. The application uses sensors to gather the patient's blood pressure, cardiograph and body temperature, and then transfers this information to the patient's wearable tag. During a physician's regular visit to the patient, he/she uses an NFC enabled phone to tap on the patient's tag and read the health information [31].

Further, Yeo Sy and Suresh (2013) developed an NFC-based check-in system. To check in, the patient taps his/her NFC tag on an NFC reader that is attached to a kiosk. The kiosk is located at the main entrance of a hospital and is connected to the hospital database [32]. In addition, some researchers proposed an NFC-based solution for shift scheduling management. This works by using the NFC peer-to-peer operation. Specifically, nurses tap their NFC-enabled phone on each other to transmit the shift schedule from the nurse on

duty's mobile to the incoming nurse's mobile, along with all necessary information [24].

2.2 Medication Administration Errors

Medication error is a serious issue that can lead to significant clinical consequences [33]. An estimated 70,000 preventable medication errors occur in Canada each year, causing up to 23,750 deaths and making them the third leading cause of death after cancer and heart disease [1]. Medication errors are defined as “[a]ny preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the healthcare professional, patient, or consumer” [19]. Medication errors can occur at any of the following stages of the medication management process:

- Prescribing stage: When the physician prescribes (issues) the medication to the patient.
- Dispensing stage: When the pharmacist dispenses the medication to the patient.
- Administration stage: When the nurse administers (provides) the medication to the patient [6].

Studies have shown that most errors occur at the administration stage [34]. One study has found that the percentage of medication errors is highest in the administration stage, reaching up to 41% [4]. Another study found that 38% of medication errors happen during the medication administration stage [35], and that one out of every three Adverse Drug Events (ADEs) was caused by medication errors initiated by nurses during medication administration [6]. The high percentage of errors is attributed to the fact that medication administration is the second most frequent task of a nurse's hospital practice after active listening [36].

The most common types of MAE include wrong medication, wrong patient, wrong dose, wrong time, and wrong route [6]. Reports of the MAE rate vary in the literature. One research study showed that 40.9% of medication errors that resulted in death involved wrong dosages, while 16% resulted from giving the wrong medication and 9.5% from using the wrong route [2]. Other research showed that 60% of medication errors are caused mainly from medications being administered at the wrong time, through the wrong route, and in the wrong dose [37]. Also, a study found that wrong medication is the most common type of medication error [38].

Furthermore, contraindication is one of the serious causes of medication administration errors that seriously affect a patient's health status. Contraindication is a condition or factor (e.g., pregnancy, high blood pressure, chronic diseases) that serves as a reason to strictly stop a certain medical treatment due to the harm that it would cause the patient. For example, *Isotretinoin*, a drug used to treat acne, is completely contraindicated in pregnancy due to the risk of birth defects. Another example is certain *decongestants*, which are contraindicated in patients with high blood pressure and should therefore be avoided to prevent serious harm to those patients [39]. A study about contraindicated medication use in dialysis patients gathered data from 829 US hospitals on 22,778 dialysis patients. They found 5084 patients (22.3%) received a contraindicated antithrombotic medication. Wrongly administering this medication caused an increased risk of in-hospital major bleeding [7]. Similarly, a research study about medication errors in patients with severe chronic kidney disease showed that in-hospital bleeding occurred in 63% of patients caused by receiving a contraindicated antithrombotic medication [40]. In addition, researchers studying the use of contraindicated drugs in patients with chronic liver disease found 30% of patients had received at least 1 contraindicated medication during medication administration and 63% patients had received at least 1 medication which requires precaution in liver disease [41]. Moreover, a research study showed that 18% of patients undergoing percutaneous coronary intervention (PCI)¹ had contraindications to common antiplatelet medications, causing risk of bleeding [43].

Patient safety and medication accuracy take priority in nursing practice during medication administration [9]. Nurses follow the universal standard of medication administration for confirming the 'five rights' before administering the medication to the patient. The five rights are: (1) right patient, (2) right medication, (3) right dose, (4) right time, and (5) right route [6]. Even though nurses check the five rights, the chance for human error remains. Moreover, the act of confirming the five rights does not prevent contraindication errors, as this requires checking the patient's condition before administering the medication.

¹ PCI is a non-surgical procedure that uses a catheter (a thin flexible tube) to place a small structure called a stent to open up blood vessels in the heart that have been narrowed by plaque buildup, a condition known as atherosclerosis [42].

Given the risk for medication errors as detailed above, some information technology interventions have been created to help nurses accurately confirm the five rights and thus reduce medication errors [10]. Keers and Williams compared interventions designed to reduce MAE in hospitals, and found that using wireless technology (e.g., Barcode) resulted in a significant reduction in MAE [44]. The following subsection discusses current wireless technologies that help in reducing MAE.

2.2.1 Current Automated Medication Administration Systems

Barcode Medication Administration System (BCMA)

The BCMA was developed in the United States in 1990 by the American federal government's Veterans Health Affairs (VHA), and has been in use since 1999 [10]. The BCMA helps to improve patient safety and confirm the five rights of medication administration in hospitals [10][12].

The BCMA system consists of a tethered or wireless handheld scanner that reads barcodes on patients and medications, and a computer-on-wheels (COW) that interfaces with an electronic medication administration records. This system requires the nurse to scan the medication barcode and the patient's ID wristband barcode. If the system detects a mismatch between the medication and the patient or between the medication and the ordered medication, it will alert the nurse audibly and/or visually. The nurse then responds to the alert by changing an action (e.g., changing the dosage) or overriding the alert [12].

Although Barcode systems are intended to enhance medication safety, there are some usability issues associated with them:

- **Malfunctioning scanners and failing batteries:** A study on how Barcode systems are used in hospitals showed that one of the main sources of difficulty with using the systems is malfunctioning scanners and failing batteries [12]. Continually charging the scanner batteries can make them fail quickly, leading to the necessity for constant scanner or battery replacement.
- **Scanning difficulty:** A survey conducted by Patterson et al. (2002) to identify nursing staff concerns about the MA system showed that nurses often have difficulty reading patient barcodes [45]. A Barcode system requires line-of-sight access, meaning that the scanner must be physically pointed at the barcode in such a way that it is able to capture all of the barcode lines. This technique requires

multiple scans to correctly read the barcode. However, for unknown reasons, the scanner does not always successfully read the barcode [12].

- Large size of system: Because Barcode systems are integrated with computers on carts, it is challenging for a nurse to move from one room to another, especially when the structure of the room impedes bedside access [10][12]. In addition, separating the barcode scanner from the computer could hinder the nurse from hearing or seeing alerts, especially if there is noise in the hallway or in the patient's room. Sometimes, nurses find it easier to enter the 7-digit number manually than to move the large cart into a patient's room just to scan a wristband [45].
- Unreadable barcodes: Barcode labels on medications or patinas can be unreadable by basic barcode scanners when they are damaged (e.g., wrinkled, smudged, ripped, curved or covered) [12][16][46]. However, directional barcode scanner (omni-directional scanners) that uses a single rotating polygonal mirror and an arrangement of several fixed mirrors to generate complex scan patterns can read poorly printed barcodes. Even though directional barcode scanners can overcome some of the readability problems, they still require a large size system (computer-on-a wheel) to function. Large size systems, as discussed earlier in previous point, are challenging for a nurse to navigate through patients room.
- Barcode label confusion: Sometimes it is difficult for nurses to differentiate between the various barcodes on the medication and to determine which one to scan [12][47].
- Slow scanning procedure: The difficulties mentioned above make it hard to achieve efficiency in the workflow and the proper use of BCMA. For example, if the scanner fails to work, the nurse has to find another scanner, which makes the process of medication administration slower. A study about lessons learned from deploying BCMA in an intensive care unit stated "*If a medication can't be scanned on a clinical care ward, it is likely the nurse will employ a work-around technique and enter the Internal Entry Number (IEN) for the medication manually, thereby bypassing BCMA and placing the patient at significant potential risk for a medication error*" [48]. Therefore, some nurses choose not to use BCMA because they find it time-consuming and affects patient safety [12].

To deal with these difficulties, nurses do workarounds², which potentially lead to medication errors and reduce the quality of healthcare [12][46][48].

Radio Frequency Identification (RFID) Medication Administration System

The RFID system has been introduced in the literature to overcome some of the BCMA difficulties [50]. The literature shows that 11.59% of RFID applications in healthcare are intended for medication administration [51]. The RFID system in healthcare is known in particular for its identification and authentication capabilities [11]. Unlike Barcode systems, RFID systems can identify patients and medications without the direct intervention of nurses [11][13]. It has thus been used to improve patient safety during the medication administration process by confirming the five rights [11].

The RFID system consists of a wireless handheld RFID reader, antennas placed in the patient's room, RFID tags on the patient and the medication, and a laptop/computer on wheels that interfaces with the hospital's information system [13] [52]. If the system uses active tags, it does not require the nurse to manually scan the medication and the patient's RFID tag. The tags will send their IDs to the reader through the antenna [13]. However, if the tags are passive, the nurse has to make sure that the tags and the reader are in the same electromagnetic field so the reader can detect the tags and read their IDs [50] [52]. If the system detects an error with the medication after obtaining the tag IDs, it alerts the nurse through the screen [13] [52]. Although the RFID system can overcome some of the Barcode drawbacks, it also raises some usability issues:

- Duplicated error alerts: When an RFID reader scans a medication for the first time and finds a mismatch between the medication and the patient, it will give an alert message. However, if the reader repeatedly tries to scan the medication's tag, an error alert duplication will result [13].
- Large size of system: Similar to the Barcode system, an RFID system is integrated with a computer and a cart. A study shows that one of the nurses' concerns about the RFID system is its size; they found it very large and heavy, and difficult to wheel from room to room [13].

² Workarounds are defined as "an alternative [way] of accomplishing a task when the standard process is not working; it's a temporary solution, but it may indicate that the standard process is in need of improvement" [49].

- **Battery life:** The battery life of the readers and active tags is another issue arising from the use of RFID systems. The RFID reader has to be charged every one to two days, and if the battery runs out, the system will not work. Moreover, active RFID tags need to be changed after six months of use, which increases the cost of applying this system. Because of these requirements, hospitals need to provide routine maintenance for RFID system batteries [11][13].
- **Radio frequency and interference problems:** A study on the requirements and adoption of RFID systems in healthcare facilities stated that interference is one of the most important obstacles to RFID implementation in hospitals [11]. Sometimes the readers cannot detect the tags because the radio waves are not strong enough to reach them [13]. However, if the radio waves are too strong, it may cause electromagnetic interference with other medical devices, resulting in their failure [51] [53].
- **Tag readability problems:** The reliability of the RFID system depends on various factors such as the tagged object, the tag location, angle of rotation, read distance, and presence of metal objects [54] [55]. Hence, the readability of the RFID system is not always 100% accurate [51]. In other words, if the readers cannot detect the tags, the system will not work and the nurse has to double-check whether the system has detected all of the tags required [13] [53].
- **Cost:** Applying the RFID system is considered expensive compared to the Barcode system [11][16][56][57]. It is estimated that installing an RFID system in a medium-size hospital would cost \$20,000 to \$600,000 [58]. Another study stated that the cost of RFID system installation ranges from \$20,000 to \$1 million, depending in hospital size [51].
- **Security and privacy issues:** Security and privacy risks associated with the use of RFID in medical environments have been frequently addressed in the literature [59]. Since RFID technology allows long-distance tag reading, it is possible to eavesdrop on the patients' tags and obtain their IDs (through an unauthentic reader) [60]. Obtaining an ID is not a problem because it is only a number of digits. The problem is that the ID has corresponding information in the hospital's database. This information can be obtained when unauthorized access to the hospital's

database occurs, which will result in exposing the patient's health information [11][57][61]. Therefore, healthcare providers have trust issues with using RFID technology in healthcare settings, as they are concerned about their patients' privacy [62].

Similar to Barcode systems, issues related to RFID technology may lead to workarounds, which may then lead to medication errors. Wen et al. (2012) stated that "the reality of RFID adoption in healthcare is far behind earlier expectation" [51], due in large part to the kind of problems detailed above. Therefore, RFID problems have to be solved before the system can be implemented in the medication administration process [59].

In addition, to the best of our knowledge, BCMA and RFID systems have thus far only been used to confirm the five rights and no studies have reported that they verify contraindications. This is a crucial point, as verifying contraindication is part of the medication administration process and failing to do so can cause serious and life threatening medication errors, as discussed earlier.

NFC Medication Administration System

Although NFC technology has been applied in different aspects of healthcare, very limited literature exists on its application in the medication administration process. NFC features help to overcome some of the Barcode and RFID drawbacks, giving NFC the potential to be applied during medication administration. The following points illustrate how NFC technology can overcome some of the previous solutions' difficulties:

- Scanner problems: Unlike Barcode and RFID, NFC does not require a special scanner to read the tags. The tag can be read with an NFC-enabled smartphone device [16]. This overcomes any difficulties associated with using a special scanner (e.g., extra device, cost, malfunctioning scanner) [12].
- Tag battery life problems: NFC uses passive tags that obtain power from the electromagnetic waves produced by the reader (smartphone); this make passive tags last longer than the active tags in the RFID system [13][14].
- Barcode labeling problems: NFC uses silicon tags that are more reliable than barcode labels. The silicon tags can be read when covered and are not easily damaged, like barcode labels [46].
- Scanning difficulties: NFC reads one tag at a time by simply tapping on the tag

[14][16]. It does not require line-of-site access, like barcodes, and does not require a specific location or angle of rotation for the reader, like RFID.

- Efficiency of scanning procedures: Since NFC requires only a simple tap to read the tag, it makes it easier and faster than barcodes [14]. Furthermore, it does not read the tag more than once, which prevents duplication alerts like in RFID.
- System size problems: NFC replaces the cart, computer, and scanner with one small device (smartphone) [14].
- Cost: Unlike the Barcode and RFID systems, the deployment of NFC in the medication administration process does not require a lot of infrastructure components [14]. Researchers stated that “[u]nlike RFID, NFC technology can be integrated into universal devices such as mobile phones, reducing the cost of the system because dedicated devices are unnecessary” [15]. In addition, NFC uses passive tags that do not need to be replaced every six months like active tags and are cheap to manufacture [13][16].
- Security and privacy: Unlike RFID, NFC requires a very short distance between the reader and the tag (tapping), which makes it difficult for unauthorized readers to eavesdrop on a patient’s ID [16].

NFC’s ability to overcome issues related to BCMA and RFID makes it an attractive option for adoption and deployment in the process of medication administration. A study published by Landman et al. (2014) proposed a prototype of an NFC-enabled tablet for medication administration called NFCMA [14]. Their prototype consists of an NFC-enabled tablet, an NFCMA application, and NFC tags on the medication and the patient. The nurse is required to tap on the patient and the medication tag, and then the application will confirm the five rights. If there is any mismatch between the patient and the medication, the application will alert the nurse. The information needed to confirm the five rights is hardcoded into the NFCMA application, and no real or a simulation of database is linked to it.

The authors tested the usability of the proposed prototype, and their users (nurses) found that NFC technology was easy to learn and use. However, some problems were of concern to them, such as tablet storage size, tablet size, and availability of tablets. First, the storage problem arose because NFCMA was developed as a standalone application, with

all of the necessary information to confirm the five rights hardcoded into it. Thus, the tablet's storage size was a critical issue for the nurses. Second, the size of the tablet is another problem for some nurses. It cannot be carried in their pocket, so they were concerned about leaving it somewhere, losing it, or dropping it. In addition, nurses usually have their hands full during medication administration and found it inconvenient to carry both the patient's medication and the tablet at the same time. Therefore, they suggested that a smaller device would be helpful. Third, nurses were concerned about whether the hospitals would be able to provide them with tablets or whether they would have to provide their own [14]. If the latter were the case, it might become an issue for the nurses who do not own tablets. A survey study with 182 participants showed that around 83% of caregivers own smartphones, while only 36% own tablets [63].

In addition to the problems discovered by the study's users, the patient information is hardcoded in the tablet application. This cannot be done for two reasons. First, for a prototype, a single patient's information can be hardcoded, but for real deployment, it is impossible to store thousands of patients' data in the tablet memory. Second, storing patient data in the tablet memory might rise privacy concerns. Furthermore, Landman's NFCMA did not consider verifying contraindications or documentation, and alerts the nurse only in case of a potential medication error [14]. It did not consider alerting other healthcare provider, even though each provider is involved in the medication management process. Because of this shortfall, the nurse has to contact the treatment team verbally or through a written report to take action. This requires extra work and time for the nurses [19].

2.3 Clinical Communication During Medication Administration

2.3.1 The Importance of Communication Among Healthcare Professionals

The medication management process involves a physician, a pharmacist, and a nurse. The physician prescribes the medication to the patient, which is the early point of the medication management process. The pharmacist then assesses the prescription appropriateness and dispenses the medication. Finally, the nurse reviews the prescription, confirms the five rights, and administers the medication to the patient. If any of the healthcare providers make a mistake during the medication management process, it will be exposed at the last point of the process (the administration), when the patient experiences

an adverse drug event (ADE³) [19]. Therefore, communication and collaboration among physicians, nurses, and pharmacists is essential during medication administration stage to provide effective patient care and prevent medication errors [9][17][64].

Failure in communication between healthcare professionals can jeopardize patient safety [20]. O'Daniel and Rosenstein stated that “when health care professionals are not communicating effectively, patient safety is at risk for several reasons: lack of critical information, misinterpretation of information, unclear orders over the telephone, and overlooked changes in status” [19]. According to the Joint Commission report from 2004 to 2014, poor communication is the number one cause of delay in patient treatment and one of the root causes of medication errors resulting in death or permanent loss of function [8].

Effective communication among healthcare professionals is affected by two factors: time and resources [6]. Because healthcare professionals have an intensive workload and everyone can be independently busy, finding the time to communicate properly is a serious issue [17][18]. Thus, communication between healthcare providers becomes ineffective (e.g., rushed or less interactive) [18]. Moreover, limited resources for communication cause delays in making proper decisions for patient safety [6]. An example of this is when a physician delays when responding to urgent nurse calls. Therefore, there is a significant need to find a sufficient and effective intervention to improve communication and collaboration between healthcare professionals [19][20].

2.3.2 Current Communication Intervention Methods

The importance of effective communication among healthcare professionals involved in the medication management process has created an increased interest in the use of information and communication technologies. Different types of technology are being used in hospitals, such as pagers, emails, hands-free devices, software messages, and smartphone applications. However, these technologies are presently mostly used for general communication between healthcare professionals, and none of them have been customized to effectively fit the medication administration stage.

Paging

³ ADE is defined as “[i]njuries that result from medication use” [19].

Pagers have been widely used in healthcare since 1950 and are considered the primary method for contacting physicians [65][66]. There are two types of pagers used in hospital settings: one-way numeric pagers and two-way alphanumeric pagers. Using one-way numeric pagers requires the nurse to send a numeric message containing a phone number (using telephone keys) to the physician. The physician is required to call the number back. On the other hand, using two-way alphanumeric pagers requires the nurse to use a computer (web-page or software) to send an alphanumeric message with a very limited number of characters to the physician pagers. The physician can then respond using the small alphanumeric keys on the pager. Although pagers are considered one of the most user-friendly and common forms of communication, healthcare professionals found it ineffective for several reasons [67]:

- Constant disruption to work flow [67][68].
- Constant sense of urgency causes persistent alarm in physicians [68][69][70][71].
- Accessibility problems arise when nurses need to find a phone or computer to page a physician, and the physician needs to find a phone to call back [67].
- Time wasted while waiting for a response [67].
- Unanswered pages (e.g., sending the page to the wrong physician) [67][72].
- Missing sender's information (e.g., missing the call-back number) [67][72].
- Failure in sending messages: sometimes messages fail to send [67].
- No acknowledgment of receipt [69].
- Character limitation makes it difficult to send necessary information [67][68].
- Very small screen makes it hard to read and identify patient's need [69].
- Inefficient search function causes delay in finding the right physician in the system [67].

The problems associated with the use of pagers have prompted healthcare professionals to demand an alternative method for improving communication in hospital settings [68]. Therefore, different uses for information and communication technologies have been introduced to improve how healthcare professionals communicate with each other.

E-mail Messages

E-mail messages have been introduced to hospital settings and used as a primary method for communication between nurses and physicians [73][74][75][76][77]. One study have

used the smartphone to send and receive emails for both physicians and nurses [73]. Other studies have used the smartphone to receive and send emails for physicians only, while nurses use a desktop computer-based email system [74][75][76][77].

Common findings across these studies showed that e-mail messages as a method of communication were well-received by physicians; it reduced their time spent for communication and increased their mobility. However, nurses were not satisfied with e-mail messages as they reported a poor rate of response to them. This forced nurses to send multiple emails and even use a direct phone call along with the e-mail messages as a primary method of communication. This in turn created a high volume of workflow interruptions for the physicians [74][75][76][77]. In addition, considering nurses' busy schedules, the process of writing an email and waiting for a response is time-consuming [74][75][77]. As well, the desktop computer-based email requires the nurses to remain next to the computer until she receives a response or to frequently check for a response, which also causes workflow interruption [73].

Wireless Hands-Free Communication Devices (HCD)

Wireless hand-free communication devices are wearable badges that enable healthcare professionals to make outgoing calls or receive calls by using verbal commands. These have already been used in hospital settings as a primary method of communication [78][79][80][81][82][83]. Studies showed that HCD improved the efficiency of communication between healthcare professionals and reduced the waiting time for responses. However, there were also reliability issues related to voice recognition, which has been addressed in the literature [78][79][81][82]. It was frustrating for the healthcare professionals when the HCD failed to recognize their voice, especially in urgent cases that required immediate communication [79]. In addition, studies found that HCD speakers cause undesirable noise in the work environment [81][82]. Other researchers have assessed the use of HCD in hospitals and discussed other problems with the speaker related to privacy, stating that *“half of the providers expressed concern that the VOIP has the potential to compromise the privacy of communications between providers or among clinical teams”* [78]. Furthermore, it increases the volume of work flow interruptions and reduces the amount of face-to-face communication [78][79]. Given the problems associated with use of HCD, it is not yet ready to be adopted as a primary method of

communication between healthcare professionals [82].

Messaging Software (MS)

Messaging software has also been used in hospital settings as a primary method of communication. In this approach, nurses use desktop computer-based messaging software to send and receive text messages. In some studies, physicians use SMS to receive and respond to nurses' messages [71][84][85]. In another study, physicians have to log into a web-based device to browse and reply to messages [86]. Common findings among these studies show an improvement in the communication efficiency and a reduction in the time spent to contact physicians. However, nurses again experienced poor response to their messages and found it time-consuming to remain near the computer waiting for responses [71][85]. Similar to email issues, the poor rate of response led nurses to send multiple messages to physicians [85]. Consequently, a steady increase in the number of messages sent to physicians was reported, which caused a high volume of interruptions to their workflow [85][86]. In addition, since nurses enter the messages manually, the possibility of missing necessary information is high. One of the main disadvantages in using MS as addressed by physicians is the lack of detailed information in the messages needed to assess a situation. Simplification and abbreviations are frequently used by nurses, which causes the possibility of misinterpretation. Therefore, the MS method is not suitable for critical, urgent, or complex cases [85][86].

Smartphone-Based Text Messaging Application

Smartphone-based text messaging applications have been recently introduced as a communication enabler between healthcare professionals. Sally Gallot (2015) [88] and Patel et al. (2016) [70] implemented a smartphone application that allowed the sending and receiving of text messages between nurses and physicians. The nurse is required to enter information manually (free-text space) and send it to the physician. The physician receives and responds to the messages through the application. Sally Gallot (2015) found that using the smartphone application cut the communication time from 28 to 6 minutes, which consequently increased efficiency. Patel et al. (2016) also expected that using a smartphone application would reduce the time spent to receive a response from physicians. Disadvantages and limitations have not been reported in these studies. However, since both applications require the nurse to enter the information manually, the problem with

providing adequate information to the physician will possibly arise as it did with the messaging software communication method.

2.3.3 Disadvantages of Manual Entry of Information

The research to date has tended to focus on improving the method of communication and ignore the content of the communication, even though the content is just as important as the type of communication, and both are complementary to each other. Providing sufficient information using text-based communication (e.g., email, SMS, smartphone application) is a critical issue for both physicians and nurses. While physicians are looking for clear, concentrated, fast and fact-based communication content, nurses prefer detailed and in-depth communication content [17]. Physicians express their frustration with nurses' content of communication as "disorganization of information, illogical flow of content, inclusion of extraneous or irrelevant information, and delay in getting to the point" [17]. The difference between them is attributed to the fact that nurses are trained to deliver a narrative and descriptive messages, whereas physicians are action-oriented and looking for the main subject matter of a problem so they can take an action [89][90].

Moreover, nurses sometimes simplify the content of the messages and use numerous abbreviations, causing miscommunication. One nurse who uses manual written messages for communication stated: "Because our tendency is, when you send messages, we kind of send the message in a text form as opposed to a paragraph or a story, right? So we might abbreviate it so much that it could be misinterpreted" [84]. Simplifying the messages increases the potential for unintentional loss of the main point of the communication. Wu et al. (2014) studied the impacts of using text-based messages in clinical conversation, stating that "*the sender says just enough to communicate what they intend, relying on the audience to fill in the details that they did not explicitly communicate*" [84]. Inefficient context of messages (eliminating important details and over use of abbreviations) causes simplification of complex and issues, increases the workload and frustration, and consequently has a negative impact on patient safety [84]. The problems associated with the use of manual entry information method for communication shows the need for improving this approach in a way that considers the content and helps nurses address issues to the physicians without excessive or insufficient information.

Chapter 3. Research Methodology and Design Phases

This chapter describes the overall approach to our research. It covers the followed theoretical framework to guide our research through the design, implementation and evaluation process of the NFC-MACC system. It describes the study design, methodology and usability testing type employed, and the software used for data collection and analysis.

3.1 Theoretical Framework

We used the Information System Research (ISR) Framework by Hevner et al. (2007) to guide our research through the design, implementation and evaluation process of the NFC-MACC system [21]. We selected this theoretical framework because it fits with our research study, as it includes the design of an innovative system and the analysis of the use and/or performance of such system to improve and understand the behaviour of aspects of information systems [21][91]. In addition, this framework has been shown to be effective to guide similar research studies that include the design of innovative healthcare-related systems [92][93].

Hevner's ISR framework consists of three research cycles, (Figure 3-1). The first cycle is the *rigor cycle*, which focuses on the knowledge base that can be applied to the *design/implement* phase (literature review and previous experience) and the *evaluation* phase (models and methods). In our study, we selected the NFC technology and initiated the idea of our innovative system (NFC-MACC) from the literature and enhanced it from our preliminary study. The method used for evaluation is a form of usability testing and will be discussed later in this chapter. The second cycle is the *relevance cycle*, which focuses on understanding the environment for which the system is designed. In our study, we seek to understand the bedside medication administration and clinical communication procedure. The third cycle is the *design cycle*, which focuses on (1) designing/implementing the system based on the input from the relevance and rigor cycles, and (2) evaluating the system based on the input from the rigor cycle.

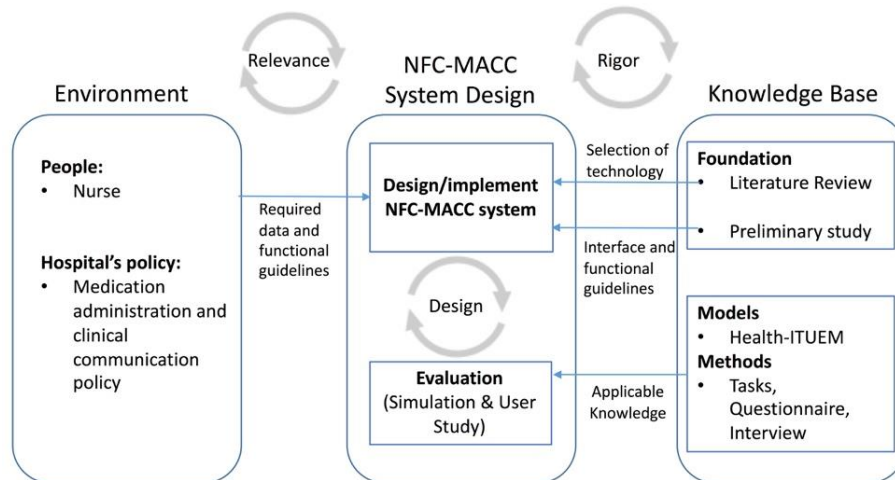


Figure 3-1. Adapting Hevner's ISR Framework [91].

3.2 Research Design

According to the ISR framework, we divided our study into three sequential phases, in which we apply the three research cycles detailed above (see Figure 3-2):

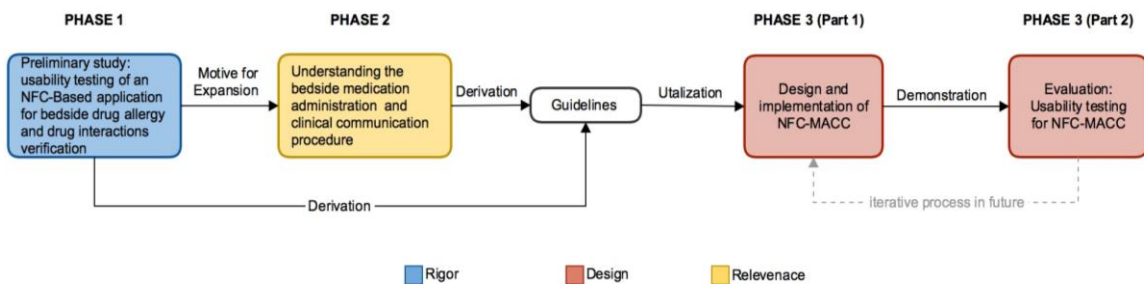


Figure 3-2. The study phases based on the ISR framework

Phase 1 was a preliminary study that aimed for understanding whether or not the idea of using an NFC-enabled smartphone application at the bedside is acceptable and usable to nurses during the medication administration stage. Therefore, we tested the usability of a prototype NFC-enabled smartphone application for checking drug interaction/allergy information and updating drug allergy data, which was implemented in previous study⁴

⁴ I implemented this prototype application in my Master degree.

[94]. This application represents an initial prototype design of two functions of the NFC-MACC system. The findings from Phase 1 provided us with a better understanding of the nurses' perception regarding the acceptability and usability of the prototype NFC-enabled smartphone application for checking drug interaction/allergy information at the bedside. The overall result showed positive feedback concerning usability and an acceptance of the NFC technology to be used at the bedside. In addition, recommendations for improvements were gathered during this phase to be used as design guidelines in Phase 3. The result of this phase motivated us to proceed with designing the prototype NFC-MACC system.

Before designing the proof of concept of the NFC-MACC system, we first had to define (outline) its functional guidelines. These guidelines describe what the system should do: for example, what data should be input and output, and processing (what must be done in order to transform inputs into outputs) that must be done by the system to (1) verify the medication, (2) document the medication and (3) notify healthcare providers. Defining the functionality can be derived from understanding the BMA procedure. Therefore, the purpose of Phase 2 is to build an understanding of the bedside medication administration procedure in nursing practice from the NSHA Policy and Procedure (theoretical source of information) and nurses' knowledge and experience (practical source of information). One-on-one semi-structured interviews with 14 nurses were conducted in this study. The findings of this phase provided us with better understanding of the required data and sources used in nursing practice to verify the five rights of medication administration, allergy, drug interactions, contraindication, and documentation, and assisted us to define their essential functional guidelines. The obtained guidelines of Phase 1 and Phase 2 were both utilized to design the proof of concept of the NFC-MACC system.

In Phase 3 (part 1), the design and functional guidelines obtained from Phase 1 and Phase 2 were utilized to design the prototype NFC-MACC system. We designed the system to reduce the major causes of medication errors by: (1) identifying the patient and the medication; (2) confirming the five rights of medication administration; (3) verifying allergies; (4) verifying drug interactions; (5) verifying contraindications; (6) alerting nurses and providing sufficient alert information; (7) providing real-time communication between nurses and other healthcare providers; and (8) documenting the administered medication.

The system uses the NFC technology to identify the patient and the medication, and it uses these IDs to access the patient and the medication information in the simulated hospital server. The hospital server verifies the patient and the medication, and replies to the nurse with an alert in case of medication error. In case of medication error, the nurse has an option to forward the alert and start a real-time communication with a healthcare provider. If no error is triggered, the nurse can electronically document the administration at the bedside.

Phase 3 (part 2) concerns the evaluation of the NFC-MACC system to understand the nurses' perception regarding its usability. Therefore, usability testing was conducted to assess objective and subjective usability attributes as well as to expose the strengths and weaknesses of the system. The findings showed that the system was well received by the nurses and offers promise to ease the steps required to verify the medications and improve bedside medication administration and clinical communication efficiency and mobility. However, findings showed that a technology-trust issue resulted in the feeling that the use of the NFC-MACC system in actual practice would add extra effort to the nurses' daily routine of medication administration. We developed a suggestion for improvements to refine and enhance the NFC-MACC system in future work.

3.3 Research Methodology

We used a mixed-methods approach (quantitative and qualitative) to gather comprehensive information about the acceptability and usability of the proposed system in Phase 1 and Phase 3. A convergent parallel design was used, which is a type of mixed-method design whereby quantitative and qualitative data are collected in parallel, analyzed separately, and then merged (see Figure 3-3). We used a convergent parallel design because it fits with the usability testing type (assessment/summative) that we used in this research to evaluate our proposed system in both Phase 1 and Phase 3. We assessed the same concept (usability) quantitatively and qualitatively concurrently during the same phase. The convergent parallel design helped us to obtain a complete understanding of the usability of the proposed system and also validated and corroborated the quantitative data [95]. The qualitative research method used in all phases was one-one-one semi-structured interviews, and we used a qualitative description approach to perform a content analysis of the interview scripts. We chose the qualitative description approach because it provides unembellished description and a comprehensive summary of an experience or an event

rather than formulating concepts or theories, as other qualitative approaches do [97]. The quantitative research methods used in Phase 1 and Phase 3 were questionnaire, time and number of errors to complete a task, and we used descriptive statistics, within-subject ANOVA, and T-test for numerical data analysis.

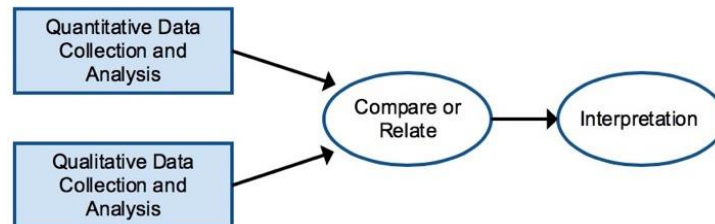


Figure 3-3. The convergent parallel design [95]

3.3.1 Usability Testing

The usability of a product (e.g. system, app, website) is important because designers need to understand whether or not their product meets the users' expectations and helps them achieve their goals without difficulty, stress, or frustration [97][98]. The International Organization of Standardization (ISO) defines usability as “[t]he extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use” [97]. The *specific user* is the user for whom the product is designed; the *specific goals* indicate that the product should have the same goal as the user; and the *specific context* means that the product is designed to fit with the user's environment (i.e., where the product is intended to be used) [97].

Usability testing is a technique employed to evaluate a product from a user's point of view, such as through a website or mobile application. Jeff Rubin (2008) defined usability testing as a “process that employs people as testing participants who are representative of the target audience to evaluate the degree to which a product meets specific usability criteria” [98]. The data gathered from users during usability testing helps designers to expose any issues with their apps and allows them to solve them during the iterative app development process [98]. There are four types of tests: exploratory, assessment, validation, and comparison. The classification of the test types depends on two factors, namely the point at which it is done during the development life cycle (Figure 3-4) and the purpose of the study (Table 3-1) [98]. The usability testing type we followed and used in

this research is assessment usability testing because our proposed system is in the early stages of the development lifecycle. In addition, this type of test assesses the usability of lower-level operations such as prototypes, and it assesses how effectively the system has been implemented. Furthermore, it shows how successfully users perform realistic tasks, and identifies the usability weaknesses of that system.

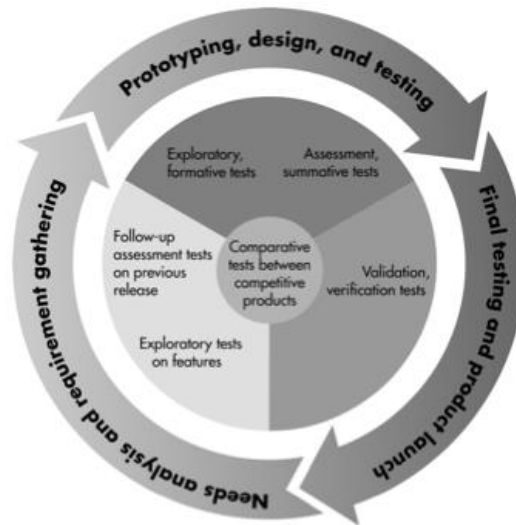


Figure 3-4. Development life cycle [98]

Table 3-1. Usability testing types [98]

Test Type	When	Objective
Exploratory/ Formative	At the very beginning of the application development lifecycle (initial stage) when the product is being defined and designed	Assess the effectiveness of the initial design concepts, and define the critical design decisions
Assessment/ Summative	Early or midway in the application development lifecycle; after the fundamental or high-level design	Assess the effectiveness of the design implementation, and evaluate the usability of a lower-level operations/functioning
Validation/ Verification	Late in the application development lifecycle; after solving the application's problem discovered earlier and before the releasing phase	Assess the application as to whether or not it meets the standards of usability and compare it to predetermined benchmarks

Test Type	When	Objective
Comparison	At the very beginning, midway, or end of the application development lifecycle	Compare the usability of two or more designs, and comprehend the pros and cons of different designs

3.4 Software Packages Used for Data Collection and Analysis

We used different software packages to collect and analyze data for all three phases of our research. Dalhousie’s *Opinio* online survey software (questionnaire tool) was used to collect responses to demographic questionnaires and post-task questionnaires. *Mobizen*, a mobile screen recorder, was used to observe the number of errors and any navigation problems. NVIVO 11, a qualitative data analysis application, was used to analyze the interviews scripts (coding, recoding and categorizing the qualitative data). *IBM SPSS* and *Microsoft Excel*, statistics software, were used to analyze numerical data to generate descriptive statistics, within-subject ANOVA, t-test, and correlations.

Summary

The theoretical framework employed to guide use through the overall research design and the methodology used in this research have been discussed in this chapter. Table 3-2 describes the three phases, their methods used, the data collection and analysis tools, and their key outcomes.

Table 3-2. Overview of research design, phases, methods, and outcomes

Phases	Type of Study	Study Sample	Methods	Data Collection methods	Data Analysis Tools
Phase 1: Preliminary Study	Usability Testing	9 Nurses	Quantitative & Qualitative	<ul style="list-style-type: none"> Demographic questionnaires Task (time and errors) Post-task questionnaires Semi-structured interviews 	<ul style="list-style-type: none"> SPSS (descriptive statistics, within-subject ANOVA, correlations)
<p>Outcome of Phase 1: Better understanding of the nurses' perception regarding the acceptability and usability of the NFC-enabled application at the bedside during the medication administration stage. Both qualitative and quantitative data showed that nurses accept the idea of using the NFC technology and are willing to use it in an actual practice. The overall findings of this phase showed that the nurses found the NFC-enabled application for drug allergy and interaction verification easy to use and easy to learn even though they had no experience with the NFC technology. Some weaknesses related to the communication feature were discovered and took into consideration in Phase 3. Developed a set of design and functional guidelines based on the suggestion of improvements to be used when designing and implementing the prototype NFC-MACC system.</p>					
Phase 2: Understanding the BMA Procedure	One-on-one Interview	14 Nurses	Qualitative	<ul style="list-style-type: none"> Demographic questionnaires Semi-structured interviews 	<ul style="list-style-type: none"> Excel (demographic data) Nvivo
<p>Outcome of Phase 2: Better understanding of the BMA and clinical communication procedure. Determined a set of required data and sources used in nursing practice to verify the medication and document administered medication. Defined the type of information used to communicate with healthcare providers. Developed the essential functional guidelines for medication verification, documentation and communication. The outcome of this phase was used as guidelines to design and implement the prototype NFC-MACC system.</p>					
Phase 3: System design and Final Study	Usability Testing	32 Nurses	Quantitative & Qualitative	<ul style="list-style-type: none"> Demographic questionnaires Task (time and errors) Post-task questionnaires Semi-structured interviews 	<ul style="list-style-type: none"> SPSS & Excel (descriptive statistics, within-subject ANOVA, correlations) Nvivo
<p>Outcome of Phase 3: Better understanding of the nurses' perception regarding the usability of an NFC-MACC system. Both qualitative and quantitative data showed that the system was well received by the nurses and offers promise to ease the steps required to verify medications, improve bedside medication administration, and enhance clinical communication efficiency and mobility. However, findings showed that technology-trust issue resulted in the feeling that the use of NFC-MACC system in actual practice would add extra effort to the nurses' daily routine of medication administration. Developed a suggestion for improvements to refine and enhance the NFC-MACC system in future work.</p>					

Chapter 4. Phase 1: Preliminary Study

4.1 Study Purpose and Objectives

Before designing and implementing the NFC-MACC system, we needed to understand whether the idea of using an NFC-enabled smartphone application at the bedside is acceptable and usable to nurses during the medication administration stage. In addition, we needed to understand the nurses' opinion regarding the instant communication to the healthcare provider during the medication administration when medication error (near-miss) is triggered. Therefore, we tested the acceptability and usability of a prototype NFC-enabled smartphone application for verifying drug interactions and known allergies, which we already implemented in a past study⁵ [94][99]. This application represents a small part of the NFC-MACC system.

The purpose of the phase is to understand nurses' perceptions regarding the acceptability and usability of the NFC-enabled smartphone application for checking drug interactions and known allergies, and to identify the application's weaknesses and strengths and provide recommendations for improvements that can be used as a guideline to design and implement the NFC-MACC system.

The objectives of this study are to:

- Assess the usefulness, learnability, efficiency, and effectiveness and satisfaction of the NFC-enabled smartphone application for checking drug interactions and known allergies from the nurses' perspective.
- Identify the weaknesses and strengths of the wireless smartphone application.
- Provide recommendations for improvement.

4.2 NFC Application for Verifying Drug Allergy/Interaction and Alerting Healthcare Providers

In previous study, we implemented an NFC-enabled smartphone application that allows the nurse to verify drug allergies/interactions and update (report) drug allergies during the medication administration stage [94]. In addition, the application provides an instant alert to the treatment team in case of allergy or potential drug interactions. We implemented the

⁵ We implemented this prototype application in the Master degree.

application using an Android smartphone, a simulated database populated with 10 patients' records and 30 medications, and classic 1K NFC tags.

The application has two main functions that the nurse can choose from: *Test* and *Update*. The *Test* function allows the nurse to check for drug interactions and allergies by simply tapping on the patient's tag and the prescribed medication tag to obtain their unique IDs. The unique IDs will be stored in the application and then sent to the simulated hospital database. The database runs query to check whether or not the patient is allergic to the medication or the medication may cause drug interactions with other medication(s) in the patient's medication history. In case of allergy or interaction, the hospital database replies to the application and the application will alert the nurse. The alert message contains specific information about the case triggered, such as near-miss type (allergy or interaction), drugs listed in the patient's history, scanned drug, classification, and description. At the same time, the hospital database sends an SMS alert and email alert to the treatment team. The SMS asks them to check their email, and the email has the exact information that the nurse received, in addition to the patient's name and file number. On the other hand, if the patient is not allergic to the prescribed medication and there is no potential of drug interaction, the application asks the nurse to proceed and administer the medication to the patient (Figure 4-1). The *Update* function allows the nurse to update (report) the patient's allergy list. This is important when the nurse detects a new allergy by observation after administering the medication. In this function, the nurse taps on the patient's and medication's tags and enters information about the allergy (allergy classification and description). This information is sent and then added to the patient's file in the hospital database. (Appendix 4.A)

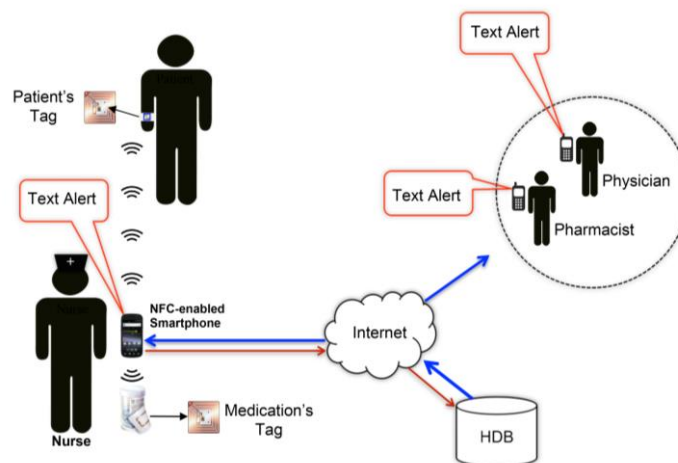


Figure 4-1. NFC-enabled smartphone application for checking drug allergy and interactions [94].

4.2.1 Usability Testing

Jeff Rubin linked the achievement of a product’s usability with the attainment of the following attributes: “useful, efficient, effective, satisfying, [and] learnable” [98]. Usefulness is the degree to which an app enables a user to achieve his/her goals, and the degree of the user’s willingness to use the app at all. Efficiency is how quickly a user can achieve his/her goal (measure of time). Effectiveness is the degree to which an app’s behavior meets the user’s expectation, and how easy it is for the user to use the app and achieve his/her goal without errors. Learnability is the ability for the user to use the app with some level of competence after some period of experience. Satisfaction is how a user feels about the app, and what is his/her opinion or perception about the app [98]. Accordingly, to test the usability of the NFC-based application for drug allergy and interaction verification, we focused on these attributes.

4.3 Study Design

We tested the usability using a one-on-one mixed method approach (quantitative and qualitative) to gather comprehensive information about the nurses’ perceptions regarding the acceptability and usability of the NFC-enabled smartphone application for checking drug interactions and known allergies. The study included the following methods to collect data: background questionnaire, tasks, post-task questionnaire, and semi-structured interview. We analyzed the quantitative data using descriptive statistics, and within subject

ANOVA. We analyzed the qualitative data using a qualitative description approach. An approval from the Nova Scotia Health Authority Research Ethics Board (NSHA REB) was acquired before starting the study (Appendix 4.B).

4.3.1 Participants Recruitment and Study Duration

The recruitment process started following the NSHA REB approval from May 2014 to October 2014 (6 months duration). A purposeful sampling was used in this study, we recruited 9 nurses, all of whom work at a hospital or clinic, have experience administering medications to patients. Even though the sample size is small, researchers claimed that 5 users are a sufficient sample size for any usability test [100]. Robert Virz stated: “Only three subjects are needed to uncover 65% of the problems, five are needed to find 80%, and nine are needed to find 95%, on average. Clearly, later subjects are not as likely to uncover new usability problems as are earlier” [100]. Based on these references, we believe that 9 participants will suffice to assess the usability of the application, expose its weaknesses and strengths, and provide recommendations to improve the application in the future. All participants were recruited through email by approaching managers or relevant leads in suitable clinic areas in Capital Health, and by approaching the charge nurses in the Nova Scotia Rehabilitation Center who distribute the recruitment email.

4.4 Study Setting and Equipment

We used a lab setting to conduct the study. The study took a place at a meeting room in one of Capital Health’s sites, depending on the participants’ workplace (Figure 4-2).

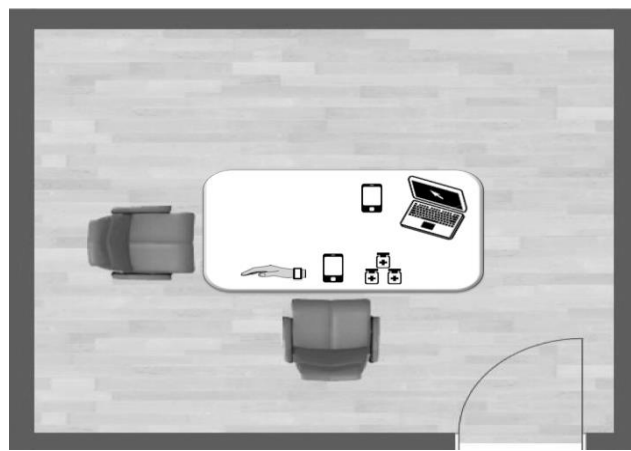


Figure 4-2. Study setting

The equipment used were: (1) NFC-enabled smartphone with installed application for drug allergy and interaction verification to be used during the tasks session. (2) Three medication bottles tagged with NFC tags, and labeled A, B, and C to be used during the tasks session (as prescribed medications to the patient). (3) Model hand with an NFC tag bracelet to be used during the tasks session as a simulation of a patient's arm (Appendix 4.C). (4) Laptop to be used during the tasks session to display the email sent to the physician and the pharmacist. (5) Smartphone to be used during the task session to display the text message sent to the physician and the pharmacist. (6) Audio recorder to be used during the interview session. (7) Digital timer to be used during the tasks session.

4.5 Study Process

The study was divided into 5 phases: background questionnaire, introduction and training session, tasks, post task questionnaire, and semi-structured interview. The duration to complete the study took about 60 minutes per participant.

4.5.1 Online Background Questionnaire

The participants were asked to complete an online background questionnaire prior to attending the study through Dalhousie's Opinio survey software (questionnaire tool). The objective of the background questionnaire was to gather general information about the participants and understand the current process (method/assessment) they are using to check drug allergy and drug interaction for hospitalized patients during the medication

administration stage (See Appendix 4.D).

4.5.1.1 *Introduction and Training*

We administered basic training to equalize the participants' experience with using the application. We introduced the study to the participants and explained the main functions of the application. In addition, since we were not evaluating their previous knowledge about how to use the NFC technology, we administered basic training that covered the following: how to open and restart the application, and how to tap an NFC tag and obtain its ID. The purpose of this training was to provide the participants with basic skills to perform the tasks and to allow them to focus on the application functions. Furthermore, this training equalized the participants' experience with using NFC technology before performing the tasks. This session lasted for about 8 minutes.

4.5.1.2 *Tasks Session*

After the introduction and training session, we asked the participants to perform a set of tasks. We designed the tasks so that the participants were given a chance to experience all of the functions in the application and expose its weaknesses and strengths.

4.5.1.2.1 *Tasks Categories*

Following the introduction and training session, the participants were asked to perform a set of tasks. During this phase we observed the participants and focused on the time spent to finish each task to evaluate the efficiency, and the number of attempts to read the tags to evaluate the effectiveness.

There were two categories of tasks: (a) *checking drug allergy/interaction* and (b) *updating the patient's drug allergies list*. Each category has a scenario and tasks that include subtasks (see Appendix 4.E). We designed the context of each scenario in a way that is close to reality and represents a familiar situation to the participants. This helps them to remain in role while performing the tasks [98]. The first category focused on experiencing the *Test Function* in the application. It has three main tasks that the participants were asked to perform in order:

1. Checking if drug A would cause potential drug interaction or if the patient is allergic to it.

2. Checking if drug B would cause potential drug interaction or if the patient is allergic to it.
3. Checking if drug C would cause potential drug interaction or if the patient is allergic to it.

Tables 4-1, 4-2, and 4-3 illustrate the tasks' results, goals, and successful completion criteria.

Table 4-1. Task 1, checking drug allergy/interaction for drug A

Task 1	Checking if drug A would cause potential drug interaction or if the patient is allergic to it.
Task result	In a synchronizing manner: <ul style="list-style-type: none"> • The application displays an alert message to the user about the drug interaction case. • The physician's smartphone receives an SMS alert message about the drug interaction case. • The physician's email website receives an email alert for the drug interaction case.
Goal	<ul style="list-style-type: none"> • To allow the user to experience the process of reading the NFC tags to get the patient's and drug's ID information (for the first time). • To show the user how the application detects drug interactions and displays the alert message. • To show the user how the physician receives an SMS alert message. • To show the user how the physician's email website receives an email alert.
Successful completion criteria	Reaching the desired screen with two times tapping on the tags
Optimum Time	5 Seconds

Table 4-2. Task 2 checking drug allergy/interaction for drug B

Task 2	Checking if drug B would cause potential drug interaction or if the patient is allergic to it.
Task result	In a synchronizing manner: <ul style="list-style-type: none"> • The application displays an alert message to the user about the drug allergy case. • The physician's smartphone receives an SMS alert message about the drug allergy case. • The physician's email website receives an email alert for the drug allergy case.
Goal	<ul style="list-style-type: none"> • To allow the user to experience the process of reading the NFC tags to get the patient's and drug's ID information (for the second time). • To show the user how the application detects drug allergies and displays the alert message. • To show the user how the physician receives an SMS alert message. • To show the user how the physician's email website receives an email alert.
Successful completion criteria	Reaching the desired screen with two times tapping on the tags

Task 2	Checking if drug B would cause potential drug interaction or if the patient is allergic to it.
Optimum Time	5 Seconds

Table 4-3. Task 3 checking drug allergy/interaction for drug C

Task 3	Checking if drug C would cause potential drug interaction or if the the patient is allergic to it.
Task result	The application displays a <i>permission to administer the drug to the patient</i> message to the user.
Goal	<ul style="list-style-type: none"> To allow the participant to experience the process of reading the NFC tags to get the patient’s and drug’s ID information (for the third time). To show the participant how the application displays the permission to proceed message.
Successful completion criteria	Reaching the desired screen with two times tapping on the tags
Optimum Time	5 Seconds

In Task 1, we provided subtasks that guide the user through the basic steps to check for drug allergy/interaction. Tasks 2 and 3 have identical steps as task #1, the only difference being that they have to scan different medications each time. The repetition in the tasks helps us to measure the learnability by counting the time spent on each task. As Sauro stated, “[t]he most common way to measure learnability is to use time-on-task and have users repeat tasks either during the same testing session or at some point in the future” [101].

The second category focuses on experiencing the *Update Function* in the application. It has two main tasks that the participants were asked to perform in order:

4. Update the patient’s drug allergy list.
5. Checking if the patient is allergic to drug C.

Tables 4-4 and 4-5 illustrate the tasks’ result, goal, and successful completion criteria.

Table 4-4. Task 4 update the patient’s drug allergy list.

Task 4	Update the patient’s drug allergy list
Task result	The application displays a <i>successful update</i> message
Goal	<ul style="list-style-type: none"> To allow the user to experience the process of reading the NFC tags to get the patient’s and drug’s IDs information (for the second time). To allow the user to experience the process of updating the patient’s allergy list through the application.

Task 4	Update the patient's drug allergy list
	<ul style="list-style-type: none"> To show the user how the application displays the successful update message if they successfully completed the update process
Successful completion criteria	Reaching the desired screen with two times tapping on the tags
Optimum Time	18 Seconds

Table 4-5. Task 5 checking if the patient is allergic to drug C.

Task 5	Checking if the patient is allergic to drug C.
Task result	In a synchronizing manner <ul style="list-style-type: none"> The application displays an alert message to the user about the drug allergy case. The physician's smartphone receives an SMS alert message about the drug allergy case. The physician's email website receives an email alert for the drug allergy case.
Goal	<ul style="list-style-type: none"> To allow the user to experience the process of reading the NFC tags to get the patient's and drug's ID information (for the fifth time). To show the user how the application detects the drug allergy that he/she recently added and displays the alert message. To show the user how the physician receives an SMS alert message. To show the user how the physician's email website receives an email alert.
Successful completion criteria	Reaching the desired screen with two times tapping on the tags
Optimum Time	5 Seconds

4.5.1.3 *Post-Tasks Questionnaire Phase*

Following the tasks phase, we asked the participants to complete a questionnaire; this phase last for about 10-15 minutes. The data collected from the questionnaire helped us to understand the participants' opinions and feelings about the NFC application. The questionnaire was classified into five categories: *willingness*, *usefulness*, *ease of use*, *learnability*, and *satisfaction*. Each of these categories had a set of questions that measured one of the usability testing attributes discussed earlier.

To collect the required data, we used the following standardized usability questionnaires as a reference and guide to design our questionnaire: The Technology Acceptance Model (TAM); the Software Usability Scale (SUS); and Usefulness, Satisfaction, and Ease of Use (USE) [101]. we modified these questionnaires to evaluate our application and achieve our

first objective. The questionnaire had a five-level Likert scale and a few open-ended questions.

4.5.1.4 *Semi-Structured Interview Session*

After the post-tasks questionnaire, we conducted a short semi-structured interview (audio recorded) that lasted for about 10-15 minutes (see Appendix 4.F). The first three questions in the interview helped us to collect qualitative data to support the post-task questionnaire answers and to identify the weaknesses and strengths of the application. In the last three questions, we provided the participants with a printed-paper that included all of the interfaces of the application. we then asked the participants to remove and/or add anything to the content or the interface that they thought might improve the application. The last three questions helped us to gather descriptive recommendations to improve the application in the third phase of our research study (Chapter 6).

4.6 Study Findings

4.6.1 Participants' Demographics

A total of nine participants with medication administration experience participated in the study. All were female, and eight of the nine participants were nurses, with one nurse practitioner. *Age* was coded within the categories “20-29” as 25, “30-39” as 35, “40-49” as 45, “50-59” as 55, and “60-69” as 65. The mean age was 41.7. *Years of experience* was coded within categories “2 years or less” as 1.0, “3-6 years” as 4.5, “7-9 years” as 8, and “10+” years as 15. We found that five of the nine participants had 10 or more years of experience, while three of the nine participants had 2 years or less, and one had 3-6 years. The mean experience, using this coding, was 7.0. In addition, participants were asked about the average number of patients that they daily administered medication to, and their responses were coded as “1-4” as 2.5, and 5-8” as 6.5. Two of the nine participants reported 1-4, and six participants reported 5-8, with a mean of 5.2. Table 4-6 illustrates the participants' characteristics.

Table 4-6. Nursing Participant Characteristics (N=9)

Characteristics	Percentage	Mean	Median
Age:			
• 20-29	(1/9) 11.1%	41.7 years	40-49 years
• 30-39	(3/9) 33.3%		
• 40-49	(3/9) 33.3%		

Characteristics	Percentage	Mean	Median
<ul style="list-style-type: none"> • 50-59 • 60+ 	(2/9) 22.2% -		
Nursing Experience: <ul style="list-style-type: none"> • 2 years or less • 3-6 years • 7-9 years • 10+ years 	(3/9) 33.3% (1/9) 11.1% - (5/9) 55.5%	7 years	10+ years
Average number of patients they daily administer medication to: <ul style="list-style-type: none"> • 1-4 • 5-8 • 9-12 • 13+ 	(3/9) 33.3% (6/9) 66.6% - -	5.2	5-8 patients

4.7 Participants' Current Experience (Practice)

All nine participants had experience in bedside checking of drug allergy/interaction and in updating/reporting drug allergies for patients. The background questionnaire attempted to form a clear picture and understand the current processes for: (A) checking drug allergies, (B) checking drug interactions, and (C) updating patient allergy records. For each process, the data collected included the time required, the methods used (check paper record, check electronic record, or other), the perceived accuracy of the method(s) used, the satisfaction with the process, the satisfaction with the perceived accuracy, the number of healthcare providers informed of updates (physicians, pharmacists, other nurses, other), the mechanisms used to inform healthcare providers (phone, personal conversation, written report, other), and the time required to notify them.

4.7.1 Drug Allergies

Table 4-7 presents the number of methods used to check for drug allergies, the number of healthcare providers informed, and the methods of informing them. We found that many participants used multiple approaches to check for allergies, informed multiple healthcare providers, and used multiple methods to inform treatment team.

Table 4-7. Checking drug allergies and informing treatment team

		Saying Yes (Number)	Saying Yes (Percentage)
Check for allergies	Paper record	7	77.8
	Electronic record	5	55.6

		Saying Yes (Number)	Saying Yes (Percentage)
	Ask patient	7	77.8
	Other (allergy bracelet)	2	22.2
Healthcare provider (s) informed	Physicians	9	100.0
	Pharmacists	7	77.8
	Other nurses	6	66.7
	Other (head nurse)	2	22.2
Methods used to inform healthcare provider	Phone	6	66.7
	Talk in person	8	88.9
	Written report	6	66.7
	Other (send reminder, message through Practimax and Kardex)	3	33.3

Table 4-8 presents the remaining data for the process of checking drug allergies. This includes the number of methods used to check for drug allergies, the number of healthcare providers contacted about discovered drug allergies, the number of methods used to contact healthcare providers, the time to check for drug allergies⁶, and the time to notify⁷. It also includes the measure of satisfaction (from 1 = not satisfied to 5 = very satisfied), the measure of perceived accuracy (from 1 = poor to 5 = excellent), and the measure of satisfaction with the perceived accuracy (from 1 = not satisfied to 5 = very satisfied). It must be considered that some of these variables represent what participants think or remember, and thus are not necessarily accurate.

Table 4-8. Measures of the drug allergy checking process

	Mean	SD	Min	Max
Number of checking allergy processes	2.3	1.2	1	4
Number of healthcare providers informed	2.7	1.1	1	4
Number of methods used for informing	2.6	0.7	1	3
Time required to check (seconds)	143.3	101.5	30	330
Time required to notify (seconds)	420.0	180.0	120	660

⁶ The time required to check for an allergy is estimated within ranges and coded as follows: “less than 1 minute” as 30 sec., “1-2” as 90 sec, “3-4” as 210 sec, “5-6” as 330 sec, and “7+” as 600 sec.

⁷ The time required to notify the treatment team was estimated within ranges and coded as follows: “less than 1 minute” as 30 sec., “1-3 minutes” as 120 sec., “4-6 minutes” as 300 sec, “7-9 minutes” as 480 sec., and “10+” as 900 sec.

	Mean	SD	Min	Max
Satisfaction with time for checking process	3.6	1.1	2	5
Perception of checking process accuracy	3.7	1.0	3	5
Satisfaction with accuracy	3.6	1.0	2	5

Most participants used more than one method to check drug allergies (2.3 on average, with the electronic method being the least used method). They also tried to inform multiple healthcare providers (2.7 on average; always the physician) and used a variety of methods to do so (2.6 on average; “talk in person” is the most commonly used method). The average time to check for drug allergy was 143 seconds (about 1.5 minutes), and the time to notify healthcare providers was 420 seconds (about 7 minutes). Despite the time involved, participants were generally satisfied with the process, scoring it 3.6/5.0. They believed the process was accurate but not perfect, scoring it 3.7/5.0, and they were satisfied with that degree of accuracy 3.6/5.0. If these scores represented grades out of 100, they would be 72%, 74% and 72%, respectively.

4.7.2 Drug Interactions

Table 4-9 illustrates the number of methods used to check for drug interactions, the number of healthcare providers informed, and the methods used for informing them. As in the previous check for drug allergies, many participants used multiple approaches in all three areas.

Table 4-9. Checking drug interactions and informing treatment team

		Saying Yes (Number)	Saying Yes (Percentage)
Check for interactions	Paper record	4	44.4
	Electronic record	5	55.6
	Drug interactions (software)	9	100.0
	Other (call the pharmacist)	2	22.2
Healthcare provider(s) informed	Physicians	9	100.0
	Pharmacists	7	77.8
	Other nurses	7	77.8
	Other (head nurse)	1	11.1
Methods used to inform healthcare provider	Phone	8	88.9
	Contact in person	7	77.8
	Written report	4	44.4

		Saying Yes (Number)	Saying Yes (Percentage)
	Other (send reminder, message through Practimax and Kardex)	3	33.3

The results here presented a contrast to the previous check for drug allergies. All participants checked some type of drug interaction information source, with most using the phone to inform healthcare providers. However, the physician was still the only healthcare provider that all participants informed. Table 4-10 presents the remaining data for the process of checking drug interactions.

Table 4-10. Measures of the drug interactions checking process

	Mean	SD	Min	Max
Number of checking interaction processes	2.2	1.0	1	3
Number of healthcare providers informed	2.7	1.0	1	4
Number of methods used for informing	2.4	0.9	1	4
Time required to check (seconds)	420.0	201.2	120	660
Time required to notify (seconds)	460.0	189.7	300	660
Satisfaction with time for checking process	2.9	0.9	2	5
Perception of checking process accuracy	3.4	0.0	3	4
Satisfaction with accuracy	2.2	1.0	1	3

Most participants used more than one method to check drug interactions. They also tried to inform multiple healthcare providers and used a variety of methods to do so. The time to check averaged 420 seconds (about 7 minutes), and the time to notify healthcare providers required an average of 460 seconds (about 7.5 minutes). Participants were not completely satisfied with the process, scoring it only 2.9/5.0 overall. They believed the process was accurate but not perfect, scoring it at 3.4/5.0, and they were not completely satisfied with the accuracy, scoring it at 2.2/5.0. If these scores represented grades out of 100, they would be 58%, 68% and 44%, respectively. Such grades would be considered too low (or even, in the latter 'grade', a failure).

4.7.3 Updating Patients' Drug Allergies Records

Table 4-11 illustrates the number of methods used to update patient's drug allergies list.

Most participants updated the paper and/or electronic records.

Table 4-11. Updating patient’s drug allergies methods

		Saying Yes (Number)	Saying Yes (Percentage)
Update patient record for drug allergies	Paper record	7	77.8
	Electronic record	6	66.7
	Other (Public Health Adverse Effect Form, Kardex)	2	22.2

Table 4-12 presents the remaining data for the process of updating patient records about drug allergies. The table includes information on the number of methods used to update, the time it takes to update, and the measure of satisfaction.

Table 4-12. Measures for Updating Patients’ Drug Allergy Record Process

	Mean	SD	Min	Max
Number of update methods used	1.7	0.7	1	3
Time required to report drug allergy	366.7	288.4	0	660
Satisfaction with time for process	3.6	1.1	2	5

Most participants used more than one method to update their patients’ drug allergies records. The time to update averaged 366 seconds (about 6 minutes). Participants were reasonably satisfied with the process, scoring it at 3.6/5.0. If this score represented a grade out of 100, it would be 72%.

4.8 Tasks

The main analyses were concerned with the performance of using the NFC smartphone application for checking drug allergy/interaction and updating drug allergies. There were five tasks: Tasks 1, 2, 3 and 5 were checking for a drug allergy or interaction⁸, and Task 4 was updating a patient’s record when an allergic reaction occurred. Task 5 was a check after updating. For each task, there were two primary measures: Time and Attempts. Time measured the *Efficiency*, and Attempts measures the *Effectiveness*. The mean times for

⁸ Tasks 1, 2, 3, and 5 have identical steps. The only difference between them is the output of the NFC application. There is a difference in the output because each task has a different tagged medication.

completion (in seconds), the number of attempts, and the number of successfully completed tasks⁹ are shown in Table 4-13. The number of attempts should be minimum two, because two separate tags need to be read in order to check for a drug allergy/interaction and update allergy (one for the patient, and one for the medication). Data for Task 4 is included in Table 4-13, although the task (updating drug allergy) was distinct.

Table 4-13. Task times (sec), number of attempts (minimum 2), and number of successful completion

Task	Time (sec)				Number of Attempts				Number of Successful Completion
	Mean	SD	Min	Max	Mean	SD	Min	Max	
1	15.88	8.60	6.00	29.00	2.67	1.32	2.00	6.00	6
2	12.11	6.72	6.00	13.00	2.89	1.53	2.00	6.00	6
3	10.44	5.10	3.00	21.00	3.00	0.86	2.00	4.00	3
4	73.22	42.98	17.00	143.00	2.33	0.71	2.00	4.00	8
5	5.89	2.85	3.00	11.00	2.11	0.33	2.00	3.00	7

4.8.1 Efficiency

We hypothesized that the participants would learn how to use the NFC application to check for drug allergy/interaction (Tasks 1, 2, 3 and 5) and the amount of time spent on each task would decrease until it reached the optimum time (5 sec). Therefore, we used within-subjects ANOVA for Tasks 1, 2, 3 and 5 to find out whether or not the time was decreasing through the tasks.

The within-subjects ANOVA indicated a general decrease in the amount of time required for checking allergies/interactions with $F(3,24) = 7.152$ ($p < .001$, $\eta^2 = .472$). We found that the mean time in Task 5 was 89 milliseconds longer than the optimum time, which may indicate that if there were a Task 6, its mean time would reach the optimum time (Figure 4-3). The maximum times were also steadily decreasing, which implies that the application was easy to learn.

⁹ A “successful completion” means completing a task with only two attempts at reading the tags

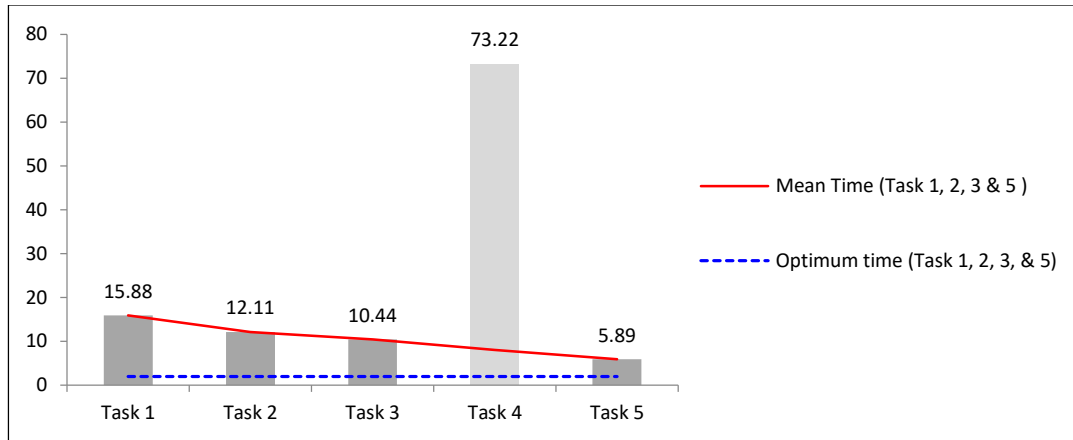


Figure 4-3. Mean times for tasks completion

In addition, times for Tasks 1, 2, 3 and 5 were correlated (mean $r = .49$, $sd r = .20$, $min r = .13$, $max r = .66$), implying that those who were fastest on Task 1 were also fastest on Task 5. In addition, times were also correlated with years of experience (mean $r = .46$, $sd r = .21$, $min r = .33$, $max r = .78$), but not so strongly with age (mean $r = .14$, $sd r = .32$, $min r = -.11$, $max r = .60$). Older and more experienced participants performed more quickly than younger, less experienced participants. It would seem that, for the use of the NFC application, experience as a nurse is more important than age.

4.8.2 Effectiveness

All five tasks required a minimum of two attempts to read the tags (there were two tags to be read). We hypothesized that the number of attempts to read the tags would decrease from Task 1 to Task 5. Hence, a second within-subjects ANOVA tested differences between the number of attempts for all five tasks was performed. The results indicated that there was no significant change in the number of attempts to completion with $F(4, 24) = 1.368$ ($p < .267$, $\eta^2 = .146$). The correlations between the number of attempts was low (mean $r = .31$, $sd r = .29$, $min r = -.09$, $max r = .88$), as was the correlation of attempts with experience (mean $r = .22$, $sd r = .21$, $min r = .00$, $max r = .50$) and with age (mean $r = .27$, $sd r = .11$, $min r = .09$, $max r = .38$).

By referring to the number of successful completions in Table 4-13, it is obvious that there was no significant difference between the attempts because most participants made the optimum number of attempts in all tasks, except Task 3.

4.9 Post-Tasks Questionnaire

The rest of the usability attributes (Usefulness, Ease of Use, Learnability, and Satisfaction) were assessed using 59 questions (37 individual questions, one of which had subsections). All questions used a five point Likert scale coded as Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5).

4.9.1 Usefulness

Table 4-14 presents the results for the Usefulness section. Note that all of the means are high (between 4 and 5). In fact, participants only responded with “Agree” or “Strongly Agree” for all questions except question 6, 7 and 14. However, even these had a minimum response of 3. There were no negative evaluations, which indicates that the participants found the NFC application generally useful.

Table 4-14. The usefulness of the NFC application

Q #	Simplified Question	Rating					Mean
		1	2	3	4	5	
1	Willing to try the application in real-world scenario	-	-	-	2	7	4.78
2a	Improve quality of: checking drug interaction	-	-	-	1	8	4.89
2b	Improve quality of: checking drug allergy	-	-	-	2	7	4.78
2c	Improve quality of: reporting drug allergy	-	-	-	2	7	4.78
3a	Give more control over: checking drug interaction	-	-	-	2	7	4.78
3b	Give more control over: checking drug allergy	-	-	-	1	8	4.89
3c	Give more control over: reporting drug allergy	-	-	-	1	8	4.89
4a	Enabling faster accomplishment of: checking drug interaction	-	-	-	2	7	4.78
4b	Enabling faster accomplishment of: checking drug allergy	-	-	-	2	7	4.78
4c	Enabling faster accomplishment of: reporting drug allergy	-	-	-	3	6	4.67
5a	Improve performance in: checking drug interaction	-	-	-	2	7	4.78
5b	Improve performance in: checking drug allergy	-	-	-	2	7	4.78
5c	Improve performance in: reporting drug allergy	-	-	-	2	7	4.78
6a	Easier process to: check drug interaction	-	-	1	2	6	4.56
6b	Easier process to: check drug allergy	-	-	1	2	6	4.56
6c	Easier process to: report drug allergy	-	-	1	1	7	4.67
7a	Faster process to: checking drug interaction	-	-	1	2	6	4.56
7b	Faster process to: checking drug allergy	-	-	1	2	6	4.56
7c	Faster process to: reporting drug allergy	-	-	1	2	6	4.56
8	Reduce known allergies and interaction errors	-	-	-	5	4	4.44
9	Improve patient safety	-	-	-	2	7	4.78
10	Notification: faster to inform the physician/pharmacist	-	-	-	2	7	4.78
11	Notification: more accurate information to physician/pharmacist	-	-	-	1	8	4.89
12	Feedback: provides accurate information about drug interaction	-	-	-	3	6	4.67

Q #	Simplified Question	Rating					Mean
		1	2	3	4	5	
13	Feedback: provides accurate information about drug allergy	-	-	-	5	4	4.44
14	Enhance knowledge about drug interactions	-	-	1	1	7	4.67
15	Enhance knowledge about drug allergies	-	-	-	2	7	4.78
16	Enabling to: insert adequate information in reporting drug allergy	-	-	-	3	6	4.67
17	Overall, the NFC application would be useful	-	-	-	3	6	4.67

4.9.2 Ease of Use

Table 4-15 presents the results for the Ease of Use section. Similar to the Usefulness section, all of the means were high (between 4 and 5). The participants responded with “Agree” or “Strongly Agree” for all questions except 19, 21 and 22. However, even these had a minimum response of 3. There were no negative evaluations.

Table 4-15. Ease of use for NFC application

Q #	Simplified Question	Rating					Mean
		1	2	3	4	5	
18a	Comfortable: using the smartphone to check for drug interaction	-	-	-	2	7	4.78
18b	Comfortable: using the smartphone to check for drug allergy	-	-	-	1	8	4.89
18c	Comfortable: using the smartphone to reporting drug allergy	-	-	-	2	7	4.78
19a	Few steps required to check for drug interaction	-	-	1	2	6	4.56
19b	Few steps required to check for drug allergy	-	-	1	3	5	4.44
19c	Few steps required to report drug allergy	-	-	1	1	7	4.67
20	Moved to Learnability Section						
21	Consistent steps for checking and updating	-	-	1	3	5	4.44
22	Easy to read/tap tags	-	-	1	4	4	4.33
23	Easy to read the feedback information	-	-	-	1	8	4.89
24	Confident about use	-	-	-	1	8	4.89
25	Moved to Learnability Section						
26	Overall, it was easy to use	-	-	-	1	8	4.89

4.9.3 Learnability

Table 4-16 presents the results for the Learnability section. Note that question 20 was reverse-coded; the wording of the original question was: “I would generally need written instructions or the support of a technical person to use it.” Question 25 also was reverse-coded. The wording of the original item was: “I needed to learn a lot of things before I could use it.”

All questions (except question 20) had means between 4 and 5, and all responses were between 3 (“Neutral”) and 5 (“Strongly Agree”). Participants felt that the NFC application was easy to learn. However, question 20 had a mean in the 2-3 range (“Disagree” to “Neutral”), implying that participants felt that they would need help to learn the application; this would raise the question of how much help and for how long. Given their other responses (e.g., question 25), it seems that participants would need help to get started, but the help would be of minimal duration.

Table 4-16. The learnability of the NFC application

Q #	Simplified Question	Rating					Mean
		1	2	3	4	5	
20	No need for instructions	1	1	2	4	1	2.67
25	No need to learn a lot of things	-	-	1	5	3	4.22
27	Easy to learn	-	-	-	1	8	4.89
28	Fast to learn	-	-	-	1	8	4.89
29	Low memory load	-	-	-	1	8	4.89

4.9.4 Satisfaction

Table 4-17 presents the results for the Satisfaction section. Question 30 was reverse-coded from the original question: “The smartphone application would make me dependent (i.e., too reliant on the application in place of my own knowledge or other checks).” All of the means were high (between 4 and 5), except for question 30. Question 30 had a minimum score of (2/5). In the interview P1 referred to her answer in the questionnaire “*I can see becoming very dependent because it’s so user friendly and so easy to use; I could see ... depending on this completely*”. Also, question 32 had a minimum score of (2/5), likely because some participants’ current work does not admit patients (e.g., clinic setting). In the interview we learned from P4 that “*we don’t do a whole lot of different drugs, we just basically have a certain set treatment that people come in and receive. So we’re very simple compared to other clinics, like we don’t have a lot of different drugs*”; thus there is no actual need for the NFC application in that particular place. Note that the NFC application is mainly intended for deployment in hospitals.

Table 4-17. The satisfaction with the NFC application

Q #	Simplified Question	Rating					Mean
		1	2	3	4	5	
30	Not dependent on the application	-	1	4	4	0	3.33
31	Pleasant to use	-	-	-	5	4	4.44
32	Useful in work	-	1	1	2	5	4.22
33	Recommend	-	-	1	2	6	4.56
34a	Satisfaction of the ease to: complete a drug interaction check	-	-	1	1	7	4.67
34b	Satisfaction of the ease to: complete a drug allergy check	-	-	1	1	7	4.67
34c	Satisfaction of the ease to: report a drug allergy	-	-	1	1	7	4.67
35a	Satisfaction of the time to complete a drug interaction check	-	-	1	3	5	4.44
35b	Satisfaction of the time to complete a drug allergy check	-	-	1	3	5	4.44
35c	Satisfaction of the time to complete reporting drug allergy	-	-	1	3	5	4.44
36a	Satisfaction of the feedback about drug interaction	-	-	-	4	5	4.56
36b	Satisfaction of the feedback about drug allergy	-	-	-	4	5	4.56
36c	Satisfaction of the information required to report allergy	-	-	-	4	5	4.56
37	Overall satisfaction	-	-	-	3	6	4.65

For each section we computed the mean of the means and determined the percentage value of that mean. The following graph shows the overall percentage of each section (Figure 4-4). It shows that participants found the NFC application 94.2% useful, 93.7% easy to use, 86.2% easy to learn, and 88.9% satisfactory. Even though the time decrease in the tasks showed that the application was easy to learn, the responses on the questionnaire showed that Learnability had the lowest percentages. This is probably because some participants felt they would need some help to get started with the application.

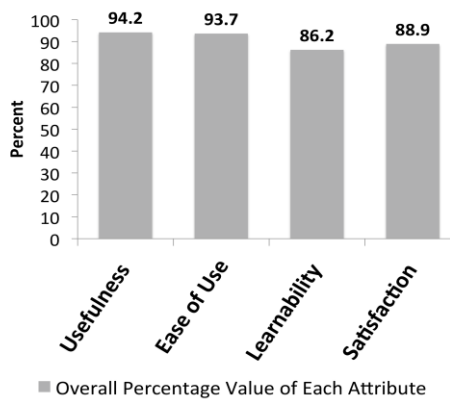


Figure 4-4. The overall mean percentage value for usefulness, ease of use, learnability, and satisfaction based on the participants' response to the questionnaire [101].

4.9.5 Relationship Between Performance and Rating

To gain a better idea of the reasons for the participants' responses (measured as their 'feelings') about the NFC application, the responses to the questionnaire were compared to the performance on the tasks through the use of correlation. In particular, responses were compared to performance on Time and Attempts of Task 5 (the last use of the NFC to check an allergy) and Time of Task 4. The correlations between the variables (time and attempts) and each response to the Usefulness, Ease of Use, Learnability and Satisfaction section are presented in Appendix 4.G.

Since correlation is bounded by -1 and +1, correlation near -1 (negative values) implies that those participants with a lower performance when using the NFC application had a lower opinion of the NFC, and vice versa. While there was no significant positive correlation, there are few significant negative correlations. We found that more negative evaluations in all sections seem to be driven by the Update Task (Task 4) and not by the Checking Task (Task 5). This is probably because the Update Task has more steps. Also, from our observations during Task 4, some participants encountered difficulties with the android smartphone keyboard. When they typed in the description of the allergy, they did not know how to make the keyboard disappear and get back to the screen. It required them to click on the built-in back button in order to get back to the screen. This problem is related to the way that android keyboards are built.

4.10 Interview

In the interview, data about the application's strengths and weaknesses were collected, along with suggestions for enhancements. The interview was transcribed and the participants' answers categorized into different categories.

4.10.1 Accepting The Idea of Using The NFC Application During Medication Administration

The first question in the interview [Appendix 4.F] helped gauge whether the participants accepted the idea of using the NFC application during the medication administration. We found that all nine participants (100%) liked the application for various reasons, most of which are discussed in the next section on strengths.

4.10.2 Strengths

The participants noted nine main strengths in the interview. These strengths have been categorized according to their frequency.

Ease of Use

Ease of use is the first strength point we found in the application according to the participants' answers. All nine of the participants (100%) admired the simplicity of using the application and found it user-friendly and very easy to use. One participant explained that checking the interaction using the NFC application is easier than the software that she currently uses: *"You have to actually go in, list the med, click on the med, and it takes you and shows you what your listing is, so it is easier to do just scanning"* [P2]. Another participant with barcode system experience found the NFC application is easy to use, and stated that a transition from barcodes to NFC would be very easy. Even though the participant has no experience with NFC technology, none of the participants found the NFC application complicated or difficult to deal with.

Quickness

Quickness is the second strength point that all nine participants (100%) agreed on. Six of the nine (67%) participants found that the NFC application provided them with instant feedback about a drug allergy/interaction case. They liked how quickly they could check for drug interaction/allergy and receive an immediate feedback. One participant remarked: *"A really great feature is the interactions ... because if someone is on a lot medication, it's nice to have that information under your fingertips"* [P8]. The participants also admired the immediate feedback because they need the right information right away when they are busy. In addition, one of the nine participants (11%) found that updating a patient's allergies through the NFC application at the bedside was faster than going back to the patient's chart.

Furthermore, all nine participants (100%) liked how fast it was for them to notify the healthcare providers in case of potential drug allergy/interaction. They liked the instant notification (alert) because it was faster than the current process they use to notify the healthcare providers. In their current practice they essentially have to chase down every healthcare provider to make sure they know. For example, one of the participants who admired the notification's quickness stated: *"I love that how quick it is, because if I have*

to call the pharmacist, the physician, my nurse manager ... if I have to call all those people to tell them about it, and also do a written report, it's going to take me forever to do that, so I'll still have to do my charting" [P7]. In addition, participants thought that notifying the treatment instantly would result in dealing with the allergy/interaction potential case very quickly.

Timesaving

Timesaving is the third strength point associated with the quickness of the NFC application. Six of the nine participants (67%) felt that using the NFC application would decrease the time spent on checking drug allergy/interactions. They found the time that it takes to use it was very short, and they thought it would cut down on time spent looking into patient charts or electronic records to check for allergies or interactions. In addition, they suggested that the time saved could be used for other important tasks, as P8 stated: *"I think that it saves time, and that time could be used at better places with the patient rather than running around trying to find information."*

Moreover, participants found that the instant notification to healthcare providers would also save a lot of their time because it allowed them to skip the step of calling each healthcare provider individually. P7 stated: *"The application cuts down a lot of time of me calling people, paging people, waiting for them to call back, to find out what they want me to do. This way, they're notified instantly, and if they have a concern, they have to get back to me. Or if I'm concerned, of course, I'd carry on further."*

Effortless

Effortless is the fourth strength point that five of the nine participants (56 %) found in the NFC application. The application checks for drug allergies and interactions immediately after scanning the patient's and medications' tags, and provides the nurse with the checking results immediately. Therefore, the participants found that the NFC application was effortless and would reduce their tasks of searching the patient's chart or electronic record in order to check for allergies. It would also reduce the tasks of searching certain software to check for interactions. P3 stated: *"It can actually pick up things that normally right now we need to dig out and look around for in a med room that's not at the patient's bedside."* In addition, participants found that notifying the treatment team instantly would decrease the effort of trying to reach out to every healthcare provider. P8 stated: *"I also like how it*

notifies everybody, like right away, so you don't have to worry about chasing people or calling people making sure everyone knows."

Sufficient information.

Sufficient information is the fifth strength point that seven of the nine participants (77%) found in the NFC application. The application provides specific information (feedback) about the case detected. The nurses found the information sufficient, but not so detailed or wordy that they got confused.

Beneficial

Beneficial is the seventh strength point that three of the nine participants (33%) found. Participants found that the application benefitted the nurses by streamlining the process of drug allergy/interaction checking. At the same time, it would benefit patients by increasing their safety.

Acceptable Size and Portability.

Acceptable size and portability is yet another strength that participants pointed to. All nine participants (100%) found the size and portability of the smartphone acceptable. They thought it would be easy and convenient to carry in their uniform (i.e., scrubs or pants pockets) from room to room. Even though the smartphone has a small screen, five participants (56%) stated that it was easy to read the information through the screen and they had no complaints about its size.

4.10.3 Weaknesses

The weaknesses that the participants discovered in the application are not all directly related to its usability. Rather, they are mostly implementation concerns that are related to what would possibly happen if the NFC application were applied in hospitals. The concerns are listed under four categories: patient safety related concerns; treatment team notification concerns; unavailability of accurate information; and technical difficulties.

Patient Safety Related Concerns

The participants were concerned about the transmission of infection, smartphone cleaning, and the NFC bracelet material allergy. First and foremost, transmission of infection is a serious issue that affects patient safety. Two of the nine participants (22%) were concerned about infection control. They felt that going from patient to patient scanning their armbands may cause transition of bacteria or viruses, especially if they for patients in isolation. P7

stated: *“The only thing I would have a problem with it being on a smartphone is, when people [are] on contact precautions and if you take it into the room to scan their ID, then you’re risking exposing the hard surfaces, say, if they are on MRSA precautions, it can get on the phone.”*. Second, cleaning the device was also considered an issue. Nurses were concerned about how to clean the smartphone to make sure that it is disinfected. P7 suggested having a protective cover for the phone that can be cleaned and disinfected. Third, the NFC bracelet we used in my study is made of latex (i.e., a type of rubber). One participant indicated that some patients might be allergic to the latex material.

Treatment Team Notification Concerns

There are four concerns about alerting the treatment team: confirmation of sending the alert, confirmation of receiving the alert, treatment team response process, and alert fatigue. Two of the nine participants (22%) found that although the application notifies the treatment team instantly, it does not indicate whether the alert notification was sent to the treatment team or not. P8 stated: *“It would be nice if it says it was sent out, just so we knew that it would have been gone out, just in case there was ever any issues with that.”* In addition, two of the participants (22%) found that the application did not tell them if the treatment team actually received the notification (i.e., opened it or read it). The participants thought that just being sure the alert was sent was not enough; there should be some type of feedback that clearly indicates whether or not the treatment team has received the alert. The participants suggested adding a notification for the nurse that confirms sending and reading the alert message. Similarly, three of the nine participants (33%) were concerned about the treatment team response process (i.e., replying back to the nurse). The application does not provide a feature that would tell the nurse when or how the physician and pharmacist would reply to the nurse after receiving an alert. In addition, one participant pointed to the possibility of causing an alert fatigue problem if many alerts were sent to the healthcare providers.

Inaccurate Source of Information

This is an important concern that two of the nine participants (22%) pointed at. The application basically retrieves the information from the hospital database and displays it to the nurse in a certain way. Thus, the participants were concerned that the information in the hospital database may not be accurate, due to human error. P1 stated: *“I guess my only*

concern would be [that] the information is not up-to-date or accurate.” In addition, dependency is a serious problem that P1 was worried about, especially if the hospital source of the information was not accurate. P1 stated: *“If the information is not recorded in the database, that would be a fear, and I can see becoming very dependent because it’s so user friendly and so easy to use; I could see ... depending on this completely”*.

Technical Problems

Weak wireless signal is a problem that one participant experienced while performing the tasks. We also found it to be one of the application’s problems. Since the application requires wireless connection to retrieve information from the database, weak signals can cause failure or delay in receiving the information. In addition, other participants were also concerned about the connectivity between the database and the application in case of a power outage.

4.10.4 Application Interface

The nurses were provided with a hard copy of each interface in the application and design and were asked to modify (e.g., add or remove) anything that they thought might be hindering the interface. Generally, all nine participants (100%) liked the basic look of the application. They emphasized keeping the design of the interfaces simple, with fewer colors, screens, and information. In addition, they recommended the following changes:

- Background and text colors: All nine participants liked how the interface doesn’t have many colors and they emphasized that it should remain with minimum colors. However, five of the participants (56%) suggested making the “alert” in interfaces 3 and 4 in a bold red color to draw their attention.
- Content order: P4 suggested putting “scanned drug” before the “drug listed in patient’s history”.
- Adding content: P3 suggested adding the patient’s name and ID at the top of interfaces 3 and 4 in order to have a triple identifier.

4.11 Discussion

The study findings show that the participants accepted the idea of the NFC-smartphone application at the bedside to verify the medication. They would be willing to use it at their work and they think it would be useful in the nursing practice. Furthermore, they felt that

the application would streamline the process of checking drug allergy/interaction for them by providing instant feedback and instant notification to the treatment team. They also thought it would reduce the number of steps they are using in their current process to check interaction/allergy and to inform the treatment team. As well, they believed it would reduce the known allergy and interaction errors and thereby increase patient safety. Overall, we found that usefulness was the main strength point in the NFC application, which implies that if we expanded the application to verify the five rights and contraindication along with documentation, it would be also useful.

Moreover, the findings in the tasks, questionnaire, and interview emphasized the effectiveness, ease of use, and simplicity of the NFC application. Even though the participants had no experience with NFC technology, no single participant found the NFC application complicated or difficult to deal with. In contrast, they found it very basic and user-friendly: tapping on the tags was fairly simple; and reading the feedback was easy, even though the screen was considered small. In addition to the user-friendliness of the application, the participants thought it would make the process of checking drug interactions/allergies and informing treatment team significantly easier than their current process. Overall, we found that the ease of use and the few simple steps required to accomplish checking the task are notable strength points in the NFC application.

Additionally, the findings of the study indicate that the application is very efficient. The participants found the NFC application has the ability to quickly check for allergies/interactions, provide them with timely and sufficient feedback, and send an instant notification to the healthcare providers. As well, based on the background questionnaire, post-task questionnaire and the interview, we expect that the NFC application would allow the participants to accomplish the checking allergy/interactions task much faster than their current practices. The quickness of the application would result in reducing the amount of valuable time spent on checking for allergies and interactions. This is time that the participants thought they could use for other important purposes that would benefit the patients. Overall, quickness and timesaving were shown to be two major strength points in the NFC application.

Furthermore, the study findings show that the NFC application was easy to learn. The participants' performance (in terms of time and tag-reading attempts) had gradually

improved from Task 1 to Task 5 (excluding Task 4), which implies that the NFC application was quick and easy to learn. Even though the participants emphasized the learnability of the NFC application in the questionnaire, it seems that they would need little instruction to get started with the application.

Finally, the findings show that the participants were satisfied with the NFC application overall. They generally found it user-friendly and pleasant to use. They were also satisfied with size and portability of the smartphone and found the feedback about potential cases of allergies/interactions to be very specific and sufficient. This means that portability and ample feedback information are two other strength points in the application.

Along with the positive findings related to the usability of the NFC application, there are also some important barriers (weaknesses) that must be considered. Infection transmission through the smartphone is a serious problem that would affect patient safety. Previous work has pointed to this issue with the use of mobile devices [14][102][103]. A suggested solution to overcome this problem is to have a protective cover that prevents the smartphone surface from directly touching the tags, and allows it to be disinfected [14]. In addition, patients may be allergic to some material that the NFC bracelet is made of (e.g., rubber). This can be solved by making the bracelets of specific material that will not harm the patient.

Another barrier to the use of the NFC application is that it does not show the nurse whether or not the healthcare providers have received the notification alert. Also, the application does not support replies to the notification, so the nurses do not know what will happen next or how the physician will reply to them. Finally, like any other wireless applications, wireless signals need to be strong in order for the application to work properly. Weak signals can cause failure or delay in the application, and power outages may affect the connectivity between the NFC application and the hospital database.

4.12 Design Guidelines

Based on the study findings we derived set of guidelines to use in designing and implementing the NFC-MACC System.

- Design a real-time two-way communication feature that allows for the following:
 - Provide the nurse with a control to choose what alert should be sent (avoid alert fatigue)

- Provide a confirmation sending and reading notification/alert to healthcare providers.
- Provide a reply function
- Design main interface that displays patient information before verifying the medication.
- Design a simple interface with fewer colors and display the alert message (in case of mismatch) in red bold color to attract the nurse's attention.

Study Limitation

The findings from the preliminary study provided us with sufficient information to generate some conclusions that serves the purpose of this phase, however, it is important to note the limitation of this phase. First, the application's usability was tested in a lab setting (meeting room), the findings may not be the same if the application was tested in a real clinical setting. Thus, the result cannot be generalizable to clinical setting. Second, due to the small sample size the result cannot be representative to the nurses' population, and it only represents the participants of this study. In addition, the duration of the study was short, which may have limited the participants' ability to discover other weaknesses that might be discovered if the study duration was longer.

4.12.1 Conclusion

The study findings showed a positive usability feedback and an acceptance of the NFC technology to be used during the BMA to verify allergy and drug interactions. In addition, recommendation for improvements was gathered at this phase to be used as design guidelines in Phase 3. The initial results in this study inspired us to proceed and create a comprehensive system that covers all the medication verifications that nurses need during medication administration.

Chapter 5. Phase 2: Understanding the Bedside Medication Administration and Clinical Communication Procedure

This chapter discusses the details of the second phase of this research, which is a qualitative study to better understand the bedside medication administration and clinical communication procedure. We considered a theoretical aspect (NSHA Policy) and practical aspect (semi-structured interview with nurses) to form a comprehensive picture about the BMA procedure. The results helped us to determine the required data and sources for BMA and define the functional requirements of the NFC-MACC system.

5.1 Study Purpose and Objectives

Before we can design the prototype NFC-MACC system, we must first define (outline) its functional requirements. The functional requirements refer to what the system should do. For example, what data should be input and output, and which processing (what must be done in order to transform inputs into outputs) must be done by the system to (1) verify the medication, (2) document the medication, and (3) notify healthcare providers. Defining the functional requirements can be derived from understanding the BMA procedure. Therefore, the purpose of this phase is to build an understanding of the bedside medication administration procedure in nursing practice from the *NSHA Policy and Procedure* (theoretical source of information) and nurses' knowledge and experience (practical source of information).

5.2 Study Objectives

- Determine the required data and sources used in nursing practice to verify the five rights of medication administration, allergy, drug interactions, and contraindication.
- Determine the required data and sources used in nursing practice to document the administered medication.
- Define the type of information used to communicate with healthcare providers.
- Define the essential functional requirements for medication verification, documentation, and communication.

5.3 Study Method

This study was conducted using a qualitative method. The data was collected using one-on-one semi-structured interview with local nurses in Nova Scotia. We analyzed the interview using a qualitative description approach. Microsoft Excel and NVivo were used as tools for analyzing and coding the collected data. An approval from the Dalhousie University Ethics Board was acquired before starting the study (Appendix 5.A).

5.3.1 Sample Size and Eligibility

Initially, a purposeful sampling was used in this study. The sample size that we had planned for the study was 15 participants and the expected duration was three months. Since there is no definitive size of samples when conducting a qualitative interview, we decided to start with 15 participants until we could clearly define functional requirements and specifications to build our system. In addition, we were targeting actual end users for the system who are the experts in the domain of the medication administration process; therefore, we believed that this number is sufficient to obtain valid and reliable data required to define the system specifications. Eligible participants included graduate students from the School of Nursing at Dalhousie University who hold a current nursing practice or have practised in the last two years. The study invitation was sent to the graduate students at the School of Nursing by email.

5.3.2 Recruitment and Study Duration

The recruitment process was initiated following the Dalhousie University Ethics Board approval from November 2016 to January 2017 (3 months duration). However, it was challenging to reach the targeted number of subjects. Therefore, we extended the time for data collection from three months to six months (until April 2017), and we were able to extend the recruitment to nurses who work at the IWK Health Center and hold current nursing practice or have practised in the last five years. The study invitation at the IWK was restricted to posters only. By the end of April, we were able to recruit 14 local nurses.

5.4 Data Collection

To understand the process of BMA, we considered the theoretical aspects and practical aspects of BMA. First, we used the Nova Scotia Health Authority (NSHA) Policy and Procedure in Medication Administration as a theoretical source and foundation to establish

the essential functional requirements [104]. The policy explains *what* the nurses should do during the BMA; however, it does not explain *how* the nurses should do it. For example, the policy instructs the nurses to adhere to the five rights of medication administration with no further explanation on how they should do that. Therefore, we conducted one-on-one semi-structured interviews with nurses to better understand the actual practice of BMA. We designed a set of interview questions based on the main tasks of BMA in nursing practice, which we obtained from the NSHA Policy (Appendix 5.B). The questions focused on the practical experience and the required data and sources used to verify the medication, document the medication, and contact healthcare providers when consultation is needed. The interviews were conducted at an office at Dalhousie University, took approximately 30-45 minutes each, and were audio recorded and transcribed for coding. The School of Nursing and the IWK requested us to positions or institution affiliation (hospital names) will be reported in the results. As a condition by the School of Nursing and the IWK Health Centre, the positions/institution of affiliation (hospital names) were asked to be left out of the results for the study.

5.5 Participants' Demography

We recruited 14 nurses (mean age of 30.7 years, 13 females and 1 male), all of whom work at local hospitals in Halifax, Nova Scotia, Canada; have experience in bedside medication administration (mean experience of 5.3 years); and administer up to 35 medications per shift (Table 5-1).

Table 5-1. Nursing participant characteristics (N=14)

Characteristics	Percentage	Mean
Sex		
<ul style="list-style-type: none"> • Male • Female 	7% (1/14) 93% (13/14)	-
Age:		
<ul style="list-style-type: none"> • 20-29 • 30-39 • 40-49 • 50-59 • 60-69 	71% (10/14) 14.3% (2/14) 7.1% (1/14) - 7.1% (1/14)	30.7 years
Nursing Experience:		
<ul style="list-style-type: none"> • 2 years or less • 3-4 years • 5-6 years • 7-8 years 	28.6% (4/14) 28.6% (4/14) 21.4% (3/14) 7.1% (1/14)	5.3 years

Characteristics	Percentage	Mean
<ul style="list-style-type: none"> • 9-10 years • 10+ years 	- 14.3% (2/14)	
Average number of medications administered to patients per shift:		
<ul style="list-style-type: none"> • 11-15 med • 16-20 med • 21-25 med • 30+ med 	21.4% (3/14) 42.9% (6/14) 14.3% (2/14) 21.4% (3/14)	21.9 med

5.6 Findings and Data Analysis

We analyzed the output of the interviews using a qualitative description approach. We chose the qualitative description approach because it provides straight description and a comprehensive summary of an experience or an event rather than employing concepts or theories, as other qualitative approaches do [96]. The qualitative description approach fits with our study because our goal is to understand the procedure of medication administration and clinical communication. Hence, we determine the required data and sources, and define the functional requirements based on our understanding.

We coded the interview scripts and generated four main categories based on the interview questions. The categories are:

1. Confirmation of the *five rights* of medication administration.
2. Verification of allergies, drug interactions, and contraindications.
3. Documentation.
4. Clinical communication with healthcare providers.

5.6.1 Confirmation of the “Five Rights” of Medication Administration

The NSHA Policy states that nurses should to adhere to the *five rights* of medication administration; however, it does not provide details on how they should do this. Therefore, we asked the nurses how they verify each right, and accordingly, we generated five subcategories. We associated the NSHA Policy of confirming the five rights with the answers obtained from the interview (Figure 5-1). The following subsections discusses the five subcategories and the methods used to verify each right.

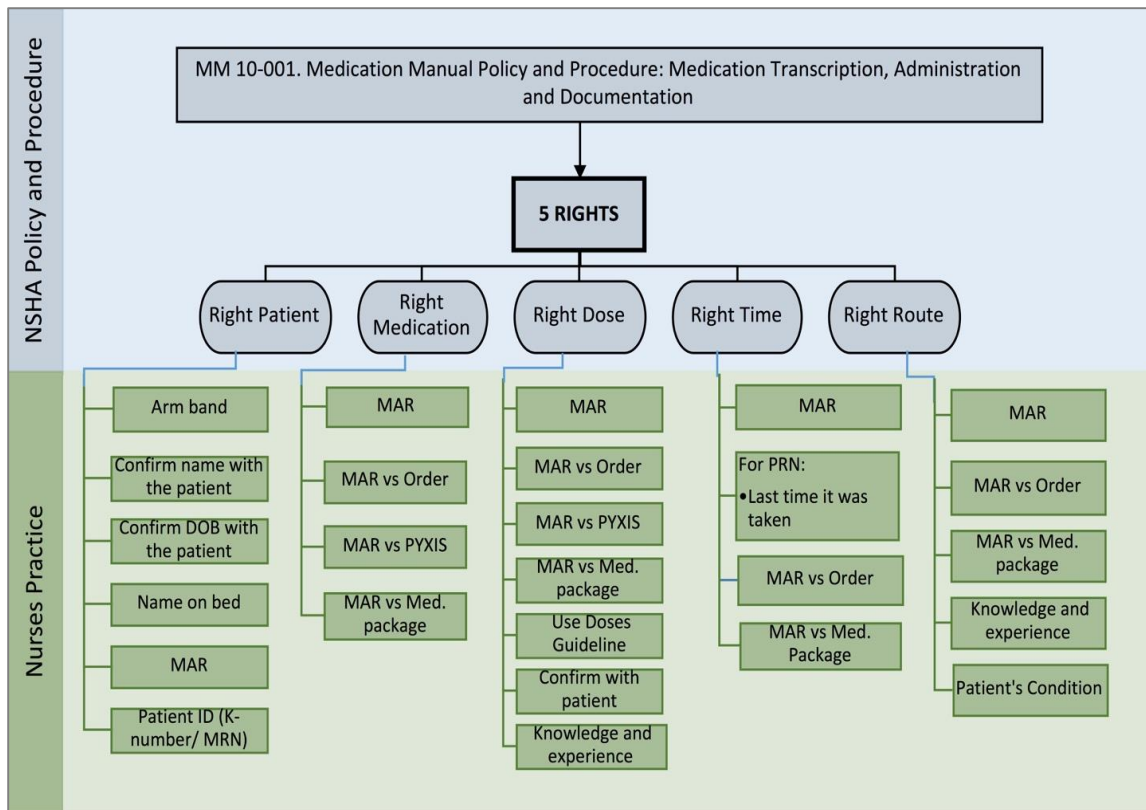


Figure 5-1. The NSHA policy and nurses’ actual practice of confirming the five rights of medication administration.

5.6.2 Confirming the Right Patient

The interviewed nurses mentioned that they follow one or more of six different methods used to confirm the right patients during the medication administration phase. These methods have been coded according to their frequency (Table 5-2). The most common method used to confirm whether the medication is delivered to the *right patient* is checking their armband. Some nurses stated that they only use the armband to identify the patients if they meet their patients for the first time.

P3 stated:

“I won’t necessarily keep checking her armband because I’ve met her this morning I know who she is now... I know that she is the right person, and like realistically, it would probably be good to have something that prompt[s] you to check every time”

The second common method used by 86% (12/14) nurses is checking the patient’s name on his/her MAR. In addition, some nurses stated that if the patient’s condition or population allows, they ask them to verbally confirm their name and date of birth. The patient’s medical record number (MRN) is also used by 43% (6/14) of the surveyed nurses to confirm the patient’s identity, especially for infants or if there are two patients with similar names in the unit.

Table 5-2. Methods used to confirm the right patient

Method Used	(n=14)
Check arm band	14 (100%)
Check name on MAR	12 (86%)
Confirm name with the patient	9 (64%)
Confirm date of birth with the patient	7 (50%)
Check patient MRN (K-number)	6 (43%)
Check name on bed	3 (21%)

5.6.3 Confirming the Right Medication

When nurses asked how to confirm the *right medication*, all of them stated that they check the medication name on the patient’s MAR and manually compare it with the medication package label (Table 5-3). Some nurses (64%: 9/14) stated that they perform additional comparison between the MAR and doctor’s order. Moreover, a total of 43% (6/14) nurses compare the medication name on the MAR with the medication name on Pyxis, an automated medication dispensing machine that displays the patient’s list of medications, their doses, and last time for dispensing (Appendix 5.C). One of the nurses reported finding it challenging to confirm the *right medication* if the medication name on the MAR is different than the name on the package or Pyxis (generic name vs. brand name).

P12 stated:

“I find it challenging that they don’t have all the medication names listed... this is a simple example, you’ll have Acetaminophen written on the MAR and the medication says Tylenol from the Pyxis. So, you have to figure out that Tylenol is Acetaminophen.”

Table 5-3. Methods used to confirm the right medication

Method Used	(n=14)
Check medication on MAR	14 (100%)
Check medication package	14 (100%)
Check doctor's order	9 (64%)
Check Pyxis	6 (43%)

5.6.4 Confirming the Right Dose

The main method used to confirm the *right dose* is referring to the dosage on the patient's MAR (Table 5-4). In addition, a total of 71% (10/14) of nurses stated that they compare the dose on the medication package with the MAR, and 57% (8/14) compare the dosage on the doctor's order with the MAR. Few nurses (14%: 2/14) stated that they use paper-based dosing guideline, rely on their knowledge and experience, or confirm the dose with the patient.

Table 5-4. Methods used to confirm the right dose

Method Used	(n=14)
Check dose on MAR	14 (100%)
Check medication package	10 (71%)
Check doctor's order	8 (57%)
Check Pyxis	4 (29%)
Check doses guideline	2 (14%)
Confirm dose with the patient	2 (14%)
Knowledge and experience	2 (14%)

5.6.5 Confirming the Right Time

When nurses were asked how to confirm the "right time", all of them stated that they check the time and frequency the patient's MAR in addition to three other methods (Table 5-5). More than half (57%: 8/14) of nurses stated that they compare the time on the MAR with the time on the medication's package. Few nurses compare the time on the MAR with the time on the doctor's order.

Table 5-5. Methods used to confirm the right time

Method Used	(n=14)
Check time on MAR	14 (100%)
Check time on medication package	8 (57%)
Check doctor's order	3 (21%)
Check last time was taken (PRN)	3 (21%)

5.6.6 Confirming the Right Route

Similar to the previous confirmations, all nurses use the MAR to confirm the *right route*, and the majority (71%: 10/14) compare it with the doctor's order (Table 5-6). In addition, 43% (6/14) of nurses stated that they check the patient's condition and make a clinical judgment of whether or not the route is suitable. Around third of the nurses stated that they rely on their knowledge and experience with the medication to confirm the *right route*.

Table 5-6. Methods used to confirm the right route

Method Used	(n=14)
Check route on MAR	14 (100%)
Check doctor's order	10 (71%)
Check medication package	9 (64%)
Check patient condition	6 (43%)
Knowledge and experience	5 (36%)

5.7 Verification of Allergies, Drug Interactions, and Contraindications

The NSHA Policy stated that nurses should assess the patient's condition and medication use to ensure that the medication is still appropriate to be administered. The information about the patients include health and physical assessment (e.g. conditions, vital signs, lab results, and allergies). The information about the medication use includes contraindication, drug interactions, possible risks, and adverse effects. While the patients' health and physical information is available on their medical records, it is not clear in the policy how nurses verify the appropriateness of medication. Therefore, we asked the nurses how they verify allergies, drug interactions, and contraindications; accordingly, we generated three subcategories. We associated the NSHA Policy of appropriateness of medication assessment with the answers obtained from the interview (Figure 5-2).

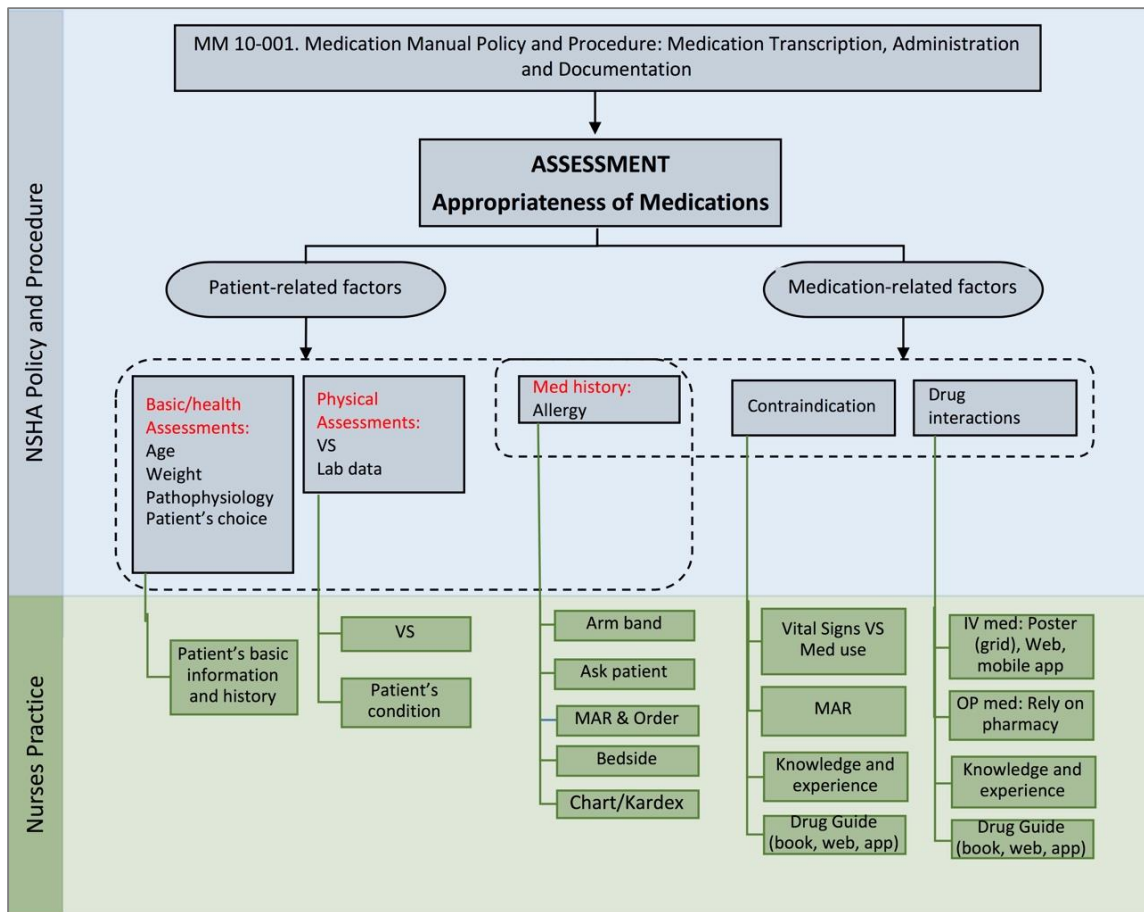


Figure 5-2. The NSHA policy and nurses actual practice of assessing the appropriateness of medication

5.7.1 Verifying Allergies

All nurses indicated that they verify allergy information by checking the patients' allergy armband (Table 5-7). The significant majority (86%: 12/14) of nurses also check the allergies listed on the patients' MAR. Few nurses (21%: 3/14) said that they check allergy labels on the bed if available. One problem mentioned about the current methods of verifying allergy information is that nurses become desensitized to allergy labels due to their frequent exposure to them.

P5 stated:

“You get desensitized to all these alerts all the time, you may not notice it”

In addition, some nurses (36%: 5/14) said that they ask the patient whether they have an allergy to the administered medication.

Table 5-7. Methods used to verify allergy

Method Used	(n=14)
Check allergy armband	14 (100%)
Check MAR	12 (86%)
Verify with patient	5 (36%)
Check patient's chart (history)	5 (36%)
Check doctor's order	4 (29%)
Check allergy label on bed	3 (21%)

5.7.2 Verifying Drug Interactions

When nurses were asked how to verify drug interactions, the majority (64%: 9/14) stated that they rely on the pharmacy for oral medications due to their limited pharmacological knowledge and time constraints (Table 5-8). Some nurses (29%: 4/14) rely on the physician's or pharmacist's instructions regarding interactions on patients' MAR.

P2 stated:

“In terms of PO med interactions, we don't actually check that often, if there is an interaction, PO wise that's primarily caught by pharmacy... we run on big trust that has been assessed, but we don't routinely check for PO med interactions at all. Which is kind of a shame, we should. There's no time. “

P6 also stated:

“I personally as a nurse I am terribly knowledgeable about drug interactions, I do rely upon for that physician and pharmacy”

In addition, a slight majority of the surveyed nurses (57%: 8/14) explained that they rely on their knowledge and experience with medication use to verify interactions, and if they are not familiar with the medication, they would look for its interaction information. Nurses explained that they use different resources to verify interactions including drug interactions poster (grid) for IV medications, websites, drug guide books, and phone applications (71%,

36%, 29%, and 14% of 14 nurses, respectively). However, they stated that looking for interaction information is time consuming.

P12 said:

“The interaction - I don’t really feel comfortable because I’m relying on my own knowledge, and if it’s a medication I haven’t seen for a long time, it is that extra time piece to look it up and we don’t always have the time.”

In addition, nurses explained that due to the long time required to look up medication information, they use online sources (websites) to gain faster access to the information. However, trusting the information from an online source can be challenging.

P3 said:

“If I only need to know a little bit about a med ... I’ll Google it, which is not good, because I feel, who knows what comes out from Google.”

Table 5-8. Methods used to confirm the verify drug interactions

Method Used	(n=14)
Rely on pharmacy (PO med)	9 (64%)
Knowledge and experience	8 (57%)
Check instructions on MAR	4 (29%)
Checking drug guide/medication use:	
Check interactions poster (IV med)	10 (71%)
Online search (web)	5 (36%)
Check drug guide book	4 (29%)
Use phone applications	2 (14%)

5.7.3 Verifying Contraindication

All nurses interviewed review their patient’s condition and vital signs to verify contraindication (Table 5-9). A total of 43% (6/14) nurses mentioned that they check the physicians’ contraindications instructions on the MAR if available. In addition, some nurses (63%: 5/14) with more experience and familiarity with medications stated that they rely on their knowledge to verify contraindication and make a personal judgment.

P2 stated:

“If I’ve got a patient that’s got their blood already way too thin, their INR should be around one and a half, is at ten, then the contraindication is no Warfarin. That comes easier with practice and with understanding.”

Similar to verifying drug interactions, nurses stated that they use different sources to compare medication use with patients’ condition; these resources include websites, drug guide books, and phone applications (36%, 14%, and 14% of 14 nurses, respectively). Although verifying contraindication is one of the core nursing responsibilities, nurses find it challenging to verify every single medication due to their limited time and pharmacology knowledge. In addition, verifying contraindication requires numerous steps and is thus a relatively long process to reach a proper clinical judgment.

P1 stated:

“We don’t have time to sit down and look up contraindications for all the medications; that will take way too long.”

P10 also said:

“I don’t have like every contraindication kind of like memorized ... So, unless I’m being prompted about it I don’t think I would think of it.”

Table 5-9. Methods used to confirm the verify contraindications

Method Used	(n=14)
Check patient condition and vital signs	14 (100%)
Check instructions on MAR	6 (43%)
Knowledge and experience	5 (63%)
Check lab results	1 (7%)
Checking drug guide/medication use:	
Online search (web)	5 (36%)
Check drug guide book	2 (14%)
Use phone applications	2 (14%)

5.8 Documentation

The NSHA Policy states that nurses should document whether the medication was delivered to patients or not by initialing their name under the appropriate time on the

patient’s MAR. When nurses were asked during the interview how they document the administered medication, their answers were very similar to the policy instructions. The only difference is that the policy instructs the nurses to use standard abbreviations if medication was not delivered. However, the nurses explained that they strikethrough or highlight medication on the MAR in the case of medication not being received (Figure 5-3). One problem with the paper-based documentation mentioned in the interview was the possibility of forgetting to sign the MAR.

P12 stated:

“Because of our busy days it would be easy for us to give the med and forget to sign it.”

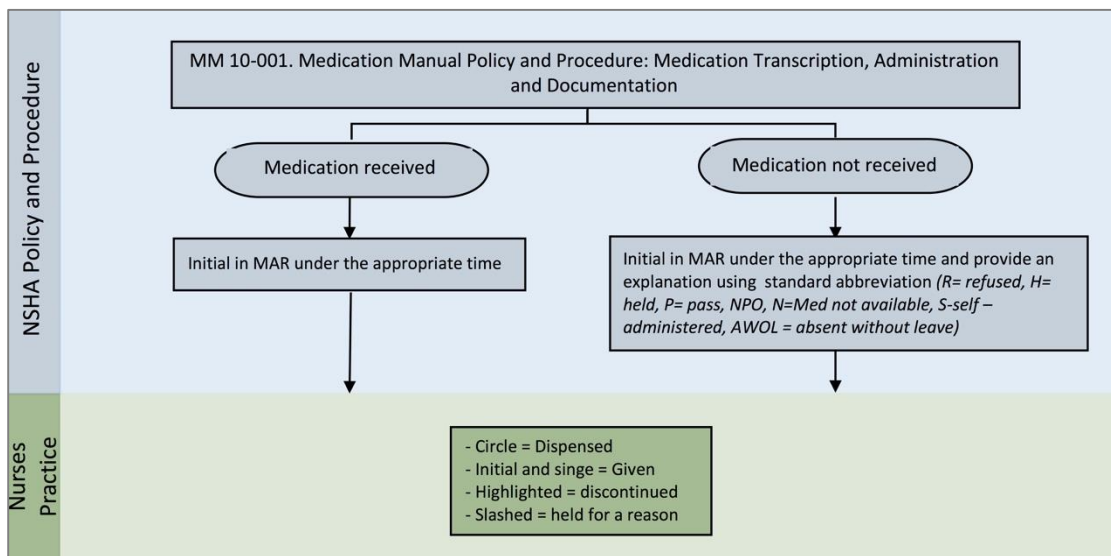


Figure 5-3. The NSHA policy and nurses’ actual practice of documenting medication administration

5.9 Clinical Communication with Healthcare Providers

The NSHA Policy states that nurses should consult with healthcare providers when further information regarding the medication administration is required. The policy provides an example that nurses may contact pharmacists or physicians regarding the appropriateness of medication. However, it is not clear how nurses should contact healthcare providers (method of communication) and what type of information should be communicated. Therefore, we asked the nurses who they contact during the medication administration process, for what reason, what are the methods used to contact them, and what is the content

of the communication. Accordingly, we generated two subcategories. We linked the NSHA Policy of contacting healthcare providers during medication administration with the answers obtained from the interview (Figure 5-4).

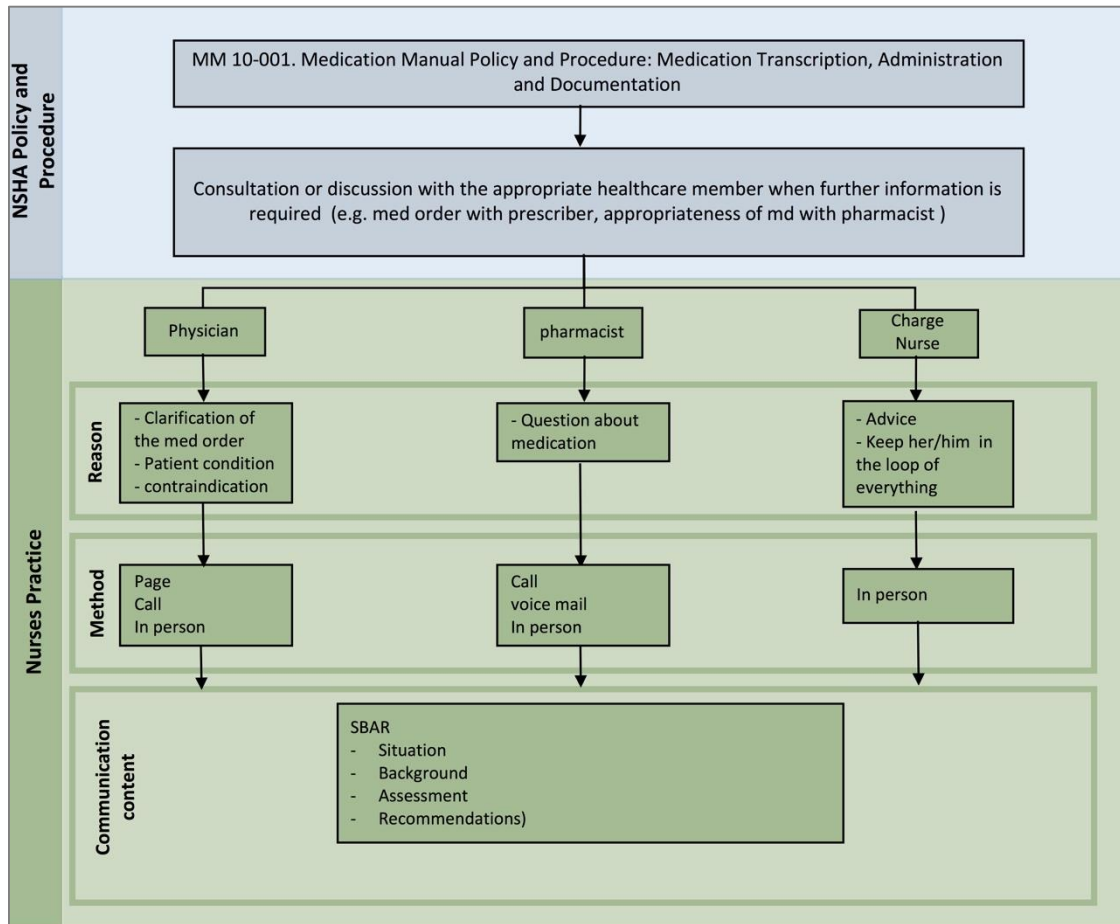


Figure 5-4. The NSHA policy and nurses' actual practice of contacting a healthcare provider.

5.9.1 Methods and Reasons for Contacting Healthcare Providers during Medication Administration

We found that all nurses contact healthcare providers including physicians, pharmacists, and charge nurses during the medication administration stage when there is a potential for medication error. The primary methods of communication used are paging, calling, and in person. Nurses contact physicians in case of contraindication (14/14), dosing concerns 50% (7/14), and route concerns 21% (3/14).

P3 stated:

“I will be like, you didn’t check off that this patient would have this IV and they’re vomiting... the best route for this patient would be IV.”

In addition, the majority of nurses (92%: 13/14) contact the charge nurse in case of uncritical concerns, and one of the nurses stated that she would contact both the charge nurse and the physician in cases of potential critical medication errors.

P12 stated:

“If it’s something outside of our nursing knowledge and it’s not physician worthy to contact, I would talk to the charge nurse.”

On the other hand, all nurses contact the pharmacist for concerns related to dose, route, time, drug interactions, and compatibility.

P2 said:

“If I had a question about a medication, say I’m not sure if this antibiotic is supposed to be due this or how should I be giving this, if it’s a question about a med, then I call the pharmacist.”

5.9.2 Communication Content

When asked about the type of information provided, all of the nurses (14/14) use the same structure of information to facilitate the communication called SBAR (situation, background, assessment, and recommendation). First, they start by identifying themselves, their role, and their unit. Second, they explain the reason for the call and the situation, i.e., what type of medication error would happen if a certain medication was administered as prescribed. Third, they provide a brief background about the patient identification information and diagnoses. Finally, they provide a personal judgment, request, or recommend an action.

P2 said:

“You just say this is the name, the age, why they’re in the hospital, and a really brief course of what had happened... would you like me to do this or this?”

5.10 Discussion

We believe that the NSHA medication administration policy (theoretical source) and the feedback of the nurses’ actual experience on clinical placement (practical source) provided

us with a complete picture of how our proposed system should be functioning. The interviews helped us to understand how nurses perform the tasks required to administer medication and what are the required data and sources we should consider when designing the NFC-MACC system.

In general, we found that although nurses follow the same policy of BMA, they differ in terms of practical experience (applying the medication administration policy). This difference is affected by a number of factors, such as patient population, background, experience, resources availability, workload, and time constraints. Despite the differences, we noticed that all nurses use the paper-based MAR as the main source of information to verify a medication because it contains all the instructions of the administration: patient's name and demographic information, allergies, medication name, dose, time and frequency, and route. The information on a medication package is also used by the majority of nurses to confirm the right medication, route, and dose. They also use the MAR to document the administered or held medication. Even though the interviewed nurses use a traditional paper-based method for BMA, the automated advance BMA systems use the same source of information to confirm the five rights and allergies. For example, the BCMA system uses an electronic MAR and the medication package (medication info linked to the barcode) to confirm the five rights and allergy information, and to electronically document the administered medication in the E-MAR [12][45]. Therefore, E-MAR and medication package (medication information linked to the NFC tag) will be used as the main sources of information to verify the five rights in our system. We will also consider an electronic signature to the E-MAR when designing the system.

In addition, the nurses use different types of information sources such as websites, mobile apps, and drug guide books to verify drug interactions and contraindications depending on the sources' availability. These sources provide guidelines about medication use and drug interactions. Thus, we will use a drug database that includes drug use and drug interactions information in our system. Nurses also stated that they verify allergy information using the MAR and the patient's chart. In our system, we will consider the patient's EMR, which is equivalent to the paper chart.

Moreover, all nurses use the same structure of information (situation, background, assessment, and recommendation) when they contact healthcare providers. Accordingly,

we will consider the first three elements, *situation*, *background*, and *assessment*, to be generated electronically when designing the communication feature in the system. The *recommendation* is based on the nurses' clinical judgment; therefore, it cannot be electronically generated. Instead, we will provide an option for the *recommendation* to be added as text messages by the nurses.

In addition, the interviews helped us to create scenarios that can be used in the tasks session in the last phase of our study when we conduct a usability testing.

5.11 Defining the Required Data and Functional Guidelines for Medication Verification and Clinical Communication

5.11.1 Essential Data, Sources, and Functional Guidelines for Patient and Medication Verification

We considered the essential data and sources to be used in designing the system. We also considered the NFC ID to be used as the main identifier from the patients and medication. Table 5-10 explains the type of verification, input, output, data required for verification, and sources that will be used in designing our NFC-MACC system.

Table 5-10. Patient and medication verification required data and sources

Verification	Input	Output	Data Required for Verification	Data Source
Right Patient	- Patient Name - Patient NFC ID	- Case 1 (right patient): Scan med screen - Case 2 (wrong patient): Alert	Patient Name Patient NFC ID Patient (MRN)	EMR
Right Medication	- Patient Name - Patient NFC ID - Med NFC ID	- Case 1 (right med.): Doc. screen - Case 2 (wrong med.): Alert	Med NFC ID Med Name	- MAR -Med Package
Right Dose		- Case 1 (right dose): Doc. screen - Case 2 (wrong dose): Alert	Med NFC ID Med Name Med Dose	
Right Route		- Case 1 (right route): Doc. screen - Case 2 (wrong route): Alert	Med NFC ID Med Name Med route	
Right Time		- Case 1 (right time): Doc. screen - Case 2 (wrong time): Alert	Med NFC ID Med Name Med time	MAR
Allergy		- Case 1 (not allergic): Doc. screen - Case 2 (allergic): Alert	Med NFC ID Med Name Allergy list	EMR
Interaction		- Case 1 (no interaction): Doc. screen - Case 2 (interaction): Alert	Med NFC ID Med Name Other prescribed meds' name in patient MAR	- MAR - Drug Interactions DB

Verification	Input	Output	Data Required for Verification	Data Source
Contraindication		<ul style="list-style-type: none"> - Case 1 (no contraindication) : Doc. screen - Case 2 (contraindication): Alert 	<ul style="list-style-type: none"> Med NFC ID Med Name Lab result Vital signs Condition 	<ul style="list-style-type: none"> - MAR - Drug Use DB - EMR

Patient and Medication Verification Functional Requirements:

1. The system should use the patient’s NFC ID to access and fetch his/her information.
2. The system should compare the patient’s NFC ID with his/her corresponding information in the database to confirm if this is the *right patient*.
3. The system should proceed to the screen of verifying the medication and use the medication NFC ID to access and fetch its information.
4. The system should compare the medication’s NFC ID with its corresponding information in the database to confirm if this the the *right medication, dose, time, and route*.
5. The system should compare the medication’s NFC ID with its corresponding information in the database to check whether the patient is allergic to the medication.
6. The system should compare the medication’s NFC ID with its corresponding information in the database to determine whether the medication interacts with other medications in the patient’s database.
7. The system should compare the medication’s NFC ID with its corresponding information in the database to check whether the medication conflicts with the patient’s condition, lab results, or vital signs.

5.11.2 Essential Data, Sources and Functional Requirements for Documentation

We mentioned earlier that nurses use the MAR to sign and document the administered or held medication. Accordingly, we considered the data elements required to electronically document the medication in the E-MAR (Table 5-11).

Table 5-11. Documentation data input, possible values and source for posting the documentation

Input	Possible values	Output	Posted in
Administration Statuses	Administered, held, refused, and discontinued	Confirmed documentation message and back to main screen	E-MAR
Note	Optional		
Nurse Name	Retrieved electronically from login info		

Documentation Functional Requirements:

1. The system should retrieve the medication information and display it on the screen prior to the documentation for review
2. The system should post the input of the documentation screen into the patient's MAR
3. The system should alert the nurses if the medication was to be given twice (duplicate administration alert)

5.11.3 Essential Data, Sources, and Functional Requirements for Clinical Communication

The notification content will consider the SBAR structure of the information used by all of the interviewed nurses. Therefore, the alert information sent from the server to the nurse will contain the situation (e.g. drug interaction alert), background about the patient, assessment if needed (e.g. vital signs, lab results, or condition in case of contraindication). The R (recommendation) will be left for the nurse's clinical judgment. This will allow the nurses to forward the same alert they received to the healthcare provider and add any further information if needed. Table 5-12 shows the data required for clinical communication and the data sources that will be used to retrieve the information.

Table 5-12. The data required for clinical communication and data sources used to retrieve the information

Data Required for Clinical Communication	Value	Data Source
- Nurses Name and Role	Retrieved electronically from login info	Staff DB
- SBA	Retrieved electronically from the alert information	E-MAR, EMR, Drug DB
- R	Personal clinical judgment	Nurses

Clinical Communication Functional Requirements:

1. The system should forward the alert to the desired healthcare provider and initiate text-based real-time two-way communication
2. The system should notify the healthcare provider with a new alert message
3. The system should display the alert information along with the nurse's information

5.12 Limitations

Although the findings of this study have provided us with sufficient data to start designing the prototype of the NFC-MACC system, it is important to note the limitations of this study. First, due to the conditions laid out by The School of Nursing and the IWK Health Centre, the result does not represent the nursing practice at certain institutions, for specific units, or for particular patient populations. It represents nursing practice that is generally followed for the paper-based method of medication administration. Moreover, the sample size served the purpose of the study; however, it cannot be generalizable to nursing practice. In addition, the findings might be different and more suitable for the use of NFC technology if the local hospitals in Nova Scotia use and advance existing technologies (e.g. E-MAR, EMR, and BCMA).

5.13 Conclusion

This study aimed to understand the BMA procedure in order to determine the required data and sources used in nursing practice to verify the five rights of medication administration, allergy, drug interactions, contraindication, and documentation, and define their essential functional requirements. It also aimed to understand the clinical communication procedure to define the type of information used to communicate with healthcare providers. The obtained result will be utilized in the next chapter when we design the NFC-MACC system.

Chapter 6. Phase 3 (Part 1): Design and Implementation of the NFC-Based Medication Administration and Clinical Communication (NFC-MACC) System

In this chapter, we discuss the design and implementation of a prototype NFC-MACC system. The system was designed based on literature and the findings of our previous studies discussed in Chapters 4 and 5. The selection of the NFC technology was derived from the literature in order to overcome the usability issues of the current automated BMA systems (BCMA and RFID), which was discussed in Chapter 2.

6.1 System Design

6.1.1 Conceptual Design of NFC-MACC System

The system is designed to streamline the process of BMA, enhance communication between healthcare professionals, enhance patient safety, and reduce medication errors. It uses the NFC technology to identify the patient and the medication, and it uses these IDs to access the patient and the medication information in the simulated hospital server. The hospital server verifies the patient and the medication, and replies to the nurse with an alert in case of medication error. The nurse has an option to forward the alert and start a real-time communication with a healthcare provider. If no error is triggered, the nurse can electronically document the administration (Figure 6-1).

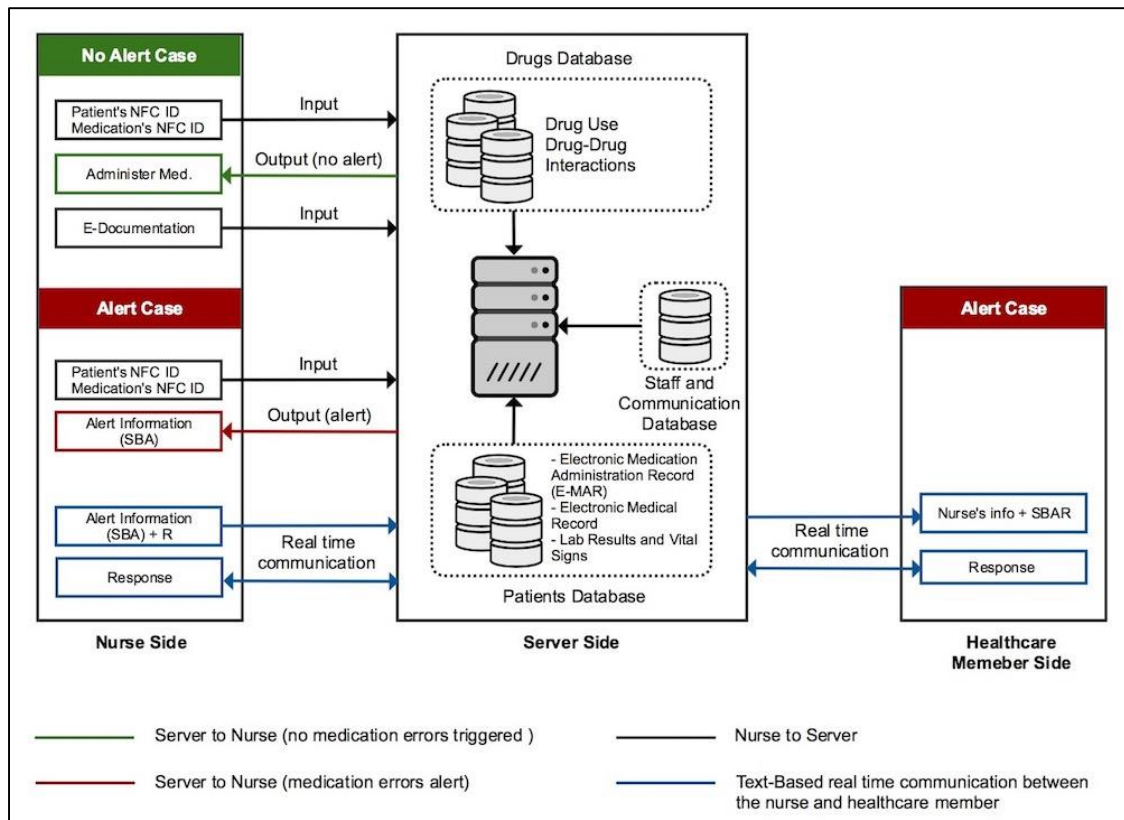


Figure 6-1. Conceptual Design of the NFC-MACC System

6.1.2 System Components and End-Users

The NFC-MACC system involves the following:

- **Simulated Hospital Server:** The server contains patient databases and drug databases that act as a trusted source for providing the required data that a nurse needs during the medication administration. It has: (1) the patient's electronic medical record (EMR), which includes the patient's personal and health information (condition, vital signs, and lab results); (2) the patient's medication administration record (MAR), which includes the patient's prescribed medications and drug allergies; (3) drug use and drug-drug interactions information; and (4) healthcare professionals' information for communication purposes.
- **Smartphones:** The nurse carries an NFC-enabled smartphone, which acts as an NFC reader to obtain the patient's and medication's tag IDs in order to verify the medication. The healthcare provider (physician or pharmacist) carries a smartphone

(not necessarily NFC-enabled) in order to receive the alerts and communicate with the nurse. The NFC-MACC application is installed on the nurses' and healthcare providers' smartphones.

- **Tagged Medication:** Each prescribed medication will be tagged with an NFC tag that has a unique ID. This ID has corresponding information in the hospital database. The NFC tag will be used to accurately identify the prescribed medication. We assume that the tagging process is performed by the pharmacy.
- **NFC-Armband for Patient:** Every admitted patient will be wearing an NFC tag bracelet that has a unique ID. This ID has corresponding information in the hospital database. The NFC tag will be used to accurately identify the patient. We assume that each patient is assigned with an NFC-armband during the admission process.

Since our study scope focuses on the medication administration stage, the primary end user is the nurse, while the secondary end-users are the healthcare provider (physician and pharmacist).

6.1.3 System Functions and Workflow

The system contains the following functions: (1) identifying the patient and the medication; (2) confirming the five rights of medication administration; (3) verifying allergies; (4) verifying drug interactions; (5) verifying contraindication; (6) alerting and providing adequate information; (7) providing real-time communication between nurses and other healthcare professionals; and (8) documenting the administered medication.

After the nurse logs into the NFC-MACC application and chooses a certain patient, the system works in the following process, respectively: NFC-based bedside identification, medication verification and documentation (five rights, allergies, interactions, and contraindication), prompting alert (in case of medication error only), and real-time communication (in case of consultation need only) (Figure 6-2).

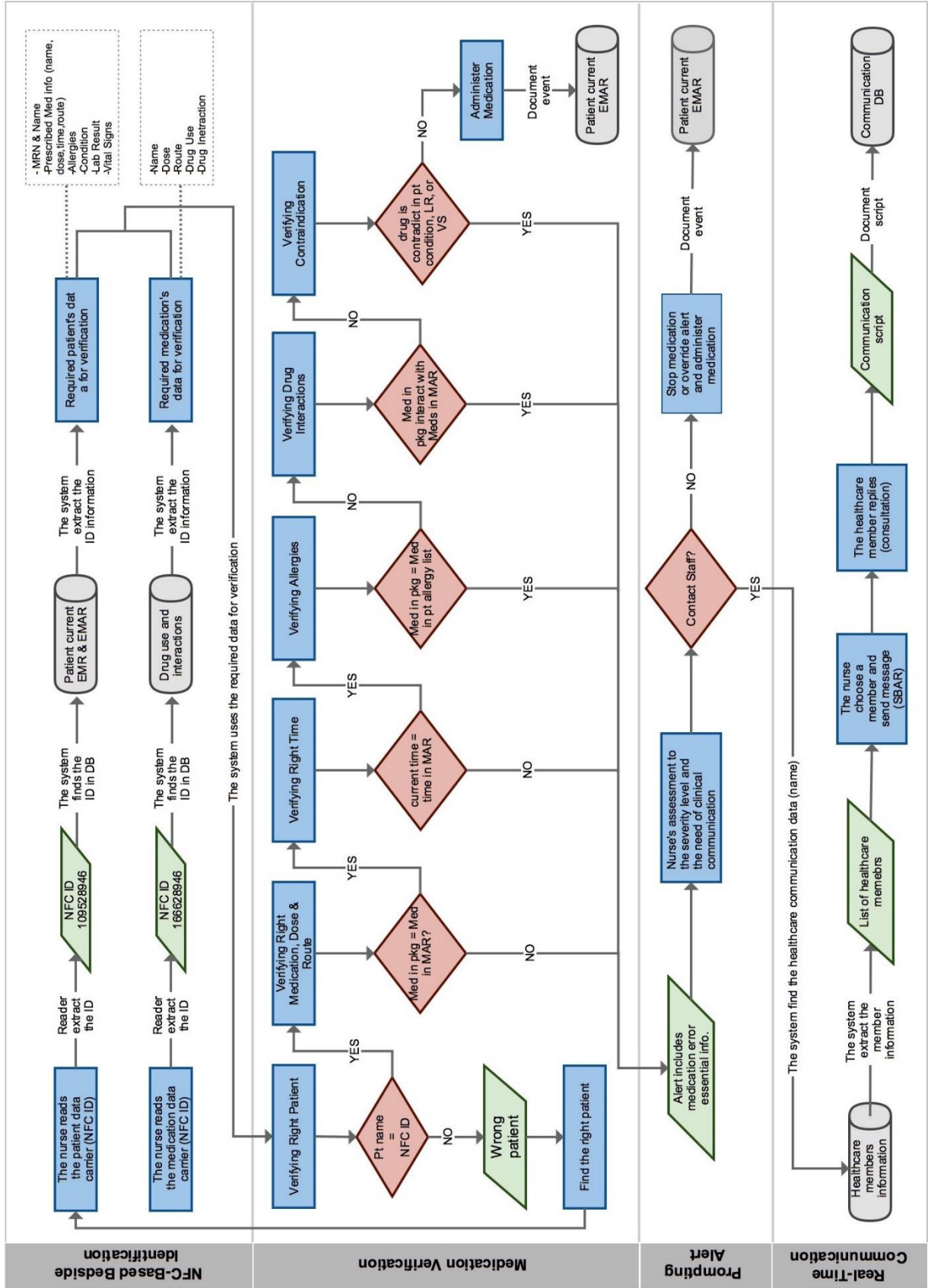


Figure 6-6-2. System functions and workflow

NFC-Based Bedside Identification

When a patient is to receive a medication, the nurse uses an NFC-enabled smartphone to read the patient's NFC armband by simple tapping. The nurses receive a short audible peeping when the NFC tag ID is obtained, which indicates successful tapping. If the nurses failed to obtain the ID, they will receive a different audible high-pitched peeping, which indicated unsuccessful tapping. After obtaining the IDs, the application will extract the tag's IDs and send it to the EMR databases for processing. The database will find the corresponding information to the patient's NFC ID. If this is not the right patient, the system will alert the nurse, who will not proceed to tapping the medication screen. However, if this is the right patient, the nurse is required to tap on the medication tag, and the application will extract the tag's IDs and send it to the database for processing.

Medication Verification

The hospital database will run queries to compare the ID's information against the patient's EMR and MAR to verify the medication and to display the output to the nurse through the smartphone screen.

- **Right Patient:** To ensure that the nurse is administering the medication to the right patient, the name and NFC ID must match the name and NFC ID in the patient EMR. If they match, the application will proceed to confirm the second right; if they do not match, the application will alert the nurse.
- **Right Medication:** To ensure that the nurse is giving the patient the right medication, the name and NFC ID on the medication package must match the prescribed medication in the patient's MAR. If there is mismatch, the nurse will be alerted; otherwise, the application will proceed to check the third right.
- **Right Time:** To ensure that the nurse is delivering the patient the medication at the right time, queries will be running in the patient's MAR to compare the time at which the medication is supposed to be given with the current time. If a verification failure has occurred, the system will alert the nurse and provide the information about the right time; if not, the system will proceed to verify the dose.
- **Right Dose:** To ensure that the nurse is giving the patient the right dose of medication, the system will compare the dose in the medication package with the dose in the patient's MAR. If there is any mismatch, the application will alert the

nurse and provide information about the right dose. Otherwise, the system will proceed to check the fifth right.

- **Right Route:** To ensure that the nurse is giving the patient the medication via the right route (oral, sublingual, rectal, topical, intravenous, or intramuscular), the system will compare the route on the medication package with the route in the patient's MAR. If they match, the system will proceed to verify allergies.
- **Allergy Verification:** To ensure that the nurse is not giving the patient a medication to which he/she is allergic, the system will compare the medication in the package information with the patient's allergy list in his or her MAR. If there is a match, the nurse will be alerted with the information of the allergy and its classification. Otherwise, the system will proceed to check drug-drug interactions.
- **Drug-Drug Interactions:** To ensure that the nurse is not administering the patient a medication that interacts with other medications in the patient's treatment, the system will compare the medication package information in the drug interaction database with the patient's medication in his or her MAR. If there is a potential of interaction, the nurse will be alerted; otherwise, the system will proceed to verify contraindication.
- **Contraindication Verification:** The final check the system will perform is verifying contraindication. The system will compare the medication in the package use against the patient's condition, lab results, and vital signs in the EMR. If there is any potential contraindication, the nurse will be alerted. Otherwise, the application will display the documentation screen.

The documentation screen will display the patient and medication information for the nurse to review as well as an option to specify if the medication was documented, held, discontinued, or refused. In addition, the nurse will have an option to add notes to the documentation. The nurse's name will be automatically linked to the documentation.

Prompting Alert

The nurse will be alerted when there is a potential of medication error (wrong patient, medication, dose, time, route, allergy, drug interaction, or contraindication), as discussed in the previous section. Only the nurse will receive the alert with clinically significant

information that is retrieved from the patients' and medication's database. The nurse will assess the alert and decide whether to override it or contact a healthcare provider.

Real-Time Communication Phase

The nurse can initiate a real-time text-based communication with a healthcare provider through the application, and the healthcare provider will receive a notification of a new message. The forwarded alert will contain the SBAR information, and it will serve as the starting point in the conversation. This will help the nurse to deliver adequate information, and help the healthcare provider to understand the main subject matter of a problem. In addition, the communication script between the nurse and the healthcare provider will be documented for future reference when needed (e.g. if the nurse wants to review the physician's consultation).

6.2 System Implementation

We implemented a prototype NFC-MACC system using the following:

6.2.1 Experimental Tools

NFC Tags and Arm Model

We used 18 NFC tags for identification purposes: 9 tags were assigned to 9 different (simulated) patients and 9 other tags were assigned to 9 medication packages (unit dose). The number of tags was decided based on the number of scenario cases that were selected for testing in the final usability testing phase of this research, which is discussed in the following chapter. We used two forms of tags, sticker tags for medicating and armband tags for patients, and both are MIFARE Classic 1K tags, which have a memory capacity of 1024 bytes. Each tag has a unique ID used to identify the patients and medications. Each medication tag was assigned to a certain unit dose and placed on a sealed plastic bag to simulate the current unit dose used in nursing current practice. Likewise, each NFC armband was assigned to a certain patient, and we placed a sticker that has the patient's identification information on it to simulate the patient's armband in hospitals. We also used an arm model to simulate the patients' arms (Figure 6-3).



Figure 6-3. The forms of NFC tags used in the study.

NFC-enabled Smartphones

We used two NFC-enabled smartphones (Samsung Nexus S with Android platform) with the NFC-MACC application installed in both of them. One to be used by the nurse will act as an NFC reader to obtain the tags' IDs by a simple tapping. The second one is to be used by the healthcare provider to contact the nurses. The NFC feature in the healthcare provider's smartphone is not a necessity because they are not involved in the patient and medication identification task; however, due to its availability, we opted to use it.

6.2.2 Experimental Software

Android Studio

Android Studio is an Integrated Development Environment (IDE) for Android platform development. We used Android Studio to create the NFC-MACC application, and we linked it to a simulated hospital database (MySQL). The application allows for an automated identification using the NFC reader integrated in the smartphone, verifying the medication, documenting the medication, alerting the nurse, and enabling communication between the nurse and healthcare providers.

Web Server

In order to connect MySQL with the Android application, we needed a web server in the middle. We used a PHP script to pass the request to MySQL and then return (fetch) the response to the Android application.

phpMyAdmin and MySQL

phpMyAdmin is a software tool that handles the administration (design and manage databases) of MySQL over the Web, and we used it to create our simulated hospital database. We populated our database with information of 9 patients. We chose 9 patients because we only require 9 case scenarios to test the functions of our system. In other word, the system will be tested in 9 different scenarios that include wrong patient, wrong medication, wrong dose, wrong time, wrong route, drug interactions, allergy, contraindication, and no alert. These scenarios are discussed in detail in the next chapter (Chapter 7).

To create the E-MAR and EMR for each patient, we used a PhysioNet restricted database called the MIMIC-II clinical database [105]. This database provides anonymous clinical information of real subjects in the form of flat files (text). We obtained permission to use the database after completing an online health-related ethics course provided by the Massachusetts Institute of Technology. We reviewed the subjects' files and we selected 9 patients' information according the case scenarios we needed to test our system. For example, for the allergy case scenario, we manually looked into the subjects' allergy lists and their medication files until we found a real case of medication error-related allergy. In addition, we used an online custom data generator to generate demographic information for the patients (name and date of birth).

The E-MAR includes the prescribed medications information and drug allergies for each patient, and the EMR includes the patients' personal and health information including condition, vital signs, and lab results. In addition, we used a drug information online database, *Drugs.com*, which is powered by leading medical-information suppliers¹⁰, to create our drug use and drug-drug interactions information in the database [106]. We chose this online database because it provides concise information about contraindications, drug interactions, and severity level.

¹⁰ Wolters Kluwer Health, American Society of Health-System Pharmacists, Cerner Multum and Micromedex from Truven Health [106].

Firestore

We used Firestore to implement the communication feature in the NFC-MACC application. We chose Firestore because it provides a real-time database that is suitable for the real-time text-based messaging communication (e.g. chat), and provides a notification feature, as well. We used the Firestore libraries to program the communication feature through Android Studio.

6.2.3 NFC-MACC Application Interfaces

When we started designing the application interface, we considered the nurses' recommendation for the interface from the first phase of our study. We kept it simple, with few colors and few clicks per screen. We only used the color red for alerts, as suggested. The following figure shows the logical flow of the application clicks.

The main screen after the login has two options from which the nurse can choose: Administer Medication or Contact Staff (Figure 6-4).

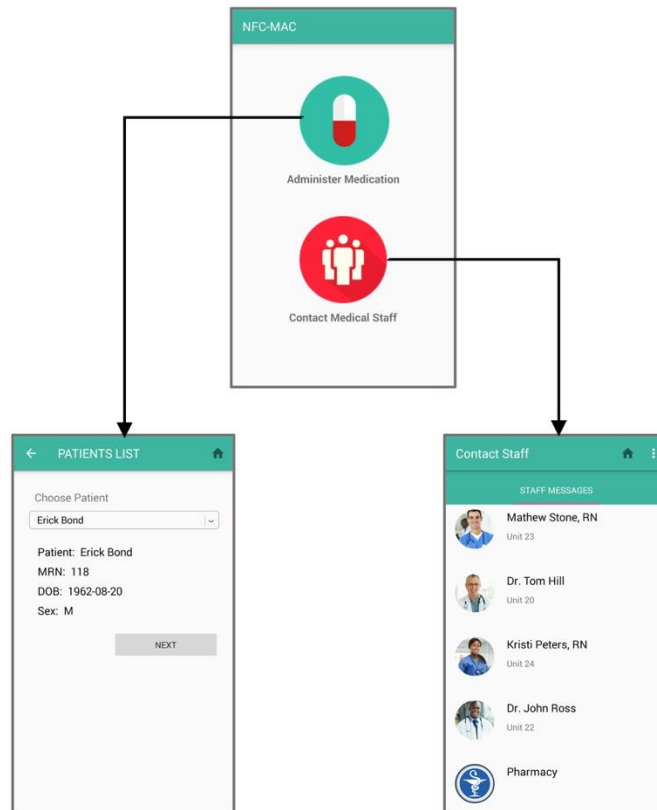


Figure 6-4. Main Screen Options

Administering medication leads to the patients list screen where the nurse chooses the patient and reviews his/her demographic information. After choosing the patient, the nurse clicks on the *NEXT* button to move to the identification screen where diagnoses are added and tapping on the patient tag is required (Figure 6-5). After obtaining the patient's NFC ID, the nurse will click on the *NEXT* button, which leads to two possible outputs: an alert message or a medication verification screen (Figure 6-6).



Figure 6-5. Automated Identification through Tapping on Patient's Tag

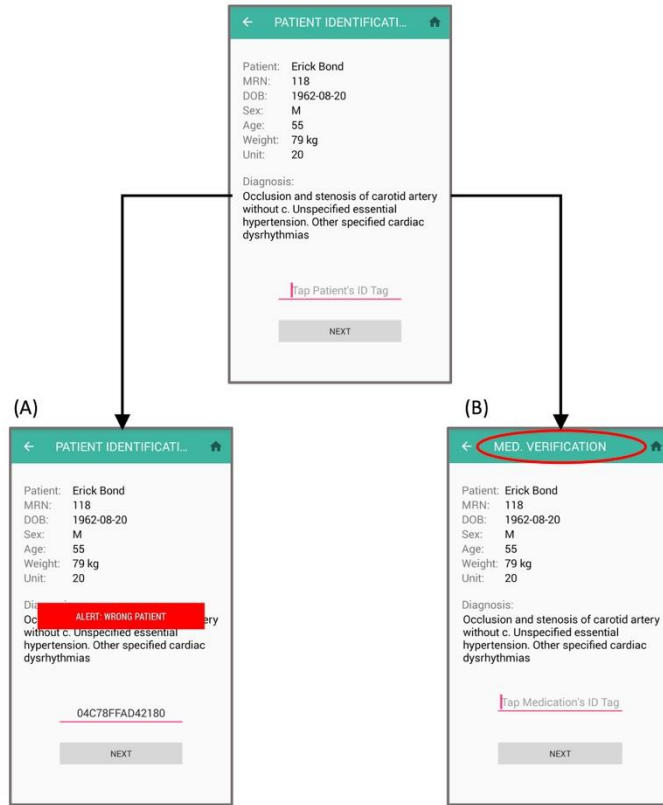


Figure 6-6. (A) The Application Displays an Alert if the Nurses Scanned the Wrong Patient (B) The Application Displays the Medication Verification Screen if the Nurses Scanned the Right Patient.

The nurse is then required to tap on the medication's tag to obtain its ID. Assuming that this is the right medication, the NEXT button leads to two possible outputs: a documentation screen or duplicate medication if the medication was already administered and documented. This is important during shift changes when nurses do not know if the medication was given or not (Figure 6-7).

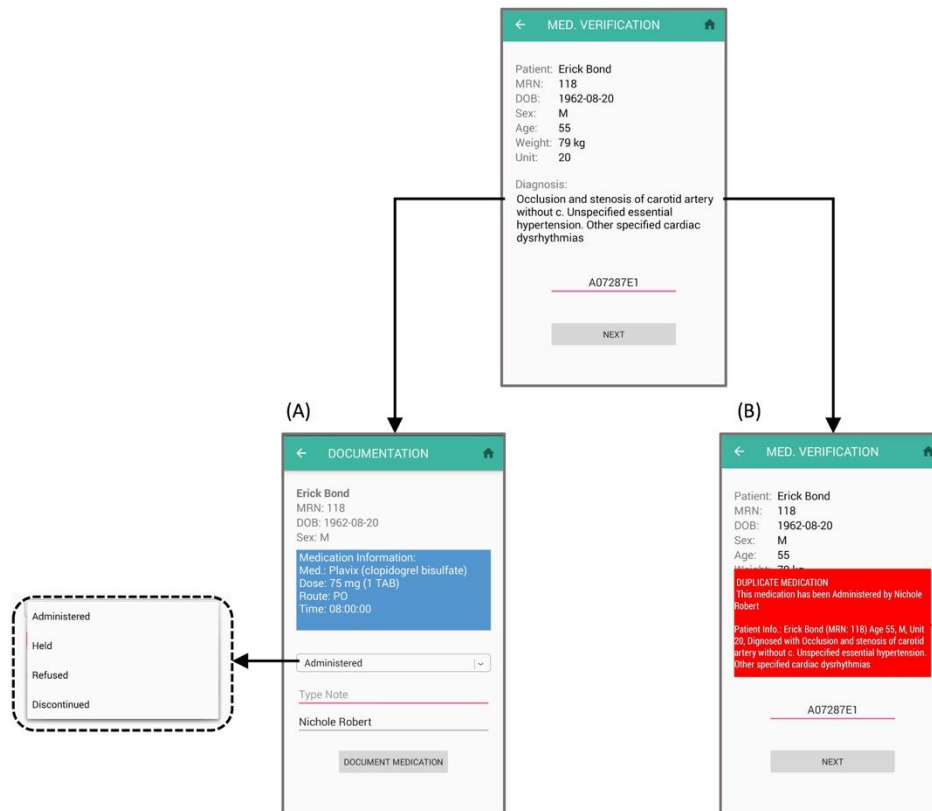


Figure 6-7. (A) The application displays the documentation screen in case of right medication. (B) The application displays a duplicate medication alert if the medication was already documented in the patient’s E-MAR.

The medication alert can be duplicate medication; wrong medication, dose, time, time, or route; allergy; drug interactions; or contraindications. The following screenshot shows an example of a contraindication alert screen. The screen has two options, either override the alert or contact a healthcare provider. If the nurse chooses to contact a healthcare provider, the alert will be automatically copied in the clipboard to be pasted and sent to the desired person. The copy/paste feature does not force the nurse to start the conversation with the alert, as opposed to an automatic forward of the alert. Instead, the nurse can start the conversation with her/his own words, and then paste the alert information. The healthcare provider will receive a notification on his/her smartphone screen of a medication error alert sent from the nurse (Figure 6-8). The process of overriding or contacting staff applies for

all types of medication errors except wrong patient, wrong medication, and duplicate medication.

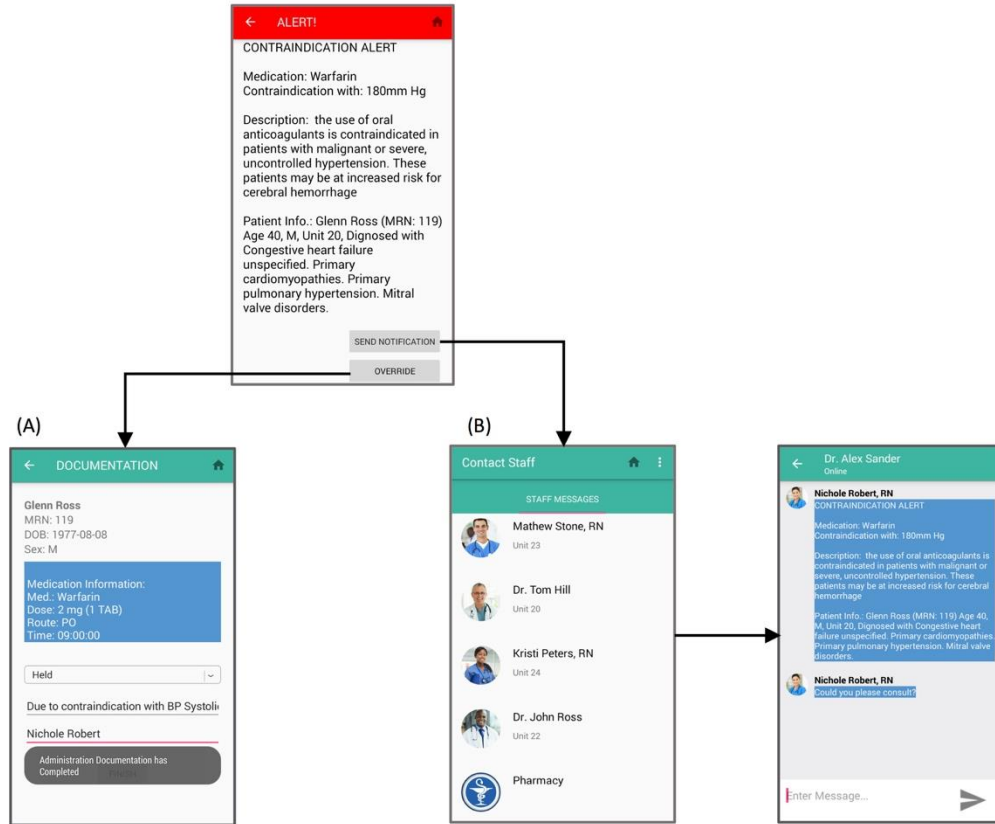


Figure 6-8. (A) The application displays the documentation screen if the nurses choose to override and can add notes if needed. (B) The application displays the Contact Staff screen if the nurses choose to notify a healthcare provider.

Summary

In this chapter we explained the conceptual design of the NFC-MACC system, and the its main components. We implemented the prototype system using Android Studio, web server, and MySQL. We created a simulation of a hospital database and populated it with real anonymized 9 patients information. We only need 9 patients because we require 9 case scenarios to test the functions of our system. The designed prototype NFC-MACC system will be tested for usability in the next chapter.

Chapter 7. Phase 3 (Part 2): Usability Testing of NFC-MACC System

In this chapter, we discuss the usability testing of the (NFC-MACC) system. We explain the study design including the recruitment, setting and study equipment. We then describe the study process and the data collection methods. Finally, we present the quantitative and qualitative findings.

7.1 Study Purpose and Research Questions

The purpose of this study is to understand the nurses' perception regarding the usability of NFC-MACC system. The usability attributes targeted in this study are: subjective (effectiveness and efficiency), objectives (perceive ease of use, and perceive usefulness for nurses' job), perceive usefulness for patient care, and beliefs: patient perceptions.

The research questions we focused on in this study are:

- RQ1: To what extent is the NFC-MACC system efficient in terms of time spent completing tasks in comparison to optimum time?
- RQ2: To what extent is the NFC-MACC system effective in terms of completing the tasks with the least number of errors?
- RQ3: How do nurses perceive the usefulness of the NFC-MACC system in comparison with their current method used for bedside medication administration and clinical communication procedure?
- RQ4: How do nurses perceive the ease of use of the NFC-MACC system?
- RQ5: How do nurses perceive the usefulness of the NFC-MACC system for patients, and what do they believe that patients would think of the system?
- RQ6: What are the strengths and weaknesses of the NFC-MACC system from the nurses' points of view?

7.2 Usability Testing Model

We used the Health Information Technology Usability Evaluation Model (Health-ITUEM) model to evaluate the usability of the system (Figure 7-1) [107]. This model has been used in different studies that evaluates the usability of health-related applications because it is mainly designed to assesses the usability of mobile technology and health information systems [92][108][109][110]. The model integrates *subjective* attributes of usability

through the Technology Acceptance Model (TAM) and *objective* attributes through ISO 9241-11 [107]. The TAM model assumes that perceived usefulness and ease of use would predict a healthcare professional’s intention to use a particular Health Information System (HIS) [111]. On the other hand, ISO 9241-11 objectively evaluates efficiency and effectiveness [112]. Health-ITUEM provides a comprehensive model for evaluating usability using both *subjective* and *objective* attributes. The definitions of these attributes are listed in Table 7.1.

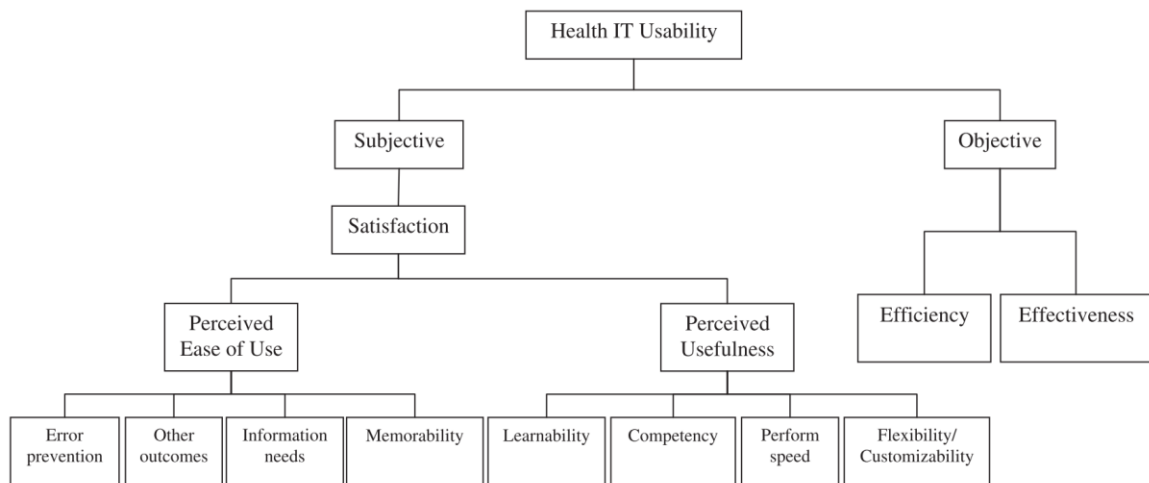


Figure 7-1. Health-ITUEM [107]

Table 7-1. Subjective and Objective attributes definition

Attribute	Definition
Efficiency	How quickly a user can achieve his/her goal (measure of time) [99].
Effectiveness	How easy it is for the user to use the system and achieve his/her goal without errors [107].
Error prevention	System offers error management, such as error messages as feedback, error correction through undo function, or error prevention such as instructions or reminders, to assist users in performing tasks [107].
Memorability	Users can easily remember how to perform tasks through the system [107].
Information needs	Information content is offered by the system for basic task performance and to improve task performance [107].
Flexibility	The system provides more than one way to accomplish tasks, which allows users to operate the system as preferred [107].
Learnability	Users are able to easily learn how to operate the system [107].
Performance speed	Users are able use the system efficiently [107].
Competency	Users are confident in their ability to perform tasks using the system [107].

In addition, since the system is meant to be used on patients, we wanted to understand how patient's will perceive it from the nurses' point of view. Therefore, we used contextualized perception variables that affects technology acceptance, which are perceive usefulness for patient care, and perceived social influence from patient (beliefs: patient perceptions). These variables are added in a modified version of TAM model that evaluate the nurses' perception regarding the usability of automated bedside medication administration systems such as BCMA [113][114].

7.3 Study Design

We tested the usability using a one-on-one mixed method approach (quantitative and qualitative) to gather comprehensive information about the NFC-MACC system usability. The study included the following methods to collect data: background questionnaire, tasks, post-task questionnaire, and semi-structured interview. We analyzed the quantitative data using descriptive statistics, within subject ANOVA, and one group T-test. We analyzed the qualitative data using a qualitative description approach. SPSS, Microsoft Excel and NVivo were used as tools for analyzing and coding the collected data. An approval from the Dalhousie University Ethics Board was acquired before starting the study (Appendix 7.A).

7.3.1 Sample Size and Eligibility

Initially, a purposeful sampling was used in this study. The sample size that we had planned for the study was minimum of 20 participants and the duration was 3 months. There is no definite sample size to test the usability of a system; Jakob Nielsen (2012) suggested that if a usability testing includes a quantitative method, at least 20 users should be tested [115]. Considering Nielsen's suggestion and our purpose in conducting a quantitative method (quantify the users' opinion), we decided to recruit minimum of 20 participants.

In addition, we were targeting actual end users for the system who are the experts in the domain of medication administration process, therefore, we believed that this number is sufficient to obtain valid and reliable data required to test the usability of the NFC-MACC system. Eligible participants included graduate students from School of Nursing at Dalhousie University who hold a current nursing practise or have practised in the last two years, and nurses who work at the IWK Health Center and hold current nursing practise or have practised in the last five years. The study invitation was sent to the graduate students

at School of Nursing by email. The study invitation at the IWK was restricted to posters only.

7.3.2 Recruitment and Study Duration

The recruitment process started following the Dalhousie University Ethics Board approval from November 2017 to January 2018 (3 months' duration). However, it was challenging to reach the targeted number. Therefore, we extended the time for data collection for two more months (until March 2018) and we were able to extend the recruitment by using local classified website Kijiji Research Study to recruit local nurses. By the end of March, we were able to recruit 32 local nurses in total.

7.3.3 Study Setting and Equipment

We used a controlled setting to conduct the study and the meeting with each nurse took a place at a meeting room at the Collaborative Health Education Building (CHEB), at Dalhousie University. The tools and equipment used during the study were: (1) NFC-enabled smartphone with installed application NFC-MACC application to be used during the tasks performance step; (2) 9 unit does tagged with NFC tags, and labeled with different medication names to be used during the tasks performance (as prescribed medications to the patients); (3) 9 NFC armband labeled with different patients names to be used during the tasks performance (as assigned patients to nurses' shift); (4) 3 model arms to be used during the tasks performance as a simulation of a patient's arm; (5) another smartphone to be used during the task session to display the text message sent to the physician and the pharmacist; (6) audio recorder to be used during the interview session; (7) digital timer to be used during the tasks session; (8) tablet to fill an online questionnaire (background questionnaire and post-task questionnaire) (see Appendix 7.B).

7.3.4 Study Process

The study was divided into 5 phases: background questionnaire, introduction and training session, tasks, post task questionnaire, and semi-structured interview. The duration to complete the study took about 50-80 minutes per participant.

Background Questionnaire Phase

The participants were asked to complete a background questionnaire through Dalhousie's Opinio survey software (questionnaire tool) using a tablet (Appendix 7.C). The

questionnaire took about (5-8 minutes) minutes to complete. The objective of the background questionnaire is to: (1) gather demographic information about the participants; (2) understand the current process they are using to confirm the five rights of MA and verify allergies, drug-drug interactions, and contraindications for hospitalized patients during the MA stage; and (3) understand the methods they are using to communicate with other healthcare professionals during the MA stage. We designed the questions concerning the nurses current experience based on the previous study output (Chapter 5).

Introduction and Training Phase

We introduced the study to the participants, and provided general information that included the following: the purpose of the study; basic information about NFC technology; a general idea about how the system functions and from where it retrieves the information; a brief discussion about the main functions of the system. In addition, since we were not evaluating their previous knowledge about how to use the NFC technology, we administered basic training that covered the following: (1) how to open and restart the application; (2) how to tap an NFC tag and obtained its ID; (3) how to document an administered medication; (4) how to forward an alert to the desired healthcare provider. The purpose of this training was to provide the participants with basic skills to perform the tasks and to allow them to focus on the application functions. Furthermore, this training equalized the participants' experience with using NFC technology before performing the tasks. This session lasted for about 10 minutes.

Tasks Phase

Following the introduction and training session, the participants were asked to perform a set of 10 tasks to give them a chance to experience all of the functions in the application and to expose as much as possible of its weaknesses and strengths. We designed a scenario context for each task in a way that is close to reality and represents a familiar situation to the participants. This helped them to remain in role while performing the tasks. We derived the scenario contexts from Phase 2 (Chapter 5). During the tasks performance, we observed the participants to collect objective data (efficiency and effectiveness). The efficiency refers to the time spent to complete each task and the effectiveness refer to the number of error (failing to obtain the ID from the first attempt of tapping on the NFC ID) made during

performing the tasks. We used a smartphone screen recorder Mobizen to observe the number of errors and any navigation problems. The tasks phase lasted about 15-20 minutes.

We divided the tasks into 4 categories: (1) confirming the five rights of medication administration (task 1 – task 7); (2) verifying allergy (task 8); (3) verifying drug-drug interactions (task 9); verifying contraindication (task 10). The tasks in all the categories are very similar, and the main difference between them is the output (i.e. alert type). They all require the nurse to tap on the patient and the medication tags, however, some tasks require extra steps such as override, document, or contact a healthcare provider (Appendix 7.D). The optimum time¹¹ to reach the desired screen is 8 seconds for all the tasks except Task 3. The optimum time for Task 3 is 5 seconds as it requires to tap on the patient’s armband only (i.e. no tapping on the medication is required).

The first category has 7 tasks, and focused on confirming the five rights of medication. This category covers 6 patients, and has the following cases:

- Task 1: The nurses do not experience any alert and can document the medication.
- Task 2 – Task 4: The nurses experience an alert that does not have an option to override or contact healthcare provider.
- Task 5 – Task 7: The nurse experience an alert and have an option to override or contact a healthcare provider (pharmacy).

The following table illustrates task 1- task 7 output, goals, and successful completion criteria (Table 7-2).

Table 7-2. Description of task 1 to task 7

Task 1	
Description	Administer <i>Plavix</i> (clopidogrel bisulfat) to Mr. Erick Bond
Output	Documentation screen and no alerts will be displayed
Required to perform	1- Login using email and password 2- Choose the patient from a drop down list and click next 3- Tap on patient’s NFC armband and click next 4- Tap on medication NFC tag and click next 5- Administer the medication and then document the administration by clicking the <i>Document</i> button
Goal	1- Allow the nurse to experience the process of tapping the NFC tags to get the

¹¹ The optimum time was calculated based on an average time spent to reach the desired screen by 5 experts who are familiar with using the NFC technology.

	patient's and medication's ID information. 2- Allow the nurse to experience the process of bedside documentation.
Successful completion criteria	Reaching the <i>Documentation</i> screen with two times tapping on the tags
Optimum time to reach the desired screen	8 seconds
Task 2	
Description	Administer <i>Plavix</i> (clopidogrel bisulfat) to Mr. Erick Bond for the second time
Output	Duplicate medication administration alert
Required to perform	1- Choose the patient from a drop down list 2- Tap on patient's NFC armband 3- Tap on medication NFC tag
Goal	1- Allow the nurse to experience the process of tapping the NFC tags to get the patient's ID information. 2- Show the nurse how the system prompts and displays duplicate administration alert
Successful completion criteria	Reaching the <i>Duplicate Alert</i> window with two times tapping on the tags
Optimum time to reach the desired screen	8 seconds
Task 3	
Description	Administer <i>Ramipril</i> to Mrs. Keely Roy
Output	Wrong patient alert
Required to perform	1 - Choose the patient from a drop down list and click next 2- Tap on patient's NFC armband and click next
Goal	1- Allow the user to experience the process of tapping the NFC tags to get the patient's and medication's ID information. 2- Show the user how the system prompts and displays wrong patient alert
Successful completion criteria	Reaching the <i>Wrong Patient Alert</i> window with one time tapping on the tags
Optimum time to reach the desired screen	5 seconds
Task 4	
Description	Administer <i>Cyanocobalamin</i> to Mrs. Sara Mike
Output	Wrong medication alert
Required to perform	1- Choose the patient from a drop down list and click next 2- Tap on patient's NFC armband and click next 3- Tap on medication NFC tag and click next
Goal	1- Allow the user to experience the process of tapping the NFC tags to get the patient's ID information. 2- Show the user how the system prompts and displays wrong medication alert
Successful completion criteria	Reaching the <i>Wrong Medication Alert</i> window with two times tapping on the tags
Optimum time to reach the desired screen	8 seconds
Task 5	
Description	Administer <i>Pantoprazole</i> to Mrs. Phoebe Morris
Output	Wrong time alert

Required to perform	1- Choose the patient from a drop down list and click next 2- Tap on patient's NFC armband and click next 3- Tap on medication NFC tag and click next 4- Override the alert by clicking the <i>Override</i> button 5- Administer the medication, write a note, then document the administration by clicking the <i>Document</i> button
Goal	1- Allow the user to experience the process of tapping the NFC tags to get the patient's ID information. 2- Show the user how the system prompts and displays wrong time alert 3- Allow the user to experience the override option 4- Allow the user to experience the process of bedside documentation
Successful completion criteria	Reaching the <i>Wrong Time Alert</i> screen with two times tapping on the tags
Optimum time to reach the desired screen	8 seconds
Task 6	
Description	Administer <i>Morphine</i> to Mr. Walter Fay
Output	Wrong route alert
Required to perform	1- Choose the patient from a drop down list and click next 2- Tap on patient's NFC armband and click next 3- Tap on medication NFC tag and click next 4- Send notification to pharmacy (forward the alert) 5- Ask Pharmacy to send the right form of medication (IV)
Goal	1- Allow the user to experience the process of tapping the NFC tags to get the patient's ID information. 2- Show the user how the system prompts and displays wrong route alert 3- Allow the user to experience the communication feature and contact pharmacy
Successful completion criteria	Reaching the <i>Wrong Route Alert</i> screen with two times tapping on the tags
Optimum time to reach the desired screen	8 seconds
Optimum time to forward the alert to healthcare provider	7 seconds
Task 7	
Description	Administer <i>Clopidogrel Bisulfate</i> to Mr. Smith Dukes
Output	Wrong dose alert
Required to perform	1- Choose the patient from a drop down list and click next 2- Tap on patient's NFC armband and click next 3- Tap on medication NFC tag and click next 4- Send notification to pharmacy (forward the alert) 5- Ask Pharmacy to send the right dose of medication (1 tab)
Goal	1- Allow the user to experience the process of tapping the NFC tags to get the patient's ID information. 2- Show the user how the system prompts and displays wrong dose alert 3- Allow the user to experience the communication feature and contact pharmacy
Successful completion criteria	Reaching the <i>Wrong Dose Alert</i> screen with two times tapping on the tags
Optimum time to reach the desired screen	8 second
Optimum time to forward the	7 seconds

alert to healthcare provider	
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The second category (verifying allergy) has one case where the nurses experience an alert and have an option to override or contact a healthcare provider (physician). Table 7-3 illustrates task 8 output, goals, and successful completion criteria.

Table 7-3 Description of task 8

Task 8	
Description	Administer <i>Aspirin</i> to Mr. John Patterson
Output	Allergy alert
Required to perform	1- Choose the patient from a drop down list and click next 2- Tap on patient's NFC armband and click next 3- Tap on medication NFC tag and click next 4- Send notification to Dr. Lisa Brown (forward the alert) 5- Ask for consultation.
Goal	1- Allow the user to experience the process of tapping the NFC tags to get the patient's ID information. 2- Show the user how the system prompts and displays allergy alert 3- Allow the user to experience the communication feature and contact the patient's physician
Successful completion criteria	Reaching the <i>Allergy Alert</i> screen with two times tapping on the tags
Optimum time to reach the desired screen	8 second
Optimum time to forward the alert to healthcare provider	7 seconds

The third category (verifying drug-drug interactions) has one case where the nurses experience an alert and have an option to override or contact a healthcare provider (physician). Table 7-4 illustrates task 8 output, goals, and successful completion criteria.

Table 7-4. Description of task 9

Task 9	
Description	Administer <i>Warfarin</i> to Mrs. Marina Fox
Output	Drug interaction alert
Required to perform	1- Choose the patient from a drop down list and click next 2- Tap on patient's NFC armband and click next 3- Tap on medication NFC tag and click next 4- Send notification to Dr. John Ross (forward the alert) 5- Ask for consultation.
Goal	1- Allow the user to experience the process of tapping the NFC tags to get the patient's ID information. 2- Show the user how the system prompts and displays interaction alert 3- Allow the user to experience the communication feature and contact the patient's physician

Task 9	
Successful completion criteria	Reaching the <i>Drug Interaction Alert</i> screen with two times tapping on the tags
Optimum time to reach the desired screen	8 second
Optimum time to forward the alert to healthcare provider	7 seconds

The fourth category (verifying contraindication) has one case where the nurses experience an alert and have an option to override or contact a healthcare provider (physician). Table 7-5 illustrates task 8 output, goals, and successful completion criteria.

Table 7-5. Description of task 10

Task 10	
Description	Administer <i>Warfarin</i> to Mr. Glenn Ross
Output	Contraindication alert
Required to perform	1- Choose the patient from a drop down list 2- Tap on patient's NFC bracelet 3- Tap on medication NFC tag 4- Send notification to Dr. Alex Sanders (forward the alert) 5- Ask for consultation.
Goal	1- Allow the user to experience the process of tapping the NFC tags to get the patient's ID information. 2- Show the user how the system prompts and displays contraindication alert 3- Allow the user to experience the communication feature and contact the patient's physician
Successful completion criteria	Reaching the <i>Contraindication Alert</i> screen with two times tapping on the tags
Optimum time to reach the desired screen	8 second
Optimum time to forward the alert to healthcare provider	7 seconds

Questionnaire

Following the tasks phase, we asked the participants to complete a questionnaire through Dalhousie's Opinio survey software (questionnaire tool) using a tablet. This phase took about (5-10) minutes to complete. The purpose of the questionnaire phase is to collect quantitative data about the subjective usability attributes and understand the participants' perception about the NFC-MACC system. The questionnaire was designed based on two standardized usability questionnaire models. First model is the Health IT Usability Evaluation Scale (Health-ITUES), which includes an evaluation of the Health-ITUEM

usability subjective attributes (i.e. perceived ease of use and perceived usefulness) [116]. We modified the questionnaire by excluding the questions that does not apply to our study (organization-related questions), and modify the wording to match our system functions. For example, the original question is “Using (system) makes it easier to [request the shift I want]”, our question is “Using NFC-MACC system will make it easier to confirm the five rights”. Second model is the modified version of TAM model that evaluate the nurses’ perception regarding the usability of automated bedside medication administration systems such as BCMA [113][114]. We only used the section that related to contextualized perception variables that affects technology acceptance, which are perceive usefulness for patient care, and perceived social influence from patient (beliefs: patient perceptions). We modified the wording in this section to fit with our system evaluation.

Accordingly, the questionnaire was classified into five categories: perceived usefulness, perceived ease of use, satisfaction perceived usefulness for patient care, and beliefs: patient perceptions. The questionnaire had a five point Likert scale coded from 1-5, where 1 equals to strongly agree and 5 is strongly disagree. (see Appendix 7).

Semi-Structured Interview

We concluded the study with a semi-structured interview to gather qualitative data, which took around 15-35 minutes. The purpose of the interview is to: find a descriptive answers to support the questionnaire answers, identify the weaknesses and strengths of the NFC-MACC system, and gather descriptive recommendations to improve the system in the future. The first 7 questions helped us to support the post-task questionnaire answers and to identify the weaknesses and strengths of the application. Question 8 helped us to understand if the nurses are willingness to use it in an actual practice and the motivation behind their answer. The last question helped us to gather list of recommendations to improve the system in future work. The interview was audio recorded and transcribed for analysis purposes (Appendix 7.E). We started with coding the first 10 interviews scripts. We revisited and refined the codes by merging the ones that share the same concepts. Accordingly, we coded the rest of the interviews scripts and kept adding new codes and generating categories.

7.4 Findings

7.4.1 Participants Demographics

We recruited 32 nurses, consisting of 29 females and 3 males with an average age of 30.50 (sd: 9.81, min: 21, max: 61). The nurses consisted of 29 RNs and 3 LPNs. The average years of experience is 7.28 (sd: 7.48, min: 6 months, max: 30 years). All nurses used a smartphone, however, only 8 had used a medical app on their smartphone. These apps included five citations of Nurse Central, one for Micromedex, one for each of RxTx, bugs and drugs, lexicomp (by the same individual) and one individual cited “google” (to look up medications). Only 6 nurses had used NFC feature in their smartphones, 19 nurses know the NFC technology but had not used it, and 7 selected the option “I am not aware of this feature.”. Table 7-6 provides the summary of the demographic information.

Table 7-6. Nursing participant characteristics (N=32)

Characteristics	N= 32 Percentage	Mean
Sex:		
Male	3 (9.37%)	-
Female	29 (90.63%)	-
Age	-	30.50
Levels		
LPN	3 (9.37%)	-
RN	29 (90.63%)	-
Years of Experience	-	7.28
Use of Smart Phone	32 (100%)	-
Use of Med Apps on a Smart Phone	8 (25%)	-
Use of NFC feature:		
1. Yes	6 (18.75%)	-
2. No	19 (59.37%)	-
3. not aware of this feature	7(21.87)	-

7.4.2 Participant’s Current Experience

Number of Medication Administered Per Shift

The first question was about the number of medication administered to patients per shift and responses coded into one of six levels (1-5 as “1”, 6-10 as “2”, 11-15 as “3”, 16-20 as “4”, 20-25 as “5”, and 25+ as “6”). The mean responses was 3.84 (SD1.89), which means the average number of administered medication is around 16-20 medications (Table 7-7).

Table 7-7. Average number of medications administered to patients per shift

Number of Medications	N= 32	Mean	SD
1-5	5 (15.62%)	3.84	1.89
6-10	4 (12.5%)		
11-15	6 (18.75%)		
16-20	3 (9.37%)		
21-25	4 (12.5%)		
25+	10 (31.25%)		

Current Methods Used for The 5 Rights Verification

Nurses were asked about the current method/methods they use to verify each of the *five rights* of medication administration for a single patient with a list of 7 options (multiple choice). The following table illustrates the nurses’ responses for methods used to verify the *right patient* (Table 7-8). One nurse has selected “Other”, however, note that two nurses provided a response in the “other” text box. The two answers were “Parent”, and “Photo, knowledge of patient from long association”. Hence, the number of “Other” options was actually two, and the nurse who had failed to indicate “other” was recoded as “Other”. After revision, the mean number of methods was 3.72 (SD: 1.30) with a range from 1 to 6 (note that there were 7 options, including “other”).

Table 7-8. Descriptive statistics for the methods used to verify the right patient

Verification Method	N= 32	Mean	SD
Arm Band	28 (87.5%)	3.72	1.30
Ask Patient	23 (71.88%)		
DOB	18 (56.25%)		
Patient ID number	18 (56.25%)		
Paper-based MAR	25 (78.12%)		
E-MAR	5 (15.62%)		
Other	2(6.25%)		

Similarly, for *right medication, right dose, right time, and right route* there were list of 7 identical options (multiple choice), illustrated in Table 7-9. For *right medication* verification, one nurse has selected “Other”, however, when specifying the other option, two nurses provided answers, one stated “Parent” and “Davids drug guide” and the other one stated “Only using physician order to verify once in a while if a medication seems odd”. The number selecting the other option was re-coded as 2. The mean number of methods was 3.63 (SD: 1.13) with a range from 1 to 6.

For the *right dose* verification, the “Other” option included “Drug dosing guidelines online”, “Only using physician order once in a while to verify if a dose seems odd”, “[hospital name¹²]”, and “Parent”. All were correctly associated with the selection of the other option. The mean number of methods was 3.75 (SD: 1.01) with a range from 2 to 6.

For the *right time* verification, the “Other” option was “Parent” (the same nurse who used this option on all previous occasions. One other stated “Only using physician order once in a while to verify if a frequency seems odd” (the same participant used this option with all other items except *right patient*). The mean number of methods was 2.75 (SD: 1.22) with a range from 1 to 5.

For the *right route* verification, the “Other” option included “Assessment and patient observation (ex: g-tube)”, “Davids drug guide”, “Drug vial/box”, “[hospital name] drug guide”, and “Parent”. In addition, one participant said “parent” without selecting the “Other” option, and was recoded to include “other”. In addition, the same individual stated “Only using physician order once in a while if a route seems odd”. The mean number of methods was 3.34 (SD: 1.21) with a range from 1 to 6.

Table 7-9. Descriptive statistics for the methods used to verify the right medication, dose, time, and route

	Paper MAR	E-MAR	Physician order	Pyxis	Med. Package	Ask Patient	Other	Mean	SD
Right med.	28 (87.5%)	5 (15.62%)	27 (84.38%)	22 (68.75%)	23 (71.88%)	9 (28.12%)	2* (6.25%)	3.63	1.13
Right dose	28 (87.5%)	5 (15.62%)	28 (87.5%)	24 (75%)	25 (78.12%)	7 (21.88%)	3 (9.38%)	3.75	1.01
Right time	28 (87.5%)	6 (18.75%)	24 (75%)	11 (34.38)	5 (15.62%)	13 (40.62%)	2* (6.25%)	2.75	1.22
Right route	28 (87.5%)	5 (15.62%)	27 (84.38%)	18 (56.25%)	16 (50%)	8 (25%)	5* (15.62%)	3.34	1.21

* adjusted

Current Methods Used for Allergy Verification

Similarly, nurses were asked about the current method/methods used to verify allergies (for a single patient) and there were list of 7 identical options (multiple choice), illustrated in Table 7-10. The “Other” options were two “Kardex”, “Not applicable in my place of work” (it is unclear if this meant that the options were not applicable, of if checking allergies was

¹² The name of the institute, hospital, organization was removed to ensure anonymity.

not applicable. The mean number of methods was 3.38 (SD: 1.07) with a range from 1 to 5.

Table 7-10. Descriptive statistics for the methods used to verify allergy.

Verification Method	N= 32	Mean	SD
E-MAR	4 (12.5%)	3.38	1.07
Paper-based MAR	21 (65.62%)		
Arm band	23 (71.88%)		
Physician order	7 (21.88%)		
Ask patient	25 (78.12%)		
Chart	25 (78.12%)		
Other	3 (9.38%)		

Current Methods Used for Drug Interactions Verification

The questionnaire continued and asked nurses about the “current method/methods you use to drug interactions (for a single patient)”, and we provided a list of 7 options (multiple choice), illustrated in Table 7-11. There were 4 actual selections of the “Other” option, however, when specifying the other option, 6 nurses provided answers. The options included variations of “Call pharmacy” (“Calling pharmacy” or “Consult Pharmacy”, “Pharmacy clarifies drug interactions”, and “Pharmacist [SIC]”. The other option was “I usually forget to do this except for concurrent [sic]iv meds”. Hence, the number of “Other” was changed to 6. The mean number of methods was 2.44 (SD: 1.01) with a range from 1 to 4.

Table 7-11. Descriptive statistics for the methods used to verify drug-drug interactions.

Verification Method	N= 32	Mean	SD
E-MAR	1 (3.12%)	2.44	1.01
Paper-based MAR	6 (18.75%)		
Paper poster (Grid)	15 (46.88%)		
Drug guide (book)	19 (59.38%)		
Computer software/ web.	27 (84.38%)		
Phone app.	4 (12.5%)		
Other	6 (18.75%)		

Current Methods Used for Contraindication Verification

The final question was related to contraindication verification. Nurses were asked about “Current method/methods you use to verify contraindication (i.e. medication interacts with patient condition, vital science or disease) (for a single patient)”, and there were were four multiple choice options, see Table 7-12. The other options included 5 variations on

pharmacy (“Call pharmacist”, “Calling pharmacy”, “Consult pharmacy”, “Pharmacy assists in this as well”, and “Physician or pharmacist [SIC]”), 2 variation of physician (“consulting physician”, “Physician or pharmacist [SIC]”), “Chart”, 3 citations of “micromedex”, 3 variations of internet searches (“Internet on computer”, “Internet serach [SIC]”, “[hospital name] drug guide (online)”, and 3 variations of personal knowledge (“Knowledge of pharmacology of medication”, “Use personal knowledge base”, and “Usually know this from experienceere [SIC]”. Many mentioned more than one other. Hence, the other category was recoded to reflect the diversity. The mean number of methods was 1.69 (SD: 0.90) with a range from 1 to 4.

Table 7-12. Descriptive statistics for the methods used to verify contraindication

Verification Method	N= 32	Mean	SD
E-MAR	1 (3.12%)	1.69	0.90
Paper-based MAR	15 (46.88%)		
Drug guide (book)	23 (71.88%)		
Other	12 (73.5%)		

Time Spent to Verify the Medication

Nurses were asked about the average time spent to verify the five rights of medication administration, allergy, drug interactions, and contraindication (for a single patient), Table 7-13. Responses were collected in seven categories: “Less than 1 minute” (coded as 1), “1-2 minutes” (coded as 2), “3-4 minutes” (coded as 3), “5- 6 minutes” (coded as 4), “7-8 minutes” (coded as 5), “9-10” (coded as 6), and “10+” (coded as 7).

For the time spent to verify the five rights, the mean coded response was 2.34 (SD: 1.066, min 1, max 4) implying that it took, on average, 1 to 2 minutes per patient. For the time to check allergies, the mean coded response was 1.88 (SD: 1.64, min 1, max 7) implying that it took, on average, less than one minute per patient. Note that the mean is a bit lower than the five rights, but the range is much larger. For the time to check drug interactions, the mean coded response was 2.94 (SD: 1.27, min 1, max 7) implying that it took, on average, 1 to 2 minutes per patient (nearer to 2 or 3). Note that the mean is higher than the previous verifications. For the time to verify drug contraindication, the mean coded response was 2.66 (SD: 1.58, min 1, max 7) implying that it took, on average, 1 to 2 minutes per patient. Note that the mean is higher than the previous operations.

Table 7-13. Time spent to verify the five rights of medication administration, allergy, drug interactions and contraindications

	< 1 min	1-2 min	3-4 min	5-6 min	7-8 min	9-10	10+	Mean	SD
Five rights	8 (25%)	11 (34.38)	7 (21.88%)	6 (18.75%)	0	0	0	2.34	1.06
Allergy	20 (62.5%)	7 (21.88%)	1 (3.12%)	1 (3.12%)	1 (3.12%)	2 (6.25%)	0	1.88	1.01
Drug interactions	3 (9.38%)	9 (28.12%)	13 (40.62%)	3 (9.38%)	2 (6.25%)	2 (6.25%)	0	2.94	1.22
Contraindications	10 (31.25%)	6 (18.75%)	7 (21.88%)	6 (18.75%)	1 (3.12%)	1 (3.12%)	1 (3.12%)	2.66	1.21

Current Methods Used for Documentation

Nurses were asked about the documentation process in their current practice, “current method/methods you use for documenting the administered medication (for a single patient):”, and we provided a list of 3 options (multiple choice), illustrated in Table 7-14. Only 3 nurses selected “Other”, however, there were 4 entries from different nurses. Thus, the number selecting other was actually 4. The other options included “Charti [SIC]”, “Computer charting using a specific program for obsetrics”, “Paper chart for prn doses”, and “Pyxis”. The mean number of methods was 1.19 (SD: 0.40) with a range from 1 to 2.

Table 7-14. Descriptive statistics for the methods used for documentation

Documentation Method	N= 32	Mean	SD
E-MAR	7 (21.88%)	1.19	0.40
Paper-based MAR	27 (84.38%)		
Other	*4 (12.5%)		

The time to document (“Average time spent to document an administered medication (from giving it to the patient until it gets documented”) was requested within the same time ranges as medication verification.: “Less than 1 minute” (endorsed by 9), “1-2 minutes” (endorsed by 7), “3-4 minutes” (endorsed by 5), “5- 6 minutes” (endorsed by 5), “7-8 minutes” (endorsed by 1), “9-10” (endorsed by 1), and “10+” (endorsed by 4). The mean coded response was 3.03 (SD: 2.01, min 1, max 7) implying that it took, on average, 3 to 4 minutes per patient. Note that the mean is higher than the previous operations (Table 7-15).

Table 7-15. Time spent to document the administered medication

Time spent to document	N= 32	Mean	SD
Less than 1 min	9 (28.12%)	3.03	2.01
1-2 min	7 (21.88%)		
3-4 min	5 (15.62%)		
5-6 min	5 (15.62%)		
7-8 min	1 (3.12%)		
9-10 min	1 (3.12%)		
10+ min	4 (12.5%)		

Current Method of Clinical Communication

Nurses were also asked about their current method used for clinical communication when consultation is needed, “Current method/methods you use to communicate with physician when a consultation is needed (e.g. clarification on a medication order is needed):”. Table 7-16 illustrates the (multiple choice) options provided and the frequency of responses. A total of 5 nurses provided “Other” alternatives. The other options included “Clipboard that they review each day”, “Write note on chart”, “Communication book”, “Fax”, “Our unit has a written list we can leave for the Dr.”, and “Vocera calling system”. The mean number of methods was 2.63 (SD: 0.61) with a range from 1 to 3.

In addition, nurses were asked about the “Current method/methods you use to communicate with pharmacist when a consultation is needed:”, (Table 7-16). Only 2 nurses provided “Other” alternatives. The other options included “FAX”, and “Order a consultation [sic] in [name¹³] Clinical Manager”. The mean number of methods was 1.88 (SD: 0.83) with a range from 1 to 3.

Table 7-16. Methods used to contact a physician or pharmacist when consultation is needed (n=32).

	Phone call	Page	In person	Email	Text messaging	Other	Mean	SD
Contact physicians	26 (81.25%)	26 (81.25%)	26 (81.25%)	0	1 (3.12%)	5 (3.12%)	2.63	0.61
Contact Pharmacist	32 (100%)	11 (34.38%)	15 (46.88%)	0	0	2 (6.25%)	1.88	0.83

The time to inform the physician (“Average time spent to contact/reach a physician and get a reply”) was requested within the same time ranges used previously (Table 7-17). The

¹³ The name of the institute, hospital, organization was removed to ensure anonymity.

mean coded response was 5.22 (SD: 1.88, min 1, max 7) implying that it took, on average, 7 to 8 minutes per one contact. Note that “more than 10 min” is the dominant response.

Similarly, the time to contact the pharmacist (“Average time spent to contact/reach a pharmacist and get a reply”) was requested within the same time ranges, (Table 7-17). The mean coded response was 3.81 (SD: 1.94, min 1, max 7) implying that it took, on average, 2 to 3 minutes per one contact. Note that less time consuming to consult a pharmacist than physician.

Table 7-17. Time spent to contact a physician or pharmacist when consultation is needed (n=32).

	< 1 min	1-2 min	3-4 min	5-6 min	7-8 min	9-10	10+	Mean	SD
Contact physicians	1 (3.12%)	2 (6.25%)	3 (9.38%)	7 (21.88%)	3 (9.38%)	2 (6.25%)	14 (43.75%)	5.22	1.88
Contact Pharmacist	2 (6.25%)	7 (21.88%)	9 (28.12%)	5 (3.12%)	1 (3.12%)	2 (6.25%)	6 (18.75%)	3.81	1.94

7.4.3 Tasks Analysis

The main analyses were concerned with the performance of using the NFC-MACC application. There were 10 tasks, and for each task, there were two primary measures: time and tapping attempts (number of tapping error). Time measured the *Efficiency*, and tapping attempts measures the *Effectiveness*.

Efficiency

The measure of efficiency tends to explore how quickly a nurse can complete the tasks in comparison to the optimum time. We measured two set of times: time spent to reach the desired screen, and time spent to contact a healthcare provider. Table 7-18 presents the descriptive statistics for each task, including the mean completion time to reach the desired screen (with the SD), the minimum and maximum, and one group t-test.

Table 7-18. Descriptive statistics for completion time for the 10 tasks and a t-test comparing performance against the hypothetical mean

Tasks	Mean	SD	Min	Max	One Group t-test	
					t	p(t)
T1	13.88	3.05	10.22	28.40	10.91	.000
T2	10.81	1.60	8.66	15.22	9.94	.000
T3	7.25	1.19	6.04	10.46	10.68	.000
T4	10.42	1.68	8.18	14.09	8.15	.000
T5	10.16	2.11	7.73	17.15	5.79	.000
T6	9.80	2.12	7.53	15.92	4.79	.000
T7	9.35	2.22	7.13	16.53	3.45	.002
T8	8.92	1.60	7.04	13.15	3.26	.003
T9	8.62	2.04	7.02	16.26	1.72	.096
T10	9.03	4.90	6.80	33.78	1.19	.245

The values in the table show a little decrease of the mean of completion times. We conducted a one-group t-test ($\alpha = .05$, non-directional) to compare the mean performance against the hypothetically expected value of 8 seconds (5 seconds for T3). All times were significantly higher than expected for all tasks except T9 and T10. This indicates that the participants were taking longer than ideal (optimum time) for most tasks. In addition, T3 which was expected to be the fastest was one of the slowest (Figure 7-2).

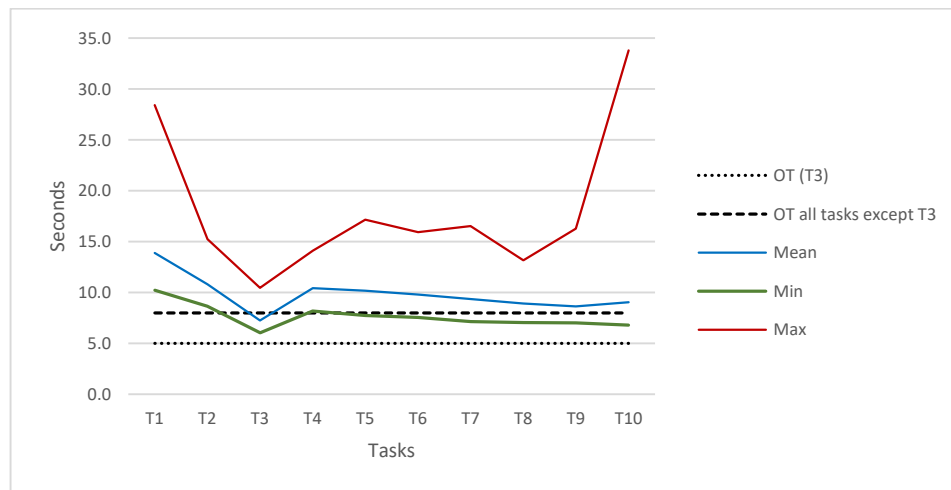


Figure 7-2. Completion Time for the 10 Tasks

In addition, to understand the relation between the completion time for all tasks across participants, we calculated the correlation (Table 7-19). We found that all the values are positive, which implies that participants who are quickest in one task are also quickest in the other tasks.

Table 7-19. Correlation between completion time for the 10 tasks

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
T1	1.00	.12	.33	.42	.53	.38	.28	.29	.29	.22
T2		1.00	.40	.57	.41	.62	.59	.29	.37	.53
T3			1.00	.26	.59	.54	.58	.31	.44	.43
T4				1.00	.53	.48	.44	.30	.48	.51
T5					1.00	.72	.59	.55	.30	.15
T6						1.00	.75	.56	.50	.15
T7							1.00	.48	.30	.14
T8								1.00	.34	.11
T9									1.00	.56
T10										1.00

Notes: $p < .05$ for $r > .35$ (bolded), $p < .01$ for $r > .45$ (bolded-italics)

We hypothesized that the participants would learn how to use the system and the amount of time spent on each task would decrease. Therefore, we used within-subjects ANOVA to find out whether or not the time was different through the tasks. The overall analysis showed a significant difference between Tasks, with $F(9,279) = 23.53$ ($p < .0005$). This indicates that there is a general decrease in the time spent to reach the desired screen, which may imply if the study has a longer duration and there were more tasks the nurses may eventually reach the optimum time. The effect size was large with $\eta^2 = .432$ (partial eta-squared).

In addition, we measured the time spent to contact a healthcare provider (forward the alert). There were 5 tasks that included instructions of contacting healthcare provider (Tasks 6, 7, 8, 9, and 10). Table 7-20 presents the descriptive statistics for these tasks, including the mean completion time to contact a healthcare provider (with the SD), the minimum and maximum, and one group t-test.

Table 7-20. Descriptive statistics for contacting a healthcare provider and a t-test comparing performance against the hypothetical mean (7 seconds)

		N	Mean	SD	Min	Max	One Group t-Test	
							t	p(t)
T6	Forward Alert Time	32	12.11	1.46	9.14	15.44	19.75	.000
	Typing Time	16	28.14	12.10	4.57	47.34		
	Total time	32	26.17	16.52	9.14	58.77		
T7	Forward Alert Time	32	9.84	1.78	6.39	12.93	9.04	.000
	Typing Time	21	22.33	7.38	11.79	36.43		
	Total Time	32	24.49	12.91	6.39	45.77		
T8	Forward Alert Time	32	8.49	1.38	6.29	10.74	6.12	.000
	Typing Time	21	23.83	10.31	8.51	43.18		
	Total Time	32	24.12	14.65	6.44	52.98		
T9	Forward Alert time	32	9.42	1.57	7.33	14.94	8.75	.000
	Typing time	22	22.21	11.54	7.22	48.46		
	Total time	32	24.69	14.09	7.33	58.68		
T10	Forward Alert Time	32	7.61	0.90	6.21	10.16	3.84	.001
	Typing Time	23	24.55	18.78	5.82	89.00		
	Total Time	32	25.26	19.80	6.21	99.16		

One important point is that there was not a *Typing Time* for all participants in T5 through T9. Hence, the sample sizes are smaller (provided in the table above). The *Total Time* reflects the time to complete the task of contacting a healthcare provider including *Forward Alert Time* and the *Typing Time*. However, since the *Typing Time* is affected by the participant's typing speed and the number of words, we focused on the *Forward Alert Time* to measure the efficiency of the communication feature.

The time to forward an alert were compared to an ideal value of 7 sec using a one-group t-test. The t-statistic is shown in Table 7-20 along with the p value. We found that all mean times were significantly different from the ideal of 7, including the last value of 7.61 (the last value also had a small SD, which is why it was significant).

We hypothesized that the participants would learn how to contact the healthcare providers and the amount of time spent on each task would decrease. Therefore, we used within-subjects ANOVA to compare the *forward alert* time over the five tasks. The overall analysis showed a significant difference between tasks, with $F(4,124) = 61.72, p < .0005$. This indicates that there is a general decrease in the time spent to contact a healthcare

provider, dropping from 12.11 to 7.61 (Figure 7-3). This may imply that if the study has a longer duration and there were more tasks the nurses may eventually reach the optimum time. In addition, the mean time in Task 9 increased by 0.93 seconds then decreased in T10 by 1.81 seconds. The increase in T9 was affected by the position of the healthcare provider name in the list. In other word, the participants were asked to contact a physician that was in the in the bottom of the list, which took an extra time to find.

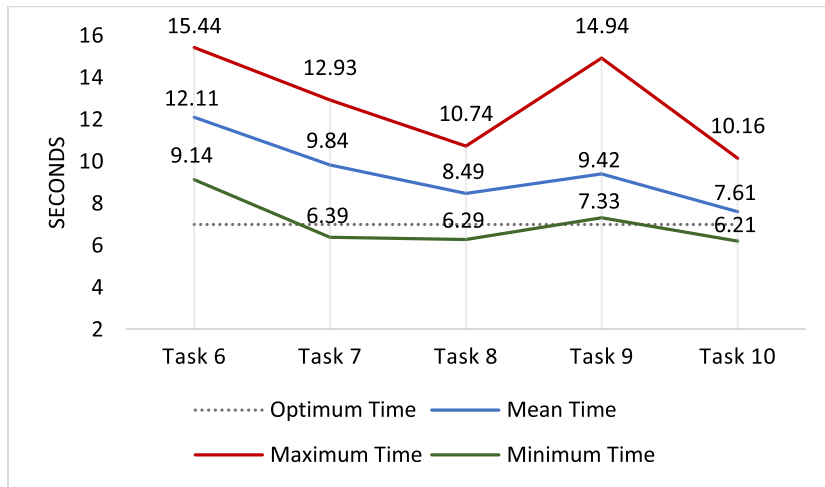


Figure 7-3. Time spent to forward alert to a healthcare provider

NFC-MACC System vs Current Methods Used for Medication Verification

Efficiency is a key component of the NFC-MACC system, therefore the time to complete tasks was assessed. Participants were asked (in the demographic questionnaire) to estimate the time to complete the verification of the five rights, allergy verification, drug interaction verification and contraindication verification using approximate ranges (e.g., “Less than 1 minute”, “1-2 minutes”, “3-4 minutes”, “5- 6 minutes”, “7-8 minutes”, “9-10”, and “10+”), see Table 7-13. These were recoded to represent time as the midpoint of the corresponding range (i.e., .5, 1.5, 3.5, 5.5, 7.5, 9.5 and 10.5). The re-coded values represent an

approximation to the real time¹⁴. We also calculated the mean time of T1-T7 is 9.8 sec which represents the mean time to verify the five rights, the mean time of T8 is 8.9 sec which represents the time spent to verify allergies, the mean time of T9 is 8.6 sec which represents the time spent to verify drug interactions, and the mean time of T10 is 9.02 sec which represents the time spent to verify contraindication. We compared the mean of all tasks using the NFC-MACC system to verify the medication with the mean of estimate time nurses spent to complete the verification of medication using their current methods Figure 4-7. A within-subjects t-test was used to compare mean time for the participants' current method to verify the medication to time for the NFC-MACC system. The average time to verify the medication was significantly shorter than the time for the current method with $t(10) = 3.18$ ($p < .002$). Thus the NFC-MACC system is considerably faster than the participants' current methods.

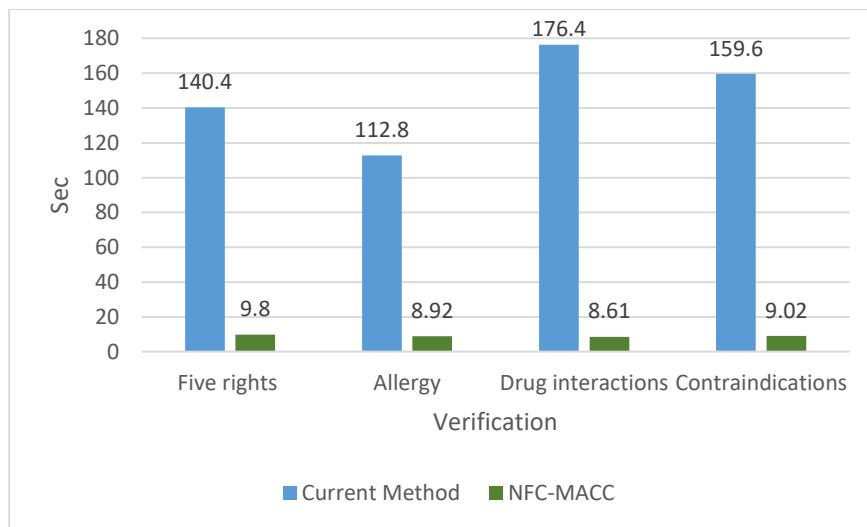


Figure 7-4. Time spent to verify the medication using NFC-MACC system vs participants' current method

¹⁴ "10+" category which was coded as 10.5 – since 10+ could be any time in excess of 10, the code of 10.5 might be an underestimation of the true time.

Effectiveness

The measure of effectiveness tends to explore how easy it is for the nurses to use the NFC-MACC system and complete the tasks with the least number of errors (scanning/tapping errors). The optimum number of tapping is one per tag, meaning that for all tasks 2 times of tapping is the ideal (except Task 3). Task 3 only requires one time tapping because only the patient tag will be tapped. Therefore, the number of errors was coded when the number of attempts in excess of the ideal. A successful completion means completing the tasks with the optimum number of attempts. Table 7-21 provides the number of attempts and the measures of success.

Table 7-21 Scanning attempts per task and success rate per task

	Scanning Attempts				Success		
	Mean	SD	Min	Max	N = 32	Mean	SD
T1	2.25	0.57	2.00	4.00	26 (81.3%)	0.81	0.40
T2	2.09	0.29	1.00	3.00	29 (91.3%)	0.91	0.30
T3	1.51	0.36	2.00	3.00	27 (84.4%)	0.84	0.37
T4	2.28	0.52	2.00	4.00	24 (75%)	0.75	0.44
T5	2.28	0.68	2.00	5.00	26 (81.3%)	0.81	0.40
T6	2.28	0.92	2.00	7.00	27 (84.4%)	0.84	0.37
T7	2.25	0.80	2.00	6.00	28 (87.5%)	0.88	0.34
T8	2.16	0.37	2.00	3.00	27 (84.4%)	0.84	0.37
T9	2.25	0.57	2.00	4.00	26 (81.3%)	0.81	0.40
T10	2.28	0.81	2.00	6.00	27 (84.4%)	0.84	0.37

We hypothesized that the number of attempts to read the tags would decrease from Task 1 to Task 10. Hence, a second within-subjects ANOVA tested differences between the number of attempts for all ten tasks (except T3) was performed. The results indicated that there was no significant change in the number of attempts to completion with $F(0.24) = 1.971$ ($p < .95$). We also hypothesized that the number of successful completion would increase from Task 1 to Task 10, and we conducted another within-subjects ANOVA to test the differences between the number of successful completion for all tasks across participants. However, the test shows no significant difference with $F(0.39) = 1.91$ ($P < .93$). By referring to the number of successful completions in Table 7-21, it appears that there was no significant difference between the attempts because the majority of participants made the optimum number of attempts in all tasks. In addition, by referring to

the maximum number of attempts, a participant could make up to 7 attempts trying to scan (tap) a single or two tags. This could mean that a participant would require some learning or it could mean using the NFC technology may raise a readability issue like its ancestors' RFID and Barcode.

To understand if there was a relation between successful completion and speed (i.e. whether or not successful participants were faster), we calculated the correlations between Success and Time to completion within each task (Table 7-22).

Table 7-22. Success and time to completion.

		Success									
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Time to Completion	T1	-.50	.01	-.02	-.10	-.23	-.30	.05	.10	-.01	.07
	T2	.07	-.67	-.33	-.36	-.18	-.28	-.22	-.02	-.13	-.57
	T3	-.02	-.16	-.75	-.05	-.58	-.47	-.40	-.09	-.37	-.34
	T4	-.02	-.13	-.13	-.60	-.25	-.10	-.05	.24	-.03	-.20
	T5	-.09	-.19	-.38	-.12	-.82	-.56	-.16	-.13	.06	-.11
	T6	-.01	-.28	-.34	-.10	-.56	-.82	-.30	-.12	-.19	-.26
	T7	.05	-.31	-.40	-.03	-.49	-.41	-.70	-.13	-.14	-.25
	T8	.07	-.23	-.08	.05	-.43	-.33	-.09	-.71	-.24	-.30
	T9	.12	-.12	-.36	-.36	-.08	-.47	-.10	-.04	-.70	-.26
	T10	.13	-.14	-.40	-.37	.07	.04	.05	.05	-.35	-.65

The Success was a binary variable (coded as 1 for success and 0 for failure). Thus, correlation between Success and Time to completion is the same as the two-group t-test comparing the times for “successful” participants with “unsuccessful” participants within each task. Furthermore, a negative correlation implies that “successful” participants were *faster*. The diagonal of Table 7-22 shows that successful participants were faster for all tasks. In other word, participants who completed the tasks more quickly also tended to have fewer errors. In addition, the first column codes for the participants who were successful (or not) in T1. We noticed that success in T1 did not predict success in the rest of the tasks. That is in general, those who were successful in T1 were not the participants who were faster in the rest of tasks (but they were faster in T1). This may imply a little learning between tasks. From our observation during the tasks phase, we noticed that participants found it easy to the extent that they become faster in *tapping motion*. Fast *tapping motion*

result in failing to pick up the tag ID. However, with multiple times of failing to obtain the ID, the participants were learning how to tap with slower motion.

7.4.4 Questionnaire

The questionnaire assessed the following usability attributes: Perceived Usefulness, Perceived Ease of Use, Satisfaction, Usefulness for Patient Care, and Beliefs about Patient Perceptions. All questions used a five point Likert scale coded as Strongly Agree (1), Agree (2), Neutral (3), Disagree (4), and Strongly Disagree (5).

Perceived Usefulness

For perceived usefulness, the questions initiated by “Compared to the current method I use for bedside medication administration, I think the NFC-MAC system:”. There were 9 questions, but 6 of the 10 had sub-questions. Hence the total number of questions was 50. Q1-2 evaluated the usefulness in terms of system impact-career mission. Q3,4 and 7 evaluated the perceived usefulness in terms of productiveness. Q5 evaluated the performance speed. Q6 and 8 evaluated the general usefulness. Q9 evaluated the information need (Table 7-23).

Table 7-23. Distributions and descriptive statistics for perceived usefulness questions

Q #	Simplified Question	SA ←Rating → SD					Mean	Std Dev
		1	2	3	4	5		
1	Improve the MA process in nursing practice	15	16	0	1	0	1.59	0.67
2	Improve the comm. between the nurses and healthcare provider	19	10	1	2	0	1.56	0.84
3a	Easier to: Identify the patient	16	14	0	2	0	1.56	0.84
3b	Easier to : Identify the medication	23	7	1	1	0	1.59	0.88
3c	Easier to : Confirm the five rights	27	5	0	0	0	1.63	0.79
3d	Easier to : Verify allergy	19	9	2	2	0	1.16	0.37
3e	Easier to : Verify drug interactions	29	3	0	0	0	1.09	0.30
3f	Easier to : Verify contraindications	26	5	0	1	0	1.25	0.62
3g	Easier to : Document the administered medication	20	10	0	2	0	1.50	0.80
3h	Easier to : Communicate with other treatment team providers	16	12	2	2	0	1.69	0.86
3i	Easier to : Administer the medication to patients in general	13	14	1	4	0	1.88	0.98
4a	Faster to: Identify the patient	18	4	8	2	0	1.81	1.03
4b	Faster to : Identify the medication	18	7	5	2	0	1.72	0.96
4c	Faster to : Confirm the five rights	21	10	1	0	0	1.38	0.55
4d	Faster to : Verify allergy	26	5	1	0	0	1.22	0.49
4e	Faster to : Verify drug interactions	29	3	0	0	0	1.09	0.30

Q #	Simplified Question	SA ←Rating → SD					Mean	Std Dev
		1	2	3	4	5		
4f	Faster to : Verify contraindications	27	4	0	1	0	1.22	0.61
4g	Faster to : Document the administered medication	25	4	1	2	0	1.38	0.83
4h	Faster to : Communicate with other treatment team providers	20	8	2	2	0	1.56	0.88
4i	Faster to : Administer the medication to patients in general	18	8	2	4	0	1.75	1.05
5	Provides a feedback in timely manner, in case of a medication error	23	7	2	0	0	1.34	0.60
6a	Provides adequate alert information related to: confirming the five rights	22	9	0	1	0	1.38	0.66
6b	Provides adequate alert information related to: verifying allergy	27	5	0	0	0	1.16	0.37
6c	Provides adequate alert information related to: verifying interactions	28	4	0	0	0	1.13	0.34
6d	Provides adequate alert information related to: contraindications	26	5	0	1	0	1.25	0.622
6e	Provides adequate message content to send to a healthcare provider	17	15	0	0	0	1.47	0.507
7a	Requires less effort to: Identify the patient	17	6	6	3	0	1.84	1.051
7b	Requires less effort to: Identify the medication	17	7	5	3	0	1.81	1.03
7c	Requires less effort to: Confirm the five rights	21	8	3	0	0	1.44	0.669
7d	Requires less effort to: Verify allergy	26	5	1	0	0	1.22	0.491
7e	Requires less effort to: Verify drug interactions	30	2	0	0	0	1.06	0.246
7f	Requires less effort to: Verify contraindications	29	2	0	1	0	1.16	0.574
7g	Requires less effort to: Document the administered medication	25	5	0	2	0	1.34	0.787
7h	Requires less effort to: Communicate with healthcare providers	24	6	0	2	0	1.38	0.793
7i	Requires less effort to: Administer the medication to patients in general	19	9	2	2	0	1.59	0.875
8a	More useful for: identifying the patient	13	12	6	0	1	1.88	0.94
8b	More useful for: identifying the medication	16	8	7	0	1	1.81	1.00
8c	More useful for: confirming the five rights	20	8	4	0	0	1.50	0.72
8d	More useful for: verifying allergy	25	4	3	0	0	1.31	0.64
8e	More useful for: verifying drug interactions	28	3	1	0	0	1.16	0.45
8f	More useful for: verifying contraindications	28	2	1	0	1	1.25	0.80
8g	More useful for: documenting the administered medication	22	6	2	2	0	1.50	0.88
8h	More useful for: Communicating with healthcare providers	22	5	3	2	0	1.53	0.92
8i	More useful for: Administering the medication to patients in general	18	9	3	2	0	1.66	0.90
9a	Enable me to find information I need to confirm the five rights	16	13	3	0	0	1.59	0.67
9b	Enable me to find information I need to verify allergy	27	4	1	0	0	1.19	0.47
9c	Enable me to find information I need to verify drug interaction	29	3	0	0	0	1.09	0.30
9d	Enable me to find information I need to verify contraindications	26	4	0	1	1	1.34	0.90
9e	Enable me to find information I need to document medications	24	5	2	1	0	1.38	0.75

Q #	Simplified Question	SA ←Rating → SD					Mean	Std Dev
		1	2	3	4	5		
9f	Enable me to find information I need to contact healthcare providers	22	7	2	1	0	1.44	0.76

The general result is positive, and most of the responses indicated a favorable impression of the NFC-MACC system in comparison to the current method used for BMA. Answers are concentrated in the SA and A categories. This is also borne out by the fact that the means are nearer to one (SA) than to five (SD). Note that all questions were valenced such that SA indicated approval of the system usefulness. To better understand the responses to the questionnaire we gathered the responses related to productiveness for identifying the patient and medication, verifying the five rights, drug allergy, drug interactions, contraindication, documentation, and communication between healthcare providers. Over 80% of participants found identifying the patient and medication easier than their current method, however, easier does not necessarily mean it is faster or required less effort (Figure 7-5). A total of 68.8% and 71.9% believed that the system is faster and required less steps to identify the patient, respectively.

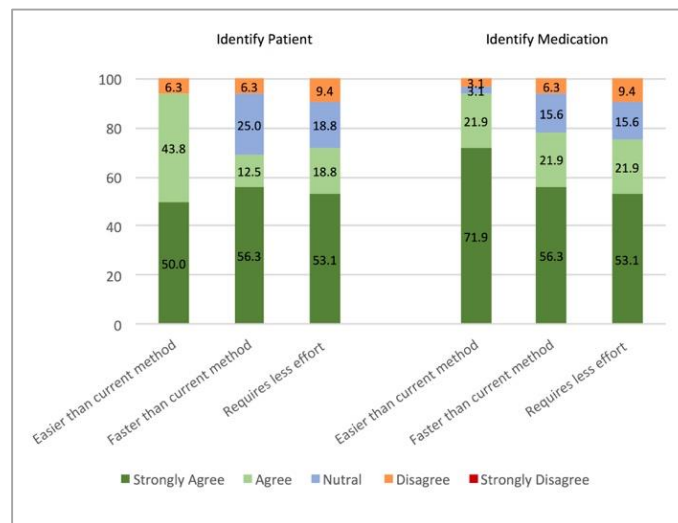


Figure 7-5. The percentage of nurses' response regarding identifying the patient and the medication using the NFC-MACC system compared to their current method

In addition, we found that compared to the current method nurses use for bedside medication administration, all participants think that the NFC-MACC system provide an

easier, faster, and effortless for verifying drug interactions. No negative responses were reported when asked about interactions verification. Similarly, no negative responses were reported for verifying the *five rights* of medication administration, however, 9.4% selected neutral for “Requires less effort to verify the 5 rights”. In addition, few participants 6.3% did not feel that the system would be easier, faster, effortless in comparison to their current method when it comes to documentation and clinical communication (Figure 7-6).

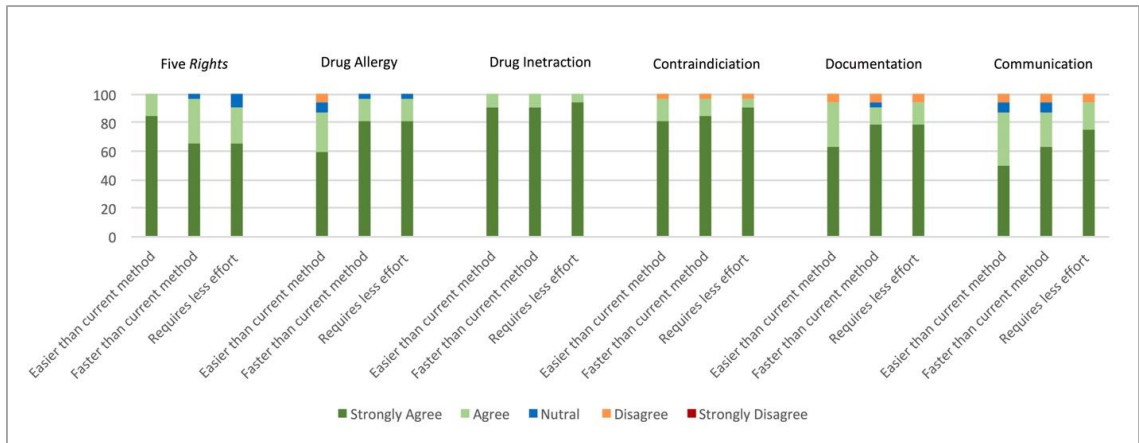


Figure 7-6. The percentage of nurses’ response regarding the medication verification, documentation and communication using the NFC-MACC system compared to their current method.

Moreover, 84.4% and 81.3% agree that the system is *easier* and *faster*, respectively, than their current method to administer the medication to patients in general, while 12.5% disagree with that, and the remaining selected neutral.

When participants asked about general usefulness and the information need, the majority found the system provides adequate information the nurses need when verifying the medication compared to their current method of seeking information, and the disagreement with that was no more than 6.3%.

Perceived ease of use

The perceived ease of use used the same template. There were only 9 questions. Table 7-24 presents the distributions and descriptive statistics for each question. Q11 and 16 evaluated the competency, Q12-15 evaluated the learnability, Q17 evaluated the general ease of use, Q18 evaluated the memorability, and Q19 evaluated the error prevention.

Table 7-24. Distributions and descriptive statistics for the perceived ease of use questions

Q #	Simplified Question	SA ←Rating → SD					Mean	Std Dev
		1	2	3	4	5		
11	I am comfortable with the ability to use the NFC-MAC system.	23	9	0	0	0	1.28	0.46
12	Learning to use the NFC-MAC system was easy	25	7	0	0	0	1.22	0.42
13	Learning to scan the patient's and the medication's tag was easy	25	6	1	0	0	1.25	0.51
14	Learning to initiate a communication with a healthcare provider was easy.	26	6	0	0	0	1.19	0.40
15	Learning to document the administered medication was easy.	27	5	0	0	0	1.16	0.37
16	It will be easy for me to become skillful at using the NFC-MAC system.	28	4	0	0	0	1.13	0.34
17	I find the NFC-MAC system easy to use	27	5	0	0	0	1.16	0.37
18	I was able to remember how to use the NFC-MAC system during the tasks phase	24	8	0	0	0	1.25	0.44
19	Whenever I make a mistake using the NFC-MAC system I recover easily and quickly	23	9	0	0	0	1.28	0.46

As can be seen in Table 7-24, almost all participants thought that the system was easy to use. All of the responses were concentrated in the SA and A categories, and the mean was always near to one. No negative response was reported and only one neutral feeling was selected about the easiness of scanning/tapping on the NFC tags.

Satisfaction

The satisfaction assessment contained just two questions with no common initial question. Table 7-25 presents the distributions and means with SDs per question.

Table 7-25. Distributions and descriptive statistics for the perceived satisfaction questions

Q #	Simplified Question	SA ←Rating → SD					Mean	Std Dev
		1	2	3	4	5		
20	I am generally satisfied with the NFC-MAC system	20	11	0	1	0	1.44	0.67
21	I like the NFC-MAC system as a method of administering medications compared to the current method I use	18	8	4	2	0	1.69	0.93

Results in Figure 7-7 indicate that the participants were generally satisfied with the system, though all do not feel that it is “better” than their current methods used for verifying medications, documentation and communication. A total of 81.3% preferred the NFC-MACC system over the current method, 12.5% felt neutral and 6.3% preferred their current method.

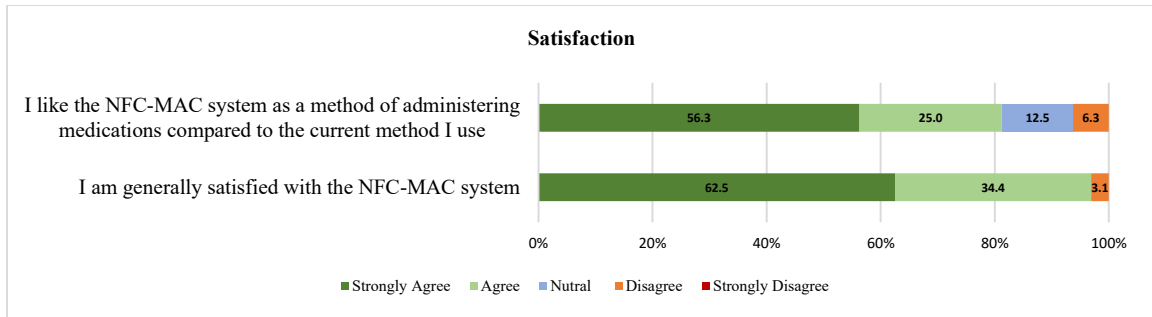


Figure 7-7. The percentage of response to the Satisfaction questions

Perceived Usefulness for Patient Care

The perceived usefulness for patient care section contained four questions preceded by a common initial questions, “Compared to the current method I use for bedside medication administration, I think the NFC-MAC system:”. Table 7-26 presents the distributions and means with SDs per question.

Table 7-26. Distributions and descriptive statistics for the perceived usefulness for patient care questions

Q #	Simplified Question	SA ←Rating → SD					Mean	Std Dev
		1	2	3	4	5		
22	Will improve patient care	15	14	2	1	0	1.66	0.75
23	Will reduce the likelihood of medication errors	24	6	2	0	0	1.31	0.59
24	Will facilitate better patient care decision-making?	18	8	4	1	1	1.72	1.02
25	Will make caring for patients easier	16	8	7	1	0	1.78	0.91

The general impression of Perceived Usefulness for Patient Care is positive. There are only one or 2 disagreements per question, and 2 to 7 remain neutral. The majority 90.7% and 75% believed that the NFC-MACC system will improve the patient care and make make caring for patients easier respectively, while 3.1% disagree with these statements (Figure 7-8). Similarly, the majority 81.3% agreed that the system will facilitate the patient care decision-making, however, 6.2% of participants disagree with that statement. A total of 93% agreed that the system will reduce the medication errors, and the no negative response was reported for this statement.

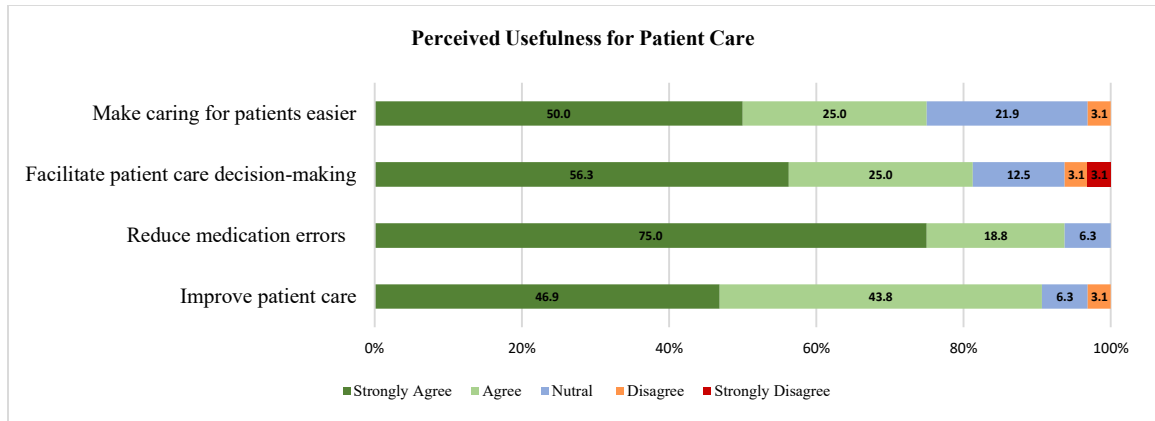


Figure 7-8. The percentage of response to perceived usefulness for patient care questions

Beliefs: Patient Perceptions

Participants were finally asked to state what they *believe* patients would think of the system. There were four questions, all of them initiated by, “In your opinion, do you think patients (or their family) would:”. Table 7-27 presents the distributions and descriptive statistics for these questions.

Table 7-27. Distributions and descriptive statistics for the beliefs: patient perceptions questions.

Q #	Simplified Question	SA ←Rating → SD					Mean	Std Dev
		1	2	3	4	5		
26	Like the NFC-MAC system	14	14	3	1	0	1.72	0.77
27	Believe the NFC-MAC system will reduce the chances of medication errors	18	11	3	0	0	1.53	0.67
28	Believe the NFC-MAC system will be good for quality patient care	16	12	4	0	0	1.63	0.71
29	Appreciate being scanned before medication administration	13	8	10	1	0	1.97	0.93

The general impression of what the participants *believe* patients would think of the system is positive. There is one disagreement per question, and 3 to 10 remain neutral. The majority of participants 87.6% and 65% believed that the patients would like the system and appreciate being scanned respectively, only one participant disagree with these statements, and the rest remained neutral (Figure 7-9). Similar to previous section, when asked about the possibility of medication errors reduction, the majority agreed that the patient would also believe that the system will reduce the medication errors, and no negative response was reported.

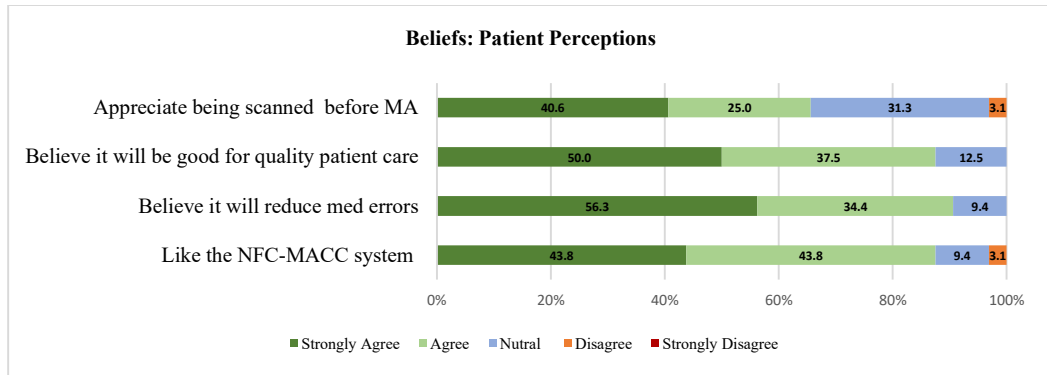


Figure 7-9. The percentage of response to beliefs: patient perceptions questions

7.4.5 Interview Analysis

Strengths

We derived the strength of the system from the interview question *what do you like about the system?* The iterative coding of the interview result in five categories of strength that are related to the system’s function, components (use of smartphone and NFC technology), interface, learnability and memorability, and usefulness. Each category has sub-categories and codes that are discussed in details in the following sections (Figure 7-10).

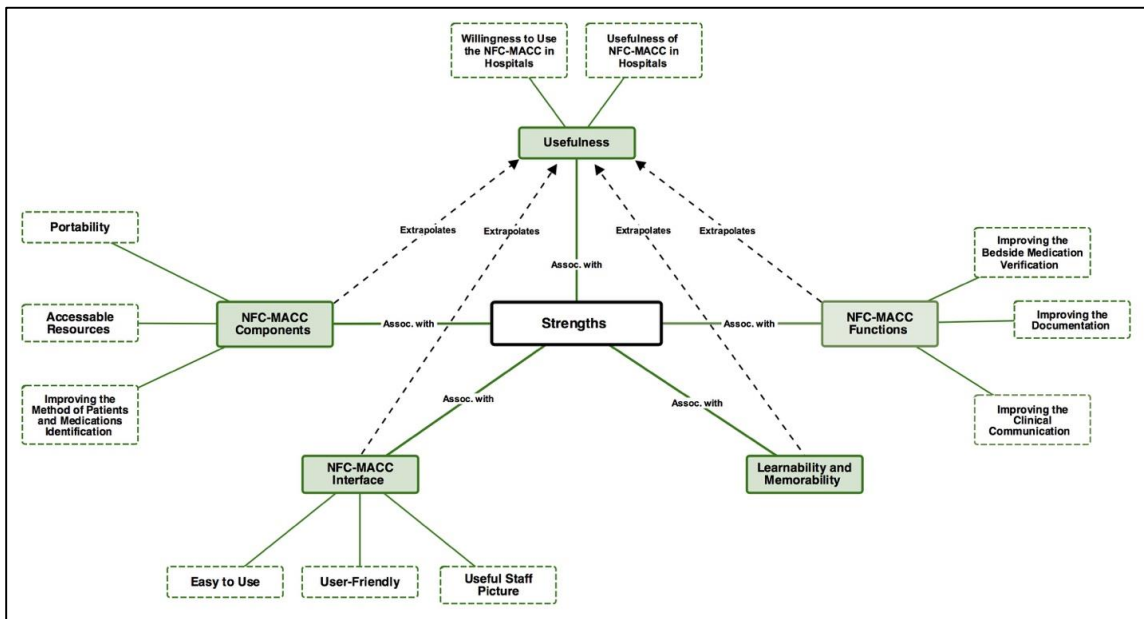


Figure 7-10. The NFC-MACC system strength categories and subcategories

The Strengths of NFC-MACC Functions:

A) Improving The Bedside Medication Verification

Nurses compared their current practice of medication verification (including 5 rights of medication administration, allergies, interactions, and contraindication) with our NFC-MACC system. From their responses we created 4 subcategories which are: *efficient medication verification*, *easy to verify medication*, *effective medication administration* and *sufficient alert information*, (Figure 7-11).

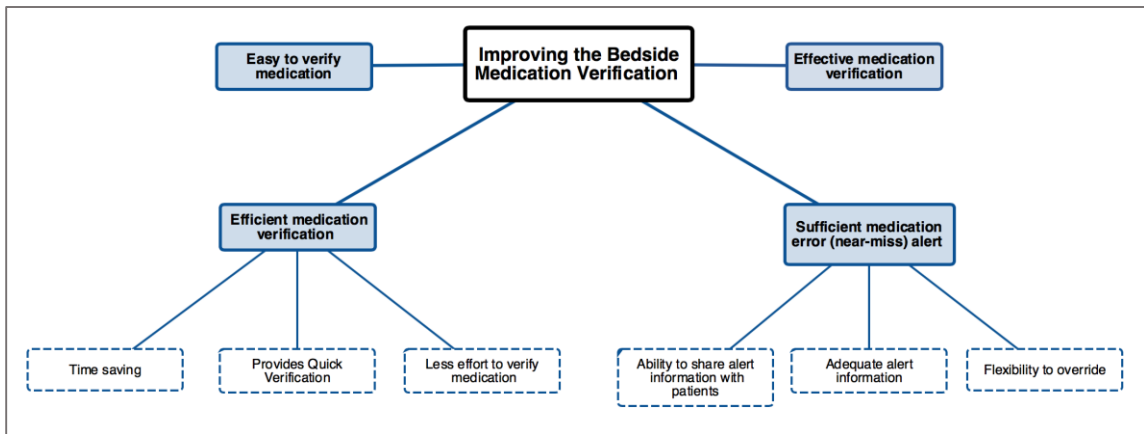


Figure 7-11. The sub-categories of *Improving the Bedside Medication Verification* and its associated codes

1) Efficient Medication Verification: the majority of the nurses (16/32) agreed that the NFC-MACC system provides an efficient verification of medication compared to their current method of verification because it requires less effort, saves time and provides quick verification.

First, the system requires less effort to verify the medication. In nurses' current practice, verifying the medications requires an effort to assure a safe delivery of medication. The patient and the medication information are not gathered in one place. In other word, nurses have to search for the information from different sources in order to verify the five rights, allergies, interactions, and contraindication. In addition, nurses explained how it is challenging when they are not sure where to find the complete information about a certain condition. For example, the patient's allergies may not be all listed in one place. Therefore, the nurses appreciated how the NFC-MACC system is linked with all the resources and provides the needed information in one screen.

P32 stated:

“For me the big one was allergies and contraindications were really good because those are things that are sometimes harder to find and there's a lot of differences between different papers. So sometimes with, like, allergies it will be written on the care plan or something, and on the MAR it might be this plus this”

In addition, nurses explained that the complications in the steps needed to verify the medication have played a vital role in skipping some verifications such as drug interactions and contraindications, and lead to the dependency on physicians and pharmacy to verify that.

P28 stated:

“I'd say we do pretty cursory kind of look at that. We rely on the physician to know what the drug interactions are, and also pharmacy.”

Thus, the nurses liked how the NFC-MACC will simplify the complications of these checks and makes them available with simple steps, and help nurses to be in compliance with the all the required medication verifications.

P10 commented:

“When you have so many patients it's sometimes impossible to remember what they're on, what you're giving, and what the interactions are. If you had to look up that for every single medication, it would be near impossible ... so to have this easily accessible is lovely.”

Moreover, the current sources nurses use to verify medication do not provide a clear way of information presentation. Nurses complained about the complex presentation of information and how it adds to the effort to find what they are looking for.

P21 said:

“I also really like that it tells you the contraindications and stuff, because I've spent 30 minutes looking up one medication to see if it interacts with other things and it can take a while”

It also worth noting that the electronic sources used in current practice provide a classic form of browsing information and they do not provide alerts or notification features based on entry. Thus, nurses liked the alert feature in the NFC-MACC and how it draws attention to the problem without an overwhelming display of text.

P32 stated:

“Just because it pops - I'm not having to go search for it. Like usually it would take you a couple of minutes to go onto the drug guide and if the drug guide's not electronic then you're searching through pages for the right medication so that takes time... so with it just popping up it felt, no, this is contraindicated, that was helpful.”

Accordingly, nurses believed that the NFC-MACC system allows for accomplishing the complicated medication verification tasks through short simple steps.

P6 commented:

“What I like about this App is that it somehow expedited all of my tasks”

Second, the system provides quick verification. Nurses stated that the NFC-MACC system provides an immediate verification right at the bedside and alerts the nurses right then and there, before they administer the medication. Not only is NFC-MACC fast, but it is also agreed upon that, in comparison to the currently used methods of verification, it is far more efficient. The nurses' current method depends completely on their searching skills for the right information. In addition, the fact that the sources of information are distributed in different places makes the searching process even slower.

P24 stated:

“I think that this gives you all the information that you need at the bedside in a way that's really efficient and really user friendly. “

Third, the system saves the nurses time. The nurses explained that due to the time constrains and the high number of medications administered to a single patient, it is nearly impossible to verify every single medication. The fact that the NFC-MACC provides a simple and fast way of verification results in saving time. Therefore, nurses pointed out

how the efficiency of NFC-MACC will cut back the time spent on looking for the right information.

P23 siad:

“I mean for me to physically go and look up a drug interaction, it takes a lot of time. We do have a chart in the backroom, and we have a computer system in our med room that allows us to look that up, but to actually get into that program and stuff it takes a lot of time that sometimes when you’re in a hurry you don’t have. So I love that feature of it.”

2) Sufficient Alert Information: the majority of nurses (25/32) were satisfied with the alert and found it provides adequate alert information, flexibility to override an alert, and ability to share the alert information with patients.

First, it provides adequate alert information. The nurses agreed that the alert content is sufficient to understand the reason for the medication error. They liked how it provides lots of information clearly and in a few words that makes them able to make an action based on that.

P14:

“I find it’s pretty straightforward. It’s just written like any other pharmacological information.”

Second, the system provides flexibility to override the alert. The alert feature is made to draw attention to potential medication error and not to replace the professional judgment of the nurse. Therefore, nurses appreciated the flexibility of overriding an alert. This is very important in nursing practice because it is common that in automatic alerting systems to have a false alarm cases. In addition, some medication alerts such as (wrong time) are more likely to be overridden due to an acceptable late administration of medication. For example, if patients are off unit for an X-ray, it is expected that they will receive their medication late.

In nurses’ current practice, Pyxis provides an option to override when nurses’ dispense the medications, however, this system are made mainly for managing the

dispensing of medication and not to verify the five rights, allergies, drug interactions or contraindication.

P2 stated:

“I’m glad you have an override because I give my medications at the wrong time all the time.”

Some nurses had an experience with BCMA system, and explained that the alert system integrated with BCMA is frustrating to override. It requires the nurses to enter a reason for each override. In contrast, NFC-MACC overriding option is linked directly to the documentation feature where the nurses have an option to add a justification for overriding or document directly in the patients’ MAR.

P14 commented:

“I really like that there’s that override built in. And I like that you don’t have to have a comment to go forward. Because that was something that really slowed people down in the barcode.”

Third, the system allows for sharing alert information with patients. The nurses pointed at the usefulness of how the alert is readily available at the bedside and displayed on the smartphone. It enables the nurses to share the alert information with patients if they have a concern or questions about the reason of holding the medication.

P16 said

“I could even share this with a patient if they’re confused or I could also show them, “Oh this is actually like why we can’t give this medication at this time” so that we could kind of be on the same page.”

3) Effective Medication Verification: the complications of the current method of verifying allergies, drug interactions, and contraindications result in the nurses skipping the verification, which in return lessens its effectiveness. In addition, (4/32) nurses explained that, even when they search for the information the chances of finding what they are looking for is pretty low. On the other hand, nurses find NFC-MACC more trustworthy and effective because it is linked to the patients’ electronic records as well as the drugs information database. This makes the NFC-MACC more accurate and provide a reliable

information readily available at the bed side.

P24 commented:

“The fact that you know that that information is being linked to their entire medical record electronically. So if you are going to give a medication, all of that information is being linked and processed there... It’s a double check that’s better realistically than the initial check that you’re doing. So I think that’s the piece I like the most.”

4) Ease of Verifying the Medication: It transforms the difficult tasks of looking for the right information to insure safe delivery of medication into easy ones. It allows for an automatic medication verification right at the bedside and provides an instant alert with a sufficient information that helps the nurses achieve a complete and accurate verification without great effort. All nurses (32/32) agreed upon the simplicity and the ease of verifying the five rights, drug interaction, allergies and contraindication compared to their current method.

P15 said:

“It would probably be a lot easier to go back and look at like the patient’s history and what they’ve had, what medications they’ve had and all the other patient’s information, than having to ruffle through a bunch of papers.”

B) Documentation Improvement

Nurses compared their current practice of documentation with the NFC-MACC system. From their responses we created four subcategories which are: *easy*, *efficient*, and *accurate documentation*, (Figure 7-12).

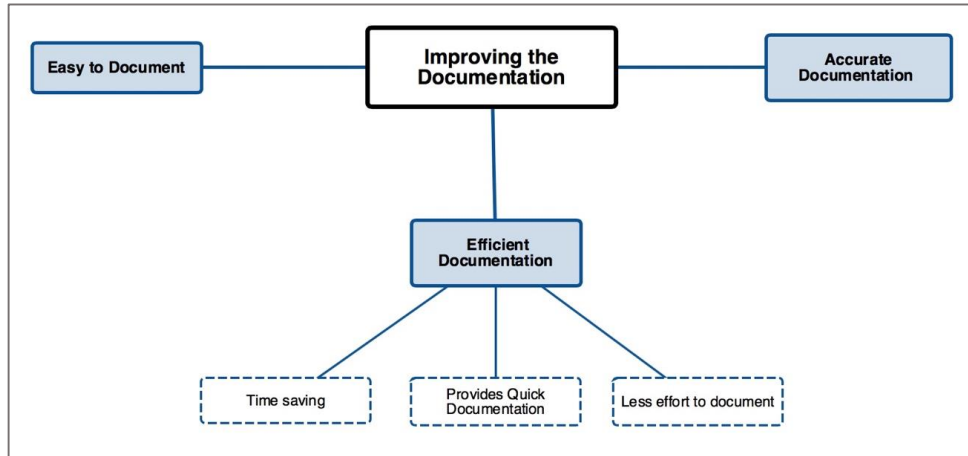


Figure 7-12 The sub-categories of *Improving the Documentation* and its associated codes

1) Accurate Documentation: the accuracy of documentation means that was the medication actually given to patients and what it is the actual time it was given. In current practice, nurses should sign the MAR after delivering the medication to patients. When nurses have a busy shift the chance of forgetting to sign the MAR is very high. The problem with forgetting to document the administered medication may cause in giving the medication twice (duplicate medication error) by the same nurse or by the nurse' next shift. In contrast, the documentation feature in the NFC-MACC allows for an immediate documentation right at the bedside when the nurses actually deliver the medication to a patient. (9/32) nurses pointed at how the NFC-MACC will help in preventing missing documentation.

P10 said:

“I feel like doing it in the room, having it documented it when you give it and before you're gone, would be lovely, because there would be no chance that it could get missed or hours would go by before someone knew it was given”

In current practice, if the medication was not documented, the nurses attempt to deliver it again. The current automated despising machine (Pyxis) does alert the nurses if they tried to dispense the same medication for the same patient again. However, the despising alert does not mean the medication was given. In the contrary, if the nurses administered the

medication and documented that at the bedside, the NFC-MACC will alert the nurses if they tried to deliver the medication twice. Therefore, giving nurses the ability to document the administration information when and where medication is being delivered allows for accuracy and eliminates the duplicate administration of medication error.

2) Efficient Documentation: almost third of the nurses (10/32) found it efficient to document a medication because it requires less effort, saves time and provides quick documentation.

First, it requires less effort to document a medication. The current method of documentation requires the nurse to leave the patient's room and manually sign each medication on the patient's MAR. This process requires an effort and causes the issue of missing the documentation during busy shifts. On the other hand, the ability to document right at the bedside replaces the steps of documentation in current method with a simple button click.

P25 stated:

"I think not having me go back and chart it, that you've given it, I think that's an awesome feature."

In addition, the accuracy of documenting the medication increases the efficiency of finding out whether the medication was given by previous shift's nurses. In other words, if the new shift's nurses tried to administer the medication again, the duplicate medication administration alert will notify the nurses of whom gave the medication and at what time. In the contrary, the current method of finding out whether the medication was given in previous shift requires longer steps.

P27 commented:

"if I was coming on shift and someone hadn't signed the paper MAR, I would call them... I feel like this would just be like a quicker way of like finding out if it was already given kind of thing."

Second, NFC-MACC provides quick documentation. It does not require a lot of effort to document a medication which makes it much faster than the nurses current

method of documentation. Nurses liked how the system is linked to the medication verification process so when there is no near-miss issues they can deliver the medication and document that at the bedside in one click.

P20 stated:

“It’s very quick and it’s just a click away”

Third, time saving in documentation is one of strength points in NFC-MACC system. The quick and simple process of documentation result in reducing the time nurses need to accomplish this task. In contrast to the nurses’ current process where they have to go back every time to MAR and initial next to medication each single medication.

P5 said:

“I think it’s going to cut down on documentation time as well. Because as soon as you give it, like, you document it”

3) Easy Documentation: in nursing best practice, nurses are expected to document each medication right after the administration. This routine is challenging for nurses especially on a busy shift where there are number of patients and number of medications that need to be delivered in a certain time. Their inefficient current documentation method makes it difficult to accomplish this task. Therefore, (9/32) nurses pointed that the NFC-MACC simplifies the documentation and save them the trips to the MAR to document every single medication.

P13 stated:

“I definitely like the documentation piece of it a lot better. The current documentation that I use is really annoying and painstaking, so I definitely like that feature. And I can see that there’s a lot of good components of it.”

In addition, the documentation feature is linked with the nurse’s login information where the nurse’s name will be automatically linked to the delivery of the medication, which means no initials or name entry is required.

P5 commented:

“I mean your name is already there and if it's...if you gave it...you just leave it as administered and press finish. That's so easy. “

The nurses also like how NFC-MACC provides an option in the documentation feature to write a note about the administration if needed. Unlike their current documentation method, the option of adding information to the patients' MAR is not available.

C) Communication Improvement

We found 11 strengths categories and 12 sub-categories under the improvement of communication. Four categories and four sub-categories are related the method of communication (smartphone/texting), four categories and three sub-categories are related to the content of the message, one category and for sub-categories are related to both. We divided the categories into three groups. The first group (blue) represents the communication improvement categories for nurses. The second group (yellow) represents the communication improvement categories for healthcare providers (physician and pharmacist). The third group (orange) represents the communication improvement categories for both nurses and healthcare providers, (Figure 7-13).

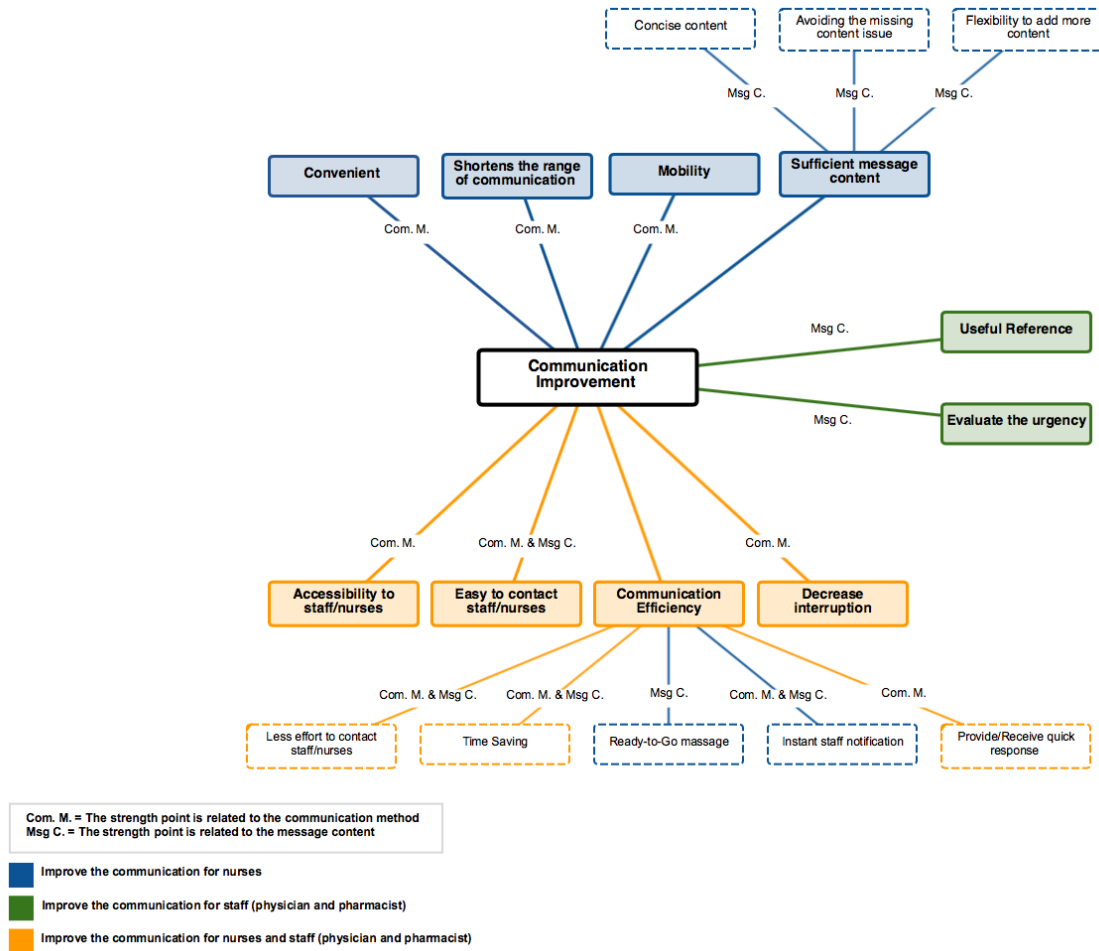


Figure 7-13. The sub-categories of *Improving the Clinical Communication* and its associated codes

1) *Instant Accessibility to Healthcare Providers/Nurses*: Accessibility to healthcare providers and accessibility to nurses is one of the strength points for our system that was discussed by (14/32) nurses. Being able to reach the physician or the pharmacist is an issue with the nurses' current method of communication. Nurses described their current method of communication with the term *phone tag* where the nurse initiates the contact request by paging the physician, then, both of them attempt to contact each other by telephone. However, neither is able to get a hold of the other for a real-time conversation, and it continues for a period of time.

P27 stated:

“Sometimes I’ll page a doctor and then it takes ten minutes, like go do something else and then they call back and I’m not there, like you’re kind of playing phone tag.”

In addition, the communication access points (telephones) are limited in the nurses' current method of communication as opposed to our proposed method of communication where the number of communication access points is multiplied through assigned clinical smartphones for each healthcare provider. Therefore, (13/32) nurses expressed that, in comparison to their current method of communication, our method will allow them to reach the healthcare provider immediately when they need a consultation.

P4 stated:

“I feel I can reach the physician at any moment which is not the case now” (P4).

Also, nurses believe that our system will allow the healthcare provider to get hold of the nurses as oppose to their current method of communication.

P32 commented:

“I think it would be beneficial in their [physicians] cases too. Take less time off their hands when they could be doing something else rather than paging somebody waiting for a phone call. Having seven pages to call. Some in different units rather than just having the text messages and being able to go through that rather than doing the paging”

2) Shortens the Range of Communication: The range of communication means how many healthcare providers are unnecessary involved in the communication between the nurse and the physician or the nurse and the pharmacist. If the nurses are not able to wait at the desk when they page a physician, somebody (who probably responded to the physician call) has to get a hold of the nurse and say a physician on the phone. The accessibility to healthcare providers/nurses strength point discussed above may has a role in shortening the range of communication. Therefore, (2/32) nurses highlighted how our communication method eliminate the unnecessary involvement of other healthcare providers.

P31 said:

“it's only one train of communication ... there's just you and the pharmacist or you and the doctor. So it kind of shortens that range of communication”.

3) Communication Efficiency: Efficiency of the communication means how fast the nurses think that they will complete the task of communication when consultation about a medication error (near-miss) is needed. This includes the preparation of the information needed to be communicated, and getting hold of the healthcare provider and vice versa. The efficiency of our method of communication is affected by the combination of the source of communication (mobile phone) and by the content of the message sent to the healthcare providers. A total of (26/32) nurses emphasized the efficiency of our communication method in different ways which we translated to sub-categories. These include instant healthcare providers notification, provide/receive quick response, time saving to contact, less effort to contact healthcare providers/nurses, and ready-to-go message (content).

First, NFC-MACC provides instant healthcare providers notification. The nurses discussed that the *phone tag* issue in the current method of communication causes unnecessary delays in notifying the healthcare provider when a medication administration-related consultation is needed. In contrast, nurses liked that how the system capable of immediately notifying the healthcare provider right at the bedside and how it will overcome the delay of using the paging method.

P24 said:

“I think having the ability to message both teams that are relevant to medication administration at the bedside is much more efficient than what we're currently using.”

In addition, the system ability of providing the alert information ready to go make the communication even faster than having to provide the information themselves.

P19 commented:

“I really like also how if something pops up you can send it right away to the pharmacy or a physician and it’s instant. “

Second, it provides quick response for both nurses and healthcare providers. The problem of the response delay is linked to the *phone tag* issue as the nurses explained. The nurses expect that the reply delays inherent in the paging will be eliminated for both nurses and healthcare providers by using our real-time communication method.

P27 said:

“For them [physicians] it’s probably quicker and they’re running around doing their thing as well. And to just like get this and read it and just say yeah, hold that medication, I feel like that’s much quicker than me calling and trying to explain everything and maybe they’d call me back and I run to do something else kind of thing. This seems like it will be much more efficient. “

Third, time saving is one of the factors of the communication efficiency. The current communication method requires multiple steps, hence, it takes time to reach the desired healthcare provider. In the contrary, nurses found that our method of communication will cut down the time spent to get a hold of the healthcare providers.

P18 also commented:

“I really like the communication, because right now we just have to page people and it takes up to like 15 minutes, and by that time you kind of miss it anyway”

In addition, in their current communication method, nurses need to prepare the verbal message of the case for the healthcare provider in order to deliver a proper explanation of the case. In contrast, nurses liked how our method generates the message content for them and saves the time spent on gathering patient’s information.

P7 stated:

“I liked that you could just copy and paste it. And, you don't have to take the time to actually write out what's going on yourself. Save time. ”

Furthermore, nurses drew attention to the inefficient use of time preparing a message or waiting for a response in their current method of communication, and how this time can be used for patient care instead. Nurses also think that this will apply to the healthcare providers as well and they can spend their time doing other tasks instead of chasing the nurses in different units.

P29 said:

“they [physicians or pharmacists] could just send us a quick message ... then we know and we don’t have to keep waiting around, we could do something else for five minutes and come back.”

Fourth, NFC-MACC requires less effort to contact healthcare providers/nurses. The nurses’ explained how their current method requires multiple steps from the nurse to prepare the case and patient’s information needed to communicate. Also, it requires multiple steps from both the nurses and healthcare providers to get a hold of each other. On the other hand, nurses commented on how our proposed method of communication will play a role in the reduction of these steps.

P3 stated:

“Makes it much easier as opposed to writing yourself a little note, having to go back to the phone, page the physician, page the pharmacy and then tell them what’s happening ... this is much more streamlined.”

Fifth, ready-to-go message (content) is one of the key features in NFC-MACC. It allows the nurses to forward the generated medication alert message to the healthcare providers. The alert contains the patient information, the medication error type and the reason for that error. When the nurses forward the alert, their identification information will appear to the other end (physician or pharmacist). A total of 10 nurses highlighted that this feature cancels the preparation of essential information step done by the nurses.

P14 commented:

“I really like that I didn’t have to explain any of that. it’s like the context was just put in there for me.”

P3 also said:

“That’s fantastic that you can immediately alert the physician or pharmacy with something that’s already been typed up for you.

Furthermore, some nurses find the information preparation process challenging as they are required to provide an accurate information and updated assessment to help the physician or the pharmacist in making a clinical judgment about the case.

P16 also said:

“I think that’s my big thing because that’s what I struggle with most in my practice is that communication and seeking note information and finding correct information. So I like how it’s all there, it’s compact and even.”

We found that all the five subcategories are correlated, meaning that if the nurses think that our method will eliminate the *phone tag* game and provide an instant notification to healthcare providers then the chances of having a quick response is high. Also, the availability of ready-to go content result in less effort of information preparation hence time saving and then allow for instant notification.

4) Evaluate the Urgency: The generated alert message not only improves the communication efficacy, but also provides the healthcare providers with the purpose of notification. (7/32) nurses stated that sending a concise message of the medication error alert (near-miss) will help the healthcare providers to form an initial idea of why they have been contacted and why their consultation is needed.

P16 said:

“I think sometimes they know it’s a page or a call and they don’t actually know what’s going on versus they can actually get a little memo of what’s going on”

P18 also said:

“But it would also be kind of nice just for them to kind of know what’s going on so you have to fill them in about everything.”

The alert information enables the healthcare providers to prioritize what needs to be done first. In other word, evaluating the importance of the messages (notifications) will help to decide the need for emergent or routine response as appropriate.

P23 stated:

“Then know what level of importance it needs too by looking at it... I think that would be a lot better, because then they’d [physicians] have an idea of why you want them. And for us, a page could be ‘Come right now. It’s an emergency’ or ‘This is not an emergency but get back to me when you can’. I think that would be good.”

In addition, one of the nurses thought that our method may help the physician to evaluate the urgency when they are actually busy caring for the other patients. The physician may ask other healthcare provider like nurses to read the notification to the physician and then he/she can evaluate the urgency and decide what actions should be made.

5) Less Interruption: Nurses explained that their current one-way of communication (paging) requires the healthcare providers to disturb workflow to respond to pages. In contrast, (4/32) nurses drew attention to the texting feature and stated that it would provide instantaneous two-way communication and reduce interruptions for healthcare providers. They can instantly response while doing other tasks.

P14 stated:

“You could instantly speak to the doctors by text, which was really nice because a lot of the times they’re in meetings or whatever, and places where they could probably respond on their phone without interrupting what they’re doing.”

In addition, as discussed in previous section, the key feature of having the ready to go content allows for evaluating the urgency of the case, hence, deciding whether or not to interrupt their current task.

P 30 commented:

“they have the option to kind of not respond right away or kind of decide for themselves the urgency of something”

6) Useful Reference: Other strength point about our method of communication is that it keeps a record of the dialog between the nurse and other healthcare providers. (/32) of the nurses explained how they document their communication with healthcare providers in their current practice. The nurse liked the idea of documenting the conversation and thought it would be beneficial to use as a reference when needed.

P18 said:

“They [pharmacist] can also kind of keep track ... they can also go back and refer to it and say just kind of like, oh, what was that again?”

7) Convenient: A total of (8/32) nurses discussed how our method of communication is convenient in four cases. The first case is when contacting healthcare providers for non-urgent situation. Some nurses found it convenient to use our method when no immediate attention is required and can replace their current method of notifying physicians with non-urgent cases.

P17 said:

“I think the texting can replace what I would usually put as a physical note on the chart”

The second case is when contacting the healthcare providers at night shift. The nurses discussed how day shift nurses have more direct access to healthcare providers than night shift nurses. Although there are physicians who are on call, nurses found it more convenient and easier to use our method than using the paging/call method.

P21 also commented:

” I don't want to... call a bunch of doctors at two o'clock in the morning. So having someone that you can just text, really quickly, would be a good way; so that they don't have to come wait half an hour to come all the way onto the unit”

In addition, nurses think that doctors would prefer our communication method over their current method.

P31 commented:

“I think doctors would love this on nights, because they wouldn't get woken up with calls all the time”

The third case is when nurses are busy caring for patients and need to contact healthcare provider. The nurses highlighted how NFC-MACC would be convenient than using the paging and waiting for a response.

P27 said:

“Like sometimes you're running around it's so busy, it's like annoying enough to call the doctor and this would be like so nice”

The fourth case is when nurses feel that paging/calling physicians is a source of worry. Nurses find NFC-MACC much more comfortable than their current communication method. Some nurses find it worrying to page physicians and not be able to get a hold of them.

P11 commented:

“I love the texting option. I think that's amazing, like that you don't have to worry about the responsibility of getting in touch with that person, because it just happens right then and there.”

Furthermore, for some nurses paging/calling the physicians can be intimidating as oppose to NFC-MACC where they expressed that it would be much more comfortable to use.

P32 stated:

“Sometimes they [physicians] don't like to be called ... that was one thing I would feel a lot more comfortable using this rather than the phone system”

8) Mobility: One of the strength point in our communication methods is that it increases the mobility of the nurses and the healthcare providers as oppose to their current method of communication. (5/32) nurses highlighted at the mobility advantage while using our method of communication and how it allows the nurses to move freely and easily in the unit with a constant accessibility to healthcare providers.

P24 said:

“I do think that it’s a much more efficient way of communicating ... if I step away from this patient right now and go to the next patient room, I can go administer my next medication but I’m going to get the message to my pocket, versus having to stand at the desk by a phone waiting for a page to be called back”

9) Sufficiency of Message Content: A total of (25/32) nurses found the message sufficient for three reasons, it provides concise content, helps in avoiding missing content, and flexibility to add content.

First, one of the most effective feature in our communication method is the forwarded alert. Not only that it saves time in typing the situation and patient’s diagnoses and background, it actually provided a lot of information clearly and in a few words. (24/32) expressed their satisfaction with the automatically generated content and described it as a brief but comprehensive. They liked how the generated message provides an updated information as oppose to the current method where nurses may rely on their last readings. P24 commented:

“I do like the fact that you can copy/paste right into that message. So all that information is there and relayed from the medical record, not from your recollection or your reading of the charts at 7:00 in the morning”

In addition, nurses agreed that this information is sufficient for the healthcare providers to evaluate the received medication error alert and make an initial judgment.

P6 also said:

“Since the situation in the background is present, I think that's enough to somehow allow the physician to make an action”

Furthermore, nurses compared the information we provided in the alert with what they would provide to the healthcare providers over the phone in their current practice. They agreed that there is a similarity between our text message in their verbal message in terms of content.

P25 said:

“I think it definitely makes it quicker and it gives all the medication, or all the information that you would have provided them over the phone”

In comparison to their current way of providing information, nurses agreed that the automatically generated content will allow a faster way of delivering the information and it reduces the chance of missed information.

Second, in current practice nurses explained how they manually prepare the patients information prior to paging the physician. This method increases the chance of missing important information that affects the physician/pharmacist clinical judgment. In addition, novice nurses explained how having the required information generated for them increase their confidence of delivering the right message.

P16 stated:

“Because sometimes over the phone things get missed or allergies might get missed if you’re saying, “Oh like I forgot they’re allergic to penicillin”, like that might get missed and that’s when dangers could happen too just talking over the phone trying to get the order.”

Moreover, a physician judgment can also be affected by the nurse’s personal way of verbally delivering information. In some cases, nurses may paraphrase things and fail to deliver the right form of the message which causes a misinterpretation of information, hence, possible wrong clinical assessment from the physician/pharmacist side. Therefore, nurses appreciate how our method of communication provides an initial base of information to start from when a consultation is needed.

P30 said:

“I think it makes it clear, especially if they know who the patient is that you're not - sometimes when you paraphrase things, like, you can miscommunicate that way. So just have a standard, this is shared information about the patient, kind of gets you started off on the right foot for them.”

Third, alongside with the advantage of having generated concise message, our communication method provides the flexibility to add more content to the message. In

other word, we establish the essential information (Three first element form SBAR) and then leave the *Recommendation* part for nurses to add. Nurses pointed at the ability to add any other information they need.

P14 stated:

“I think one of the biggest strengths of this system is the real-time communication, and that it copies out the details. So you give them the context and then you can ask your question”

P27 said:

“It’s nice that you can add extra on and then I don’t have to type all this out, which is nice, this looks like it summarises everything and then if there’s anything specific to that patient, and then you can add it on.”

In addition, nurses like how the NFC-MACC does not replace their clinical judgment, instead, it provides the flexibility of combining the alert information with their own assessment in the message.

10) Easy to Contact Healthcare Providers/Nurses: According to the nurses’ opinion, NFC-MACC allows for convenient and efficient way to deliver messages to healthcare providers/nurses. This is particularly important in a hospital setting wherein nurses may need an immediate reply from a doctor. In addition to the efficiency of our communication method, the strength points discussed earlier makes it easy for nurses to contact healthcare providers. (11/32) nurses shared this view and linked the *easy to contact healthcare providers* strength point to one or more of the other strength points.

P32 said:

“I think they would like it better than being paged all the time, rather than calling people back. I think that’s an easier, quicker way to get to people, have the information there and then make your decision. Rather than again playing the phone tag”

In addition, some nurses prefer the texting as method of contact over the calling.

P18 stated:

“especially communication-wise, like it’s so much easier than paging...I find it easier to message someone than to talk anyway over the phone”

The nurses expressed their desire to have the texting method of communication and thought that it would bring them into clinical conversations more easily. Their judgment on the appropriateness of this method was derived from their colleague physicians who, regardless of the hospital protocol of communications, use smartphones and texting to discuss clinical matters.

P14 also said:

” I know they [physicians] communicate amongst themselves a lot through their smart phones, and it’s I think completely appropriate and makes sense. But we’re not really encouraged necessarily to participate in that, and we don’t have a system to do that. So I think having that as part of the app really fills a need in there to help bring us into clinical conversations more easily.”

The Strengths of NFC-MACC Components (Technology used – hardware):

From the interview coding we generated 3 sub-categories under the strengths of NFC-MACC components (hardware). Two of them is associated with the use of smartphone and one associated with the use of NFC technology, (Figure 7-14).

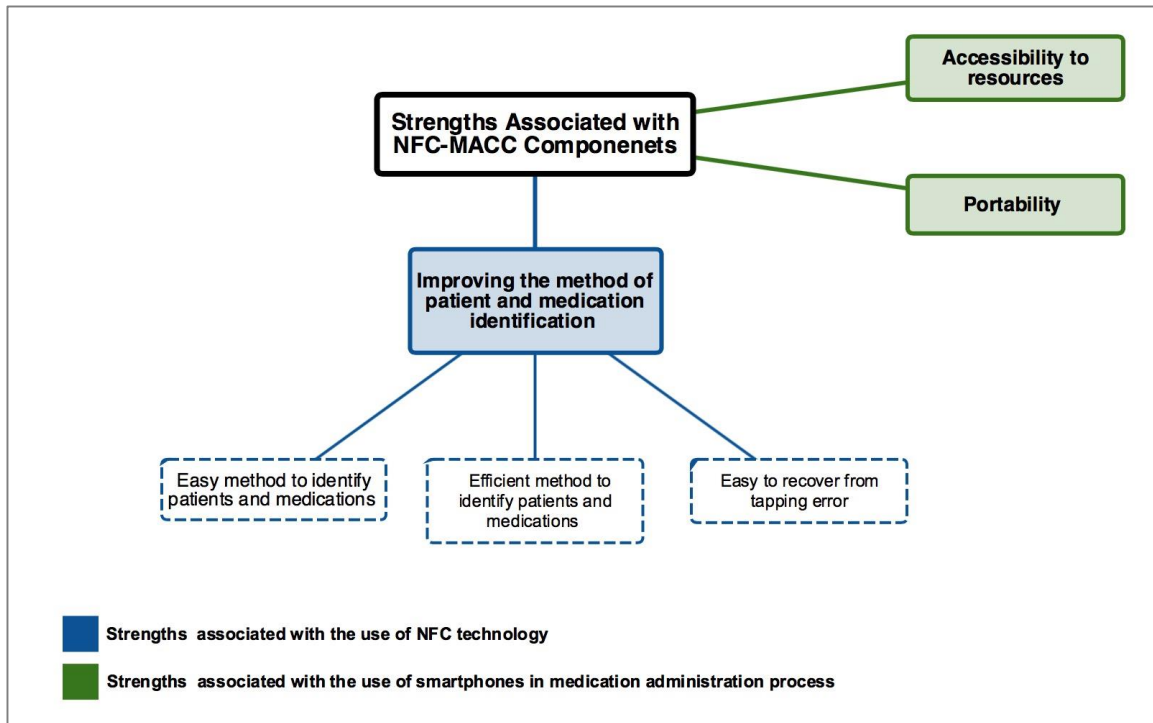


Figure 7-14. The sub-categories of the strengths associated with NFC-MACC components and its associated codes

A) Accessibility to Resources

One problem nurses refer to with the current method of medication verification and communication with healthcare providers is the limited accessibility to the resources to accomplish their tasks. In some units, nurses share one computer to verify the medication and look up interactions or contraindications. Sharing one source of information increases the wait time and causes delay in delivering the medication to patients.

P21 stated:

“It can take a while and if there’s only one computer on the unit there’s a lineup to see who can use it. So you have to wait to use the computer to look up stuff “

Therefore, (6/32) nurses expressed their satisfaction with how the NFC-MACC system provides a single device for each nurse on the shift that is accessible anytime and anywhere and allows them to easily and efficiently verify the medication.

P16 also said:

“Yeah, it’s easy, it’s compact... It’s mine too, I’m not on the unit fighting over a computer”

In addition, some nurses linked the accessibility of the device to the communication with healthcare providers. In other word, having the device in their pocket make them capable of contacting the healthcare providers and vice versa.

B) Portability

One of the strength points in NFC-MACC system that (5/32) nurses highlighted is portability. Using the smartphone helps in navigating through the units and patients room more easily and provides more time for patient care at bedside. Using the smartphone supports the workflow portability needs where nurses can verify medications, document them and contact healthcare providers at the bedside. Some nurses emphasized on the portability of the device to the communication with healthcare providers. In other word, having the device in their pocket makes them capable of contacting the healthcare providers and vice versa without worrying about being at a fixed location.

P24 stated:

“I’m going to get the message to my pocket, versus having to stand at the desk by a phone waiting for a page to be called back. “

Furthermore, some nurses compared the portability of the NFC-MACC system with the BCMA. Unlike BCMA, they found carrying the smartphone is more convenient and does not take too much space.

P17 stated:

“Very portable, which is nice. Again, kind of pulling around the cart while you’re through your stuff in it can be heavy... The portable computers that we had, we can’t bring those into the rooms, so I guess having the phone is less bulky, more portable. “

C) Improving the Method of Patients and Medications Identification

First, one of the strength points of the system discussed by (25/32) nurses is the ease and the accuracy of identifying patients and medications. They mentioned how their current method of identifying patient is not always effective, hence, increases the chance of administering the medication to the wrong patient. For example, asking patients their name and their date of birth is not always applicable if the patients are not able to respond or not in the right mentation state. In addition, nurses check the patient's armband to identify them, however, this method is not always helpful if the patient's information are not readable.

P6 mentioned:

“What we use right now is just a plastic band and you just put a sticker on top of it ... sometimes it can just be simply rubbed off, just because it's paper. So, that somehow leaves you at risk of getting the wrong patient”

In contrast, the nurses admired the NFC-based method of identification and found it much easier and effective than their current method. It identifies the patient with simple tapping and it does not require verbal confirmation from the patient and it eliminates the problem with the readability of armband. Moreover, nurses find it also convenient to tap on the patient NFC ID band rather than reading the information in the night time.

P24 also stated:

“It's really easy to just do the tap, and tap on the medication and on the patient's armband”

In addition, (22/32) of the nurses brought their experience with Barcode scanning (BCMA and Barcode-based blood glucometer) into comparison with the NFC-based method of identification. They found that the barcode system requires line-of-sight access, meaning that the scanner must be physically pointed at the barcode in such a way that it is able to capture all of the barcode lines. This technique requires multiple scans to correctly read the barcode. Therefore, they found the NFC tapping is much easier to obtain the patient ID than the Barcode.

P5 stated:

“I remember like when I used the bar code system, you had to line it up just perfectly and it was really frustrating because sometimes it wouldn't work. So, I found that frustrating to use the bar code system. This one was a lot easier. Like, it seemed to pick it up “

P11 also agreed:

“It's much more simpler... I didn't have any issues with that. Like, it was quick and easy, fast. You didn't have to worry about the distance, getting the distance right and getting it lined up right, the light's working and, yeah, much, much easier.”

Second, the fact that the NFC-based method of identification automates the processes of identifying patients and medications increases its efficiency and decrease the effort it takes nurses to correctly identify their patients. The nurses expressed their satisfaction with how quick it was to obtain the IDs by simple tapping and how it would streamline the task of identifying the patients.

P27 stated:

“It's quick. I feel like by the end of like just doing the nine patients, I was like doing it in just like seconds,”

As we mentioned in the previous strength point, nurses compared the NFC-based method of identification with the barcode scanning in terms of efficiency and the effort to obtain the IDs. They explained that scanning the barcode can be challenging to accomplish sometimes and it forces them to reprint the patient's ID and scan it on separate paper instead of their arms, which deftest the purpose of bedside automated identification. Therefore, nurses admired how the NFC armband are not easily get damaged, and preferred the NFC tapping to identify the patients at the bedside over the Barcode scanning.

P22 stated:

“I like the NFC better, just because a lot of the time the barcode isn't stuck on the armband, or like something's covering it and then it won't

scan and then you have to go get a new one, and it just takes a lot more time. So this is more time efficient”

P18 also commented:

“I much prefer this way because the barcodes always wear off on the patient’s armband, so you have to go back to their chart... find the barcode and then scan that one.”

Third, during the tasks session some nurses were not able to obtain the patient or medication ID from the first tap and they had to do multiple tapping attempts. The readability problem arose in three cases, the tapping is too fast, the tapping distance is too far (distance between the smartphone and the patients or medication tag), or not tapping on the right spot of phone where the NFC reader is located. However, nurses agreed that they were able to recover from the tapping error easily with minimum effort and finding the right spot just takes some time to get used to.

P11 said:

“The only thing is I had to remember to tap on the top part of the phone. But I picked up that very quick. I noticed that very quickly and I correct that quick and easy.”

The Strengths of The NFC-MACC Interface:

From the interview coding we generated 3 sub-categories under the strengths of NFC-MACC interface, which are *easy to use, user-friendly, and useful staff picture*. The *user friendly* sub-category had three associated codes which are *simplicity and few clicks, clear layout, and suitable use of colors*, (Figure 7-15).

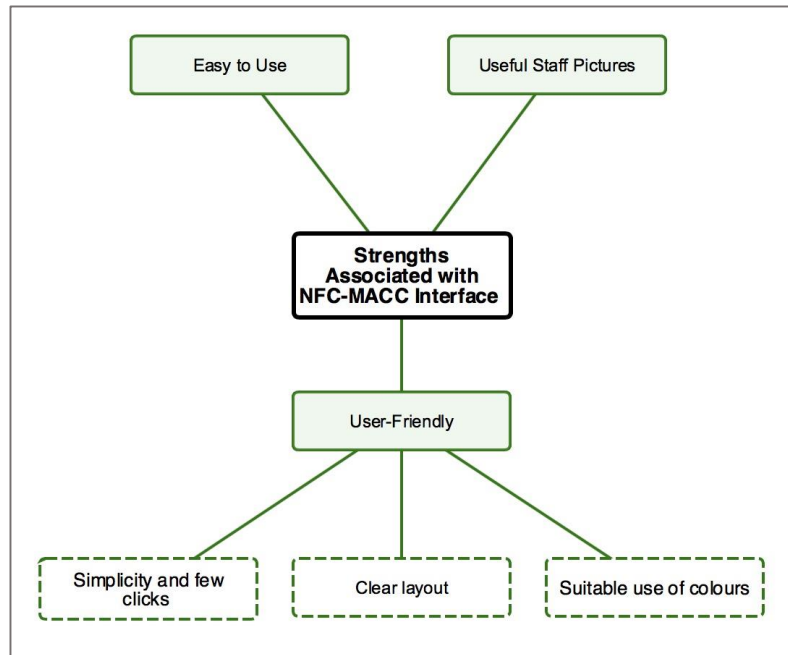


Figure 7-15. The sub-categories of the strengths associated with NFC-MACC interface and its associated codes

1) User Friendly: The first point of strength related to the NFC-MAC system interface is that it is user friendly. (14/32) nurses express their satisfaction with the interface in terms of simplicity, few number clicks, colors, and clarity of presenting the information. They pointed the simplicity was due to the application having only two options for starters, and a single button per screen encountered during the tasks.

P10 stated:

“Like, literally there’s two buttons to push, so I feel like it’s just very nice and concise, because when you have too much going on in a screen, like if you had the notifications on here or all the doctors on the first page, things like that, it would just be too much.”

In addition, the nurses found the information in the alert is nicely arranged and clearly presented. The arrangement of text helps to draw attention to the important pieces of patients information and makes it clear and easy to read.

P16 commented:

“I really like how everything is laid out clearly on the phone ... it’s nice to have the information spread out like that to be able to see.”

Moreover, nurses liked how the interface has few colors and pointed that the red color in the alert was appropriately used. It stands out and gives a sense of warning, hence, it grabs the nurses’ attention to stop administering the medication.

P4 stated:

“I like the fact that it’s red, like stop, stop, it’s psychologically we’re very – we understand the color code without even – before even looking into the message.”

Overall, nurses agreed that the tapping technique, and the interfaces for the medication verification, the documentation and the communications were user friendly and can be used with no extra help or guidance.

P24:

“it’s so user friendly ... I didn’t need any extra guidance, even in terms of the administration piece or the contacting other people piece. Like I think it’s excellent.”

2) Ease of Use: Approximately two-third (20/32) of the nurses have used the word *easy to use* to describe the NFC-MACC interface. Some nurses linked the ease of use to the familiarity with smartphones and applications. Based on demographic data, all interviewed nurses use smartphones which contributed to finding it easy to use.

P12 stated:

“I like the system and the ease of it. And I’m familiar with cell phone apps, and that makes it easy. “

In addition, nurses also linked the ease of use to the clear and less complex layout and mentioned that the interface simplicity and ease of use will make it adaptable and acceptable to older generation who may not be familiar with smartphones or application. It’s worth mentioning that we had verity of ages in this study, and there were no complains or sense of frustration in relation to the interface.

P2 mentioned:

“I like the colors. Things are well laid out, things are simple. I think it’s simple enough that someone who’s not used to being on a Smartphone, like an older generation, wouldn’t be too frustrated with it. “

3) Useful Healthcare Providers Pictures: (3/32) nurses liked the idea of having the healthcare providers’ pictures in the contact list. Nurses found that having the healthcare provider’s pictures allows them to know who are they actually contacting and recognizing them when they see them on an everyday shift.

P11 commented:

“It helps me get to know the physicians a bit better, because the floor I work on now there’s just so many physicians. I’ve been there for almost [number] years and I still see faces I don’t know who they are. So to have that visual of putting that face to that name right next to each other, I really like that. “

Learnability and Memorability

The simplicity of the NFC-MACC interface, the ease of use of its the functions, and the familiarity with the smartphone applications make the system easy to learn. Around third of the interviewed nurses (10/32) pointed at the learnability of the system. They explained that the simplicity and the few number options in the interface makes it easy to predict the purpose or the function of each button. In addition, the familiarity with the technology used makes it easy to understand how to use it with minimal help. They also explained that it can be learned how to use it in a short time.

P12 said:

“I guess it’s pretty easy to use once you’re familiar with it. Even if you aren’t, you know it’s quick to learn.”

P26 also said:

“It’s all pretty straightforward. I liked how simple it was, easy to learn.”

In addition, nurses mentioned that it is easy to remember because, as discussed earlier, the few number of options per screen are mostly limited to one, which makes them intuitive to use. Nurses explained that if they use the system after a period of time they will be able to recognize its functions and remember how to use it.

P10 said:

“Like I don’t think I would forget this, I think I would come back in a year and still know how to use this.”

Usefulness

All the strengths associated with the NFC-MACC functions, technology used, and interface lead to the usefulness of the system. In other word, based on their experience during the tasks, nurses were able to picture and see the value of the system in a clinical setting. They explained how it is going to enable them to achieve the medication administration tasks successfully, hence enhance nursing practice and improve patients safety. Also, they express their willingness to use it in their nursing practice for different reasons discussed in the following sections (Figure 7-16).

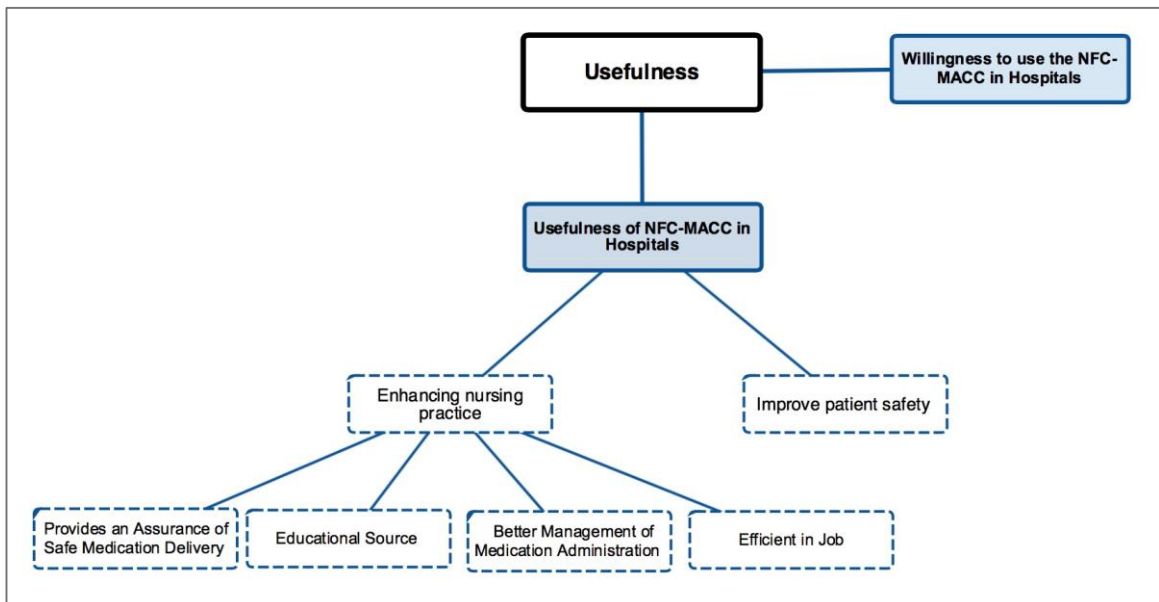


Figure 7-16. The sub-categories of Usefulness and its associated codes

A) Usefulness of NFC-MACC in Hospitals

Enhance Nursing Practice: First, the NFC-MACC provides and assurance of safe medication delivery. Approximately half of the interviewed nurses (17/32) indicated that the system will aid in delivering the medication to patients safely. They discussed how the system will add an extra layer of confirmation and will work as an automated double check at the bedside. In addition, nurses mentioned that it reinforces their initial medication verifications conducted during their busy day shift, or during the late night shifts where they are likely to be tired and less alert about any potential medication errors.

P24 supported that saying:

“It’s a double check that’s better realistically than the initial check that you’re doing. So I think that’s the piece I like the most.”

In addition, nurses indicated that the double check provided by the NFC-MACC system boost their confidence and gives them the ability to administer the medication properly. When they have a heavy load of patients and medications, it will increase the certainty about their medication verifications and makes them less stressed.

P11 said:

“I’d feel a lot more competent having that additional check right at the bedside. “

Second, NFC-MACC would provide a better management of medication administration. Nurses explained that due to their limited time and the heavy load of tasks, they tend to skip some critical checks. These checks require time and effort to accomplish such as drug interaction and contraindication. As a result, they rely on the other healthcare providers to verify them. A total of (16/32) nurses stated that the NFC-MACC will help nurses to be compliant to the required checks and verifications.

P3 stated:

“I like that it forces you to do your five rights and it forces you in a good way. You know, like it’s easy to go in and just scan the medication, scan the armband”

Furthermore, the effectiveness and the efficiency of the NFC-MACC will help them to manage the medication administration. In other word, they believe that it will streamline the verification process.

P24 stated:

“I think it would really make the workload much more manageable, and make the process of administering medications much more streamlined, also reduce the risk of errors significantly. I think it would make a huge impact. “

Third, as mentioned in earlier sections, the nurses’ current practice of verifying medication and contacting healthcare providers when a consultation is needed is complex and consumes a lot of the nurses’ time. Therefore, (8/32) nurses mentioned that the NFC-MACC system will help them accomplish the medication administration verification task in a timely manner and make them do their job more efficiently.

P7 said:

“it helps me to be efficient in my job”

Fourth, some nurse (4/32) pointed that one of the advantages in the NFC-MACC is the provided alert information. Nurses stated that they lack pharmacological knowledge and having the alert information not only prevents them from administering the wrong medication but also enhances their knowledge and works as an educational source.

P2 said:

“I think it’s just a good learning opportunity as well, when you see the interactions come up or the contraindications. Like, oh, I didn’t know that. You know, that’s just helpful for your overall learning as well. “

In addition, P13 have mentioned that during the performance of task 10 she learned something new related to contraindications and stated:

“The super high blood pressure it was contraindicated. And I was like Interesting, I didn’t actually know that! “

Improve Patient Safety: The enhancement of nursing practice leads to improving patient care and safety. The majority of nurses (25/32) believed that the NFC-MACC system will reduce medication errors. Even though the system was not tested in clinical setting, nurses derived this point of strength from their experience with the system functions during the tasks.

P2 said:

“I think it mostly takes away the errors of the five rights of the medications”

They explained their experience with medication errors and described how the NFC-MACC system would prevent them from happening. For example, some nurses linked the distributed sources of information in their current practice to medication errors, and stated that NFC-MACC system has all the needed information available at their fingertips.

P32 said:

“Everything's like right there [in the NFC-MACC system], and you're not relying on flipping through charts and taking the extra time where steps can be missed. And that's when the medication errors are happening. “

Moreover, nurses usually stop asking the patients their name or check their armband when they are familiar with them, and sometimes they just forget to ask. This may lead to administering the medication to the wrong patient.

P22 mentioned:

“I think it's really good because it's better than just like asking the patients or checking their armbands, because a lot of the time that's forgotten about, so now you actually have to do it with this.”

Moreover, some nurses mentioned that medication errors increase when there is no last point verification at the bedside, and stated that NFC-MACC system could eliminate such errors. They also believe that the system's ability to electronically verify medications

will be able to pick up the small errors that are common but do not cause a serious adverse outcomes and sometimes are not even realized.

P17 said:

“It’s usually those small errors that do happen, I’ve made medication errors a lot... So kind of having measures in place that I think would help to prevent that I’m absolutely all for it, and I think this is one of them,”

B) Willingness to Use the NFC-MAC System in Clinical Setting

The strengths mentioned in previous sections contributed in the nurses’ willingness to use the system in an actual practice. The majority of nurses (28/32) expressed their desire to have the system introduced in their work place, (3/32) expressed their willingness to use it if it has an option to access the E-MAR of the patient at the bedside, and (1/32) stated that it would depend in the context and the patients’ population (e.g. mental illness or confused patients).

P31 stated:

“I would love to get an email in a year's time saying we're going to be getting it. “

To understand the nurses desire, we asked them what motivates them to use it. All the answers are related to one or more of the strengths discussed earlier. The following figure shows the distribution of their motivations among 9 strengths (Figure 7-17).

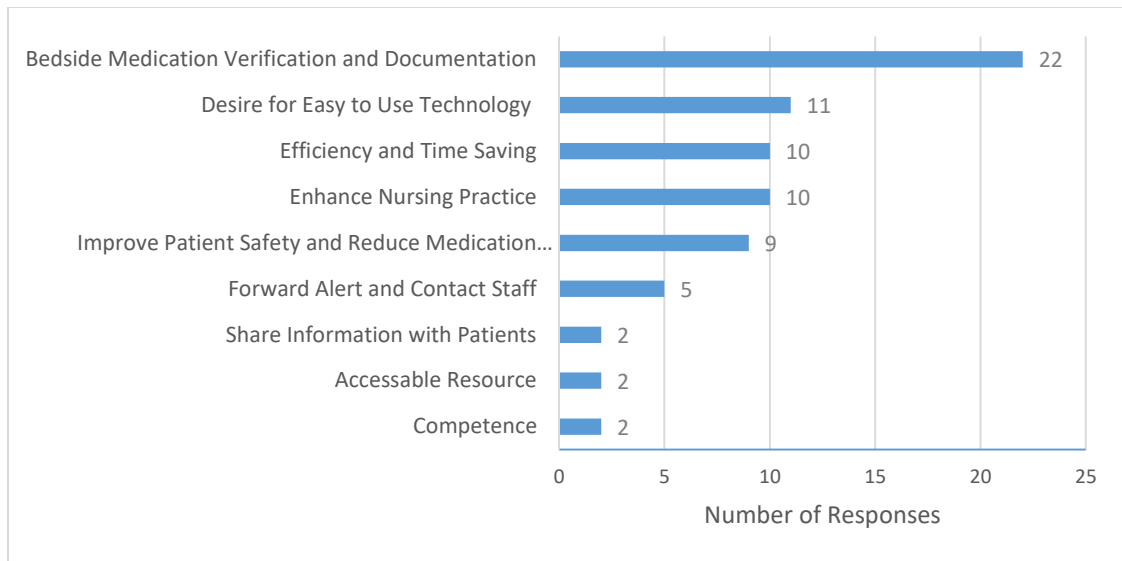


Figure 7-17. Motivation to use the NFC-MACC system in clinical practice

Weaknesses

We were able to obtain the weaknesses of the system by asking the nurses *what do you dislike about the system?* We found three sub-categories of weaknesses related to the NFC-MACC functions and four sub-categories of weaknesses related to the NFC-MACC components category (Figure 7-18).

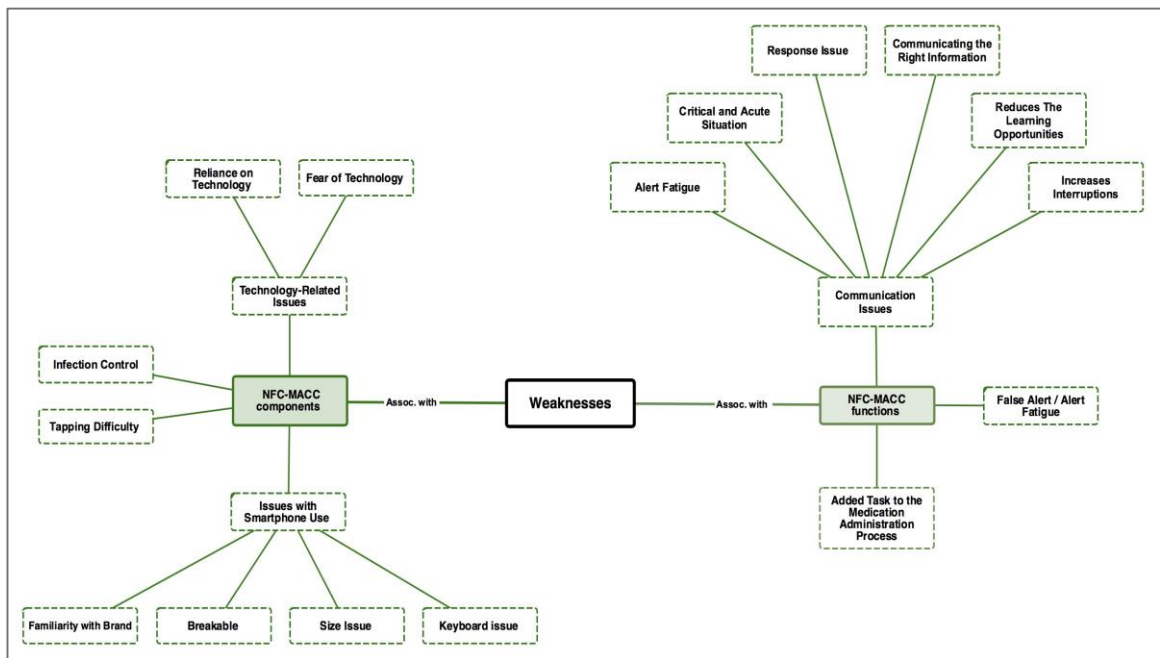


Figure 7-18 The NFC-MACC system weaknesses categories and subcategories

Weakness of the NFC-MACC Functions

A) Communication Issues

Nurses pointed at six issues of the NFC-MACC method of communication discussed in the following subsections. These issues affect the nurses, the healthcare providers, or both of them, see the following figure (Figure 7-19).

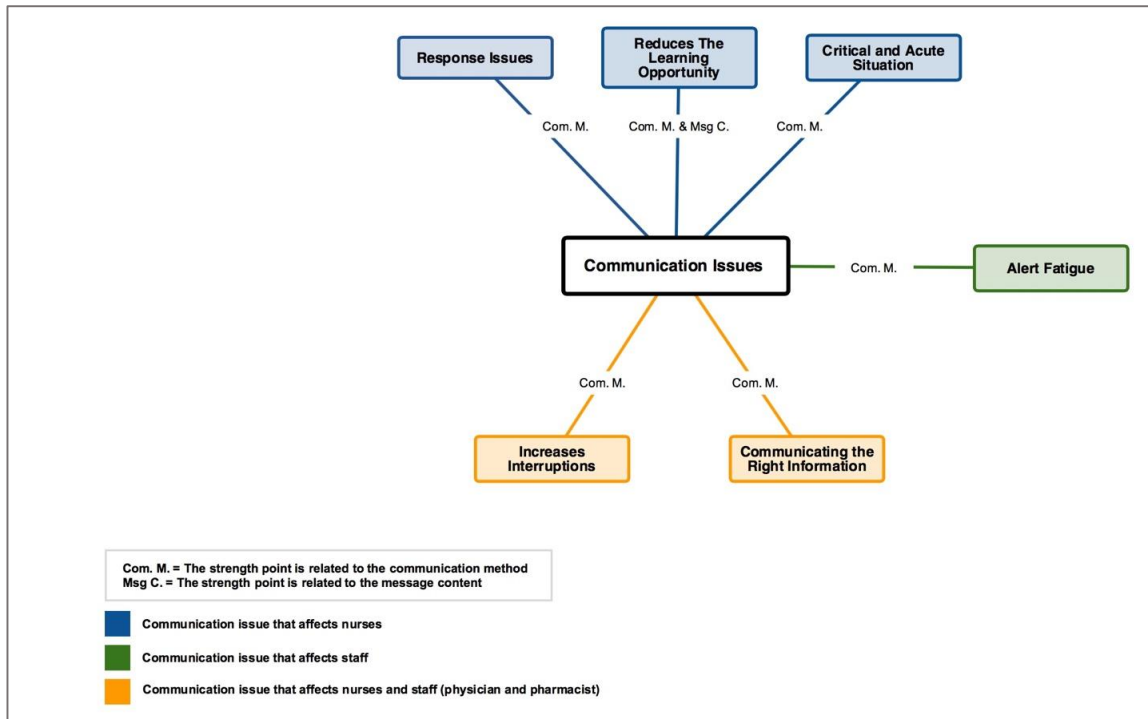


Figure 7-19. The subcategory of Clinical *Communication Issues* and its associated codes

First, one of the issues associated with the NFC-MACC communication method is the possibility that a healthcare provider will not respond to nurses in a timely manner. A total of (7/32) nurses were concerned whether this method will actually improve the efficiency of clinical communication or will increase the waiting time, hence, forces the nurse to use different methods. They discussed that physicians might be too busy to check their phones, or might turn off their phone if they choose not to respond at all.

P19 commented:

“It might not be as fast and as efficient as we think because if we’re typing something out to the physician and he doesn’t answer his phone right away, we’re kind of waiting on the other end.”

In addition, nurses explained that the physicians’ workload affects their response rate despite what method is used to contact them.

Second, NFC-MACC system uses text as a primary method of communication. (2/32) nurses stated that this method will not be appropriate if they needed to discuss critical and acute situation with healthcare providers. In such cases, they would prefer to call healthcare providers or talk in person over texting. In addition, texting may affect the culture of interprofessionalism in hospitals where nurses and physicians are encouraged to effectively communicate and collaborate. Nurses foresees that texting may separate the nursing duties from the other healthcare providers’ duty.

P2 said:

“For bigger issues that require more interprofessional discussion, I think it’s not necessarily as good”

Third, texting may not deliver the right information or may raise the issue of miscommunication. (4/32) nurses believed that texting will not be convenient for them as well as the healthcare providers. They prefer talking over typing and explained how, in their current practice, delivering the information in text format can be challenging to communicate the right information.

P4 stated:

“Finding the words to write is hard for people even people in the health care system, like when we write our notes people struggle with this”

In addition, NFC-MACC method of communication does not allow for verbal explanation where nurses or healthcare providers can deliver their questions or consultations and repeat things easily when they are not clear to the others.

P25:

“I would rather talk to them. Just because I feel, if there's a misunderstanding I think it gets better resolved through verbal or face-to-face communication. “

Fourth, the fact that the NFC-MACC uses texting as a primary method of communication during the medication administration stage, it reduces the chance of verbally exchanging information. One of the nurses explained that it is important to have a face-to-face communication with healthcare providers because verbal clinical conversation can be a source of educations.

P25 said:

“I do find it's better to talk to somebody. Because that also offers opportunities for more learning.”

Fifth, alert fatigue is another communication issues discussed by (6/32) nurses. They indicated that the immediate accessibility to healthcare providers and the easiness of forwarding the alerts may not be appreciated if it causes alert fatigue. When physicians cover a large number of patients and prescribe large number of medications, it is expected that they will receive questions or concerns regarding the medications. Nurses were concerned that physicians will be exposed to a large number of alerts and it will be a source of annoyance rather than a safety feature. The alert fatigue will force the physicians to ignore them, hence, miss the important or critical ones.

P29 said:

“I could see physicians getting frustrated with us sending them alerts.

“

In addition, (2/32) nurses explained that receiving continues alerts and messages from nurses will increase the healthcare providers' workflow interruptions, especially when they are busy.

Medication Error Alert Fatigue: As discussed in previous section, NFC-MACC system alert the nurses when there are minor medication administration errors that may not cause an adverse event such as late administration. One of the nurses highlighted that the

frequency of minor alerts may lead to the loss of the attention grabbing which they are intended for. They may become desensitized after receiving large number of minor alerts that result in automatic overriding behavior. This may raise a problem of skipping an important alert, hence, affects patients safety.

P14 said:

“I think that some of these alerts are going to result in people spending a lot of time overriding stuff... Half the time a doctor hasn’t thought of the contraindications, and half the time they have thought of them and they don’t care. So it’s half the time it would be useful, and then half the time they’d just be like ‘No, it’s fine’”

Added Task to The Medication Administration Process: (5/32) nurses found that the NFC-MACC may add an extra task to their daily routine of medication administration process. This becomes an issue when nurses do not trust technology. They feel more comfortable doing the checks themselves and not rely on technology to do this task. Therefore, they feel that having an additional method to verify medications will be an assurance of their initial verifications, however, it will be an additional step to their practice.

P9 stated:

“I didn't really dislike it, but, I still do the check on my own, because you can't always trust technology.”

In addition, nurses who have an experience with transmission from paper-based to electronic-based system stated that sometime going from routine to another results in adding extra tasks that they were not supposed to do in their previous practice (paper-based). Therefore, they pointed the introduction of the NFC-MACC system may feel more burdensome to healthcare providers and lead to an uptake problem.

Weakness of the NFC-MACC Components

A) Technology Related Issue

Fear of Technology: fear of technology can affect the nurses being receptive of NFC-MACC system and information technology in healthcare in general. (5/32) nurses

discussed that sometimes it can be intimidating to use technology in clinical settings for two reasons. First, when they are not used to the way things are, they become resistant to change it in their work. Second, it can be irritating to feel that technology would replace nurse's role, hence be reluctant to adopt it in work place.

P25 said:

“But there's always - in my mind it always - I never want to see the nurse be replaced.”

Complete Reliance on Technology: In contrast to the fear of technology, nurses may become completely reliant on NFC-MACC system and not be compliant to the required initial verifications that should be done before approaching the bedside. (3/32) nurses explained their fear of being dependent on the system to do their job. Being completely dependent on the system may eliminates their clinical judgment and increase the possibility of being irresponsible and blaming the system when errors happen.

P4 stated:

“I like technology, but I'm afraid that reliance of technology would reach a level where people don't use their critical judgment anymore”

Nurses linked their experience with barcode scanning with this issue; they stated that when using the glucometer barcode scanning, they do not check the name and trust the technology to verify the patient identity. Therefore, they expected the same issue will happen with using NFC-MACC system.

B) Tapping Difficulty

Some nurses (3/35) found it a little difficult to obtain the patient or medication ID during the task session. As discussed earlier, the readability problem arose in three cases, the tapping is too fast, the tapping distance is too far (distance between the smartphone and the patients or medication tag), or not tapping on the right spot of phone where the NFC reader is located. Even though nurses found it easier than barcode scanning, some of them had to tap multiple time until they successfully obtain the ID.

P22 said:

“Learning to tap it I guess would be the only challenge with using it.”

C) Issues with Smartphone Use

One of the issues encountered during the tasks session is familiarity with the smartphone brand. (5/32) nurses mentioned being unfamiliar with brand makes it a little inconvenient to use, and it affected on their performance during the task session. For example, the smartphone we use has a little arrow that is designed as a *Back* button. Some nurses were accidentally clicking on that arrow which causes them to go back to the previous screen. In addition, nurses stated that being unfamiliar with the keyboard affected their typing speed during the tasks as well.

P21 said:

“I find it’s kind of hard to type, but that might be because I have an iPhone. “

Another issue with using smartphone in the process of medication administration is its small size. (2/32) nurses mentioned that it can be too small for older nurses to reading information. And some nurses mentioned because it is small and convenient to carry in their scrub, it is possible to forget in their pocket when they leave the shift.

P4 said:

” it can easily be kept in pockets, like a nurse can forget that in her pocket and go home with it.”

In addition, one of nurses mentioned that it might not be practical to use the smartphone during the medication administration stage due to the possibility of dropping it. Using it constantly from patient to patient will make it subject for breakage.

D) Infection Control

Infection transmission is one of the possible issues associated with using the NFC-MACC system, which affects patients safety. (4/32) nurses pointed that using the same smartphones to tap on number of patients’ ID band would contaminates it and causes transition of bacteria or viruses, especially if used on patients in isolation. Therefore, nurses mentioned that there should be some cleaning guidelines to make sure that is disinfected.

P5:

“Probably have to think of, infection control, if you're using it in between patients. You'd have to think of a way to clean it.”

Beliefs: Patient Perceptions

A common opinion (28/32) nurses have brought up was patients would perceive the NFC-MACC system to be important for their safety, and appreciate being tapped. Nurses explained that being tapped prior to the delivery of medication would assure the patients of safe delivery of medication.

P19 stated:

“I think the patient would feel more safe if we were tapping everything and they were seeing that we're confirming and that it's the right patient, the right medication, that kind of thing “

In addition, nurses pointed that the familiarity with the scanning process (e.g. Barcode glucometer scanning) would result in a comfort of the patient towards the tapping process of NFC-MACC system. They have explained that from their own experience with barcode scanning and Elaps RFID¹⁵ monitoring, patients never complained about wearing the bracelets or being scanned.

P8 stated:

“I don't think people are minding that. There is a device that we check blood sugar that also requires scanning a code on the tag. So, people don't mind getting scanned “

Moreover, one of the nurses stated that, in current practice, nurses use their smartphone sometimes to share clinical information with patients. The benefit of sharing information with patients at bedside may lead them to be more open to the use of smartphones in clinical settings.

On the other hand, some nurses (12/32) mentioned that patient might be concerned with the use of NFC-MACC system and being tapped for different reasons. First, patients'

¹⁵ RFID-based real time location system used for patients who are at risk for leaving the units.

population plays an important role of being receptive of technology used on them in general. For example, nurses mentioned that population with certain health condition (e.g. mental health) and old population might fear technology. Second, patients may think that nurses are relying on the technology to do the checks and they are not being responsible. Third, having the smartphone in the patient's room may rise a privacy concern (e.g. patients may think that the nurse is taking picture of them). Forth, patients may think that nurses are texting or browsing in smartphone and not being unprofessional.

P24 stated:

“it may be perceived as being somewhat disrespectful to be texting while you're at work.”

Therefore, nurses explained that to overcome the concerns mentioned above, patients have to be educated about the purpose of the system and informed that it is used for their safety. In addition, the smartphones have to be labeled in a way that covers the camera and indicates that they are the hospital's property and not nurses personal smartphones.

Summary

In this chapter we discussed the usability testing study conducted to evaluate the NFC-MACC system. The usability attributes targeted in this study are subjective (effectiveness and efficiency), objective (perceive ease of use, and perceive usefulness for nurses' job), perceive usefulness for patient care, and beliefs: patient perceptions. The study design included a demographic questionnaire, tasks, post-task questionnaire, and concluded with a semi-structured interview. The subjective data were collected through the task session. We calculated the time spent to finish each task (efficiency) and the number of tapping errors (effectiveness). The objective data were collected through the questionnaire and the interview.

The findings show that there was a general decrease in the time spent to reach the desired screen from the first task to the last task, and the majority of participants made the optimum number of attempts in all tasks. In addition, the general result of the post-task questionnaire was positive, and most of the responses indicated a favorable impression of the NFC-MACC system in comparison to the current method used for BMA. Moreover,

the interview uncovered different strengths and weaknesses of the system related to the functions and the components of the system.

Chapter 8. Key Findings and Discussion

This chapter provides answers to the research questions of Phase 3 (part 2). It also discusses the findings in relation to the literature and provides suggestions for improvement to the NFC-MACC system.

8.1 Answers to Research Questions

The quantitative findings discussed in the previous chapter helped us to answer the first two questions related to objective usability attributes, and both quantitative and qualitative findings helped us to answer the remaining questions.

RQ1: To what extent is the NFC-MACC system efficient in terms of time spent completing tasks in comparison to optimum time?

By referring to the results of *efficiency* in Chapter 7 (section 7.4.3), it can be observed that the descriptive statistics for completion time for the 10 tasks and the t-test comparing performance against the hypothetical mean showed that there was a generally decrease in time spent to reach the desired screen from T1 to T10. However, the t-test indicated that the time in all tasks was 0.62 to 5.88 seconds longer than the optimum time. This may imply that if the study has a longer duration and there were more tasks, the nurses may eventually reach the optimum time. In addition, the result showed that participants who are quickest in one task are also quickest in the other tasks. That may be due to experience with the use of technology in general. It is worth mentioning that there was no correlation between speed and familiarity with the use of NFC technology (e.g. tap payment) or familiarity with mobile applications. Even though the mean time did not reach the optimum time for the 10 tasks, the finding showed that the system is still much more efficient than the current method used for medication verification.

Moreover, it can also be observed that the descriptive statistics for time spent to contact a healthcare provider (forwarding the alert) for Task 6 – Task 10 and the t-test comparing performance against the hypothetical mean showed that there was an improvement. The participants' speed to initiate a communication and send the alert to the physician or pharmacist was improving through task 6 – task 10. The last task was completed in a few microseconds longer than the optimum time. This implies that if there

were more tasks to perform, participants may reach the 7-second optimum time. It is also worth mentioning that by observing the minimum time, some participants were even faster than optimum. This can be affected by the participants' skills of texting and scrolling through contacts. In addition, finding the targeted person to contact can be affected by the name's position in the list (top or bottom of the list). When the targeted person was in the bottom of the list, the time to forward the alert was increasing (Task 9). However, this factor may disappear if the nurse contacts the same person multiple times. We noticed that in the tasks that required contacting the pharmacy (Task 6 and Task 7), nurses memorized the Pharmacy position in the list from Task 6, hence, in Task 7, they were faster in finding Pharmacy.

RQ2: To what extent is the NFC-MACC system effective in terms of completing the tasks with the least number of errors?

The overall result in Chapter 7 (section 7.4.3) indicated that there was no significant difference between the tapping attempts because the majority of participants made the optimum number of attempts in all tasks, which implies that the system was fairly effective. However, the results also showed that some participants made up to 7 attempts to read the tags. From our observation during the tasks phase, we noticed that participants found it easy to the extent that they become faster in performing the *tapping motion*. Fast *tapping motion* resulted in failing to pick up the tag ID, but with multiple instances of failing to obtain the ID, the participants were learning how to tap with slower motion. In other words, it appears that for some participants tapping on the tag requires a bit of learning.

In addition, the results showed a relation between the efficiency (time to reach the required screen) and effectiveness (number of scanning/tapping errors). The participants who completed the tasks more quickly also tended to have fewer errors.

RQ3: How do nurses perceive the usefulness of the NFC-MACC system in comparison with their current method used for bedside medication administration and clinical communication procedure?

To answer this research question, we associated the quantitative data with the qualitative data. The attributes measured for usefulness were *productiveness*, *performance*

speed, information need, general usefulness, and impact career mission. By referring to the quantitative analysis in Chapter 7 (section 7.4.4), it can be observed that the descriptive statistics showed that the nurses have a favorable impression of the NFC-MACC system in comparison with the current method. Answers were concentrated in the *strongly agree* and *agree* categories. This is also borne out by the fact that the means are nearer to the value of 1 (*strongly agree*) than to 5 (*strongly disagree*).

The majority of nurses found the system to be useful more than their current method in terms of *productiveness* (84.37% found it easier, 81.25% found it faster, and 87.5% found that it required less effort than the current system). The interview findings illustrated the reason behind nurses' response to the questionnaire. In nurses' current practice, verifying the medications requires effort to assure a safe delivery of medication; the patient and the medication information are not gathered in one place. In other words, nurses have to search for the information from different sources in order to verify the five rights, allergies, interactions, and contraindications. In addition, nurses explained how it is challenging when they are not sure where to find the complete information about a certain condition. Therefore, nurses appreciated how the NFC-MACC system is linked with all the resources and provides the needed information at the bedside. It transforms the difficult tasks of looking for the right information to ensure safe delivery of medication into easy ones. However, up to 12.5% disagreed with the system being useful in terms of *productiveness*. The reason behind this disagreement was related to being skeptical about using the technology to verify the medication. Some nurses felt more comfortable doing the checks themselves and not relying on technology to do the task. Therefore, they feel that the system will be an additional method to verify medications and assure their initial verifications; however, it is considered an extra effort added to their practice.

In addition, the *performance speed* was well received by 93.8% of nurses, and no negative quantitative data was reported. They believe that the system provides feedback in a timely manner, in case of a medication error in comparison with their current method. Due to the time constraints and the high number of medications administered to a single patient, it is nearly impossible to verify every single medication. Therefore, nurses pointed out how the efficiency of the system will reduce the time spent on looking for the needed information.

Moreover, the majority of nurses found the system to be useful more than their current method in terms of *information need*. The descriptive statistics data showed that the majority of nurses believed that the NFC-MACC system provides sufficient alert and communication information. They liked how it provides concise information that makes them able to take action. However, the quantitative data showed that up to 9.3% were between disagreement and neutral. The reason behind this is that the contraindication alert does not provide a complete view of the patient vital signs and it only shows the data related to the medication error (e.g. blood pressure). In addition, few nurses preferred the current method of communication of the NFC-MACC texting-based method because texting may not deliver the right information or it might introduce the issue of miscommunication.

Furthermore, the majority of nurses found the system to be useful more than their current method in terms of *impact carrier mission*. Almost all nurses (96.88%) felt that the NFC-MACC system would improve the bedside medication administration process in nursing practice. The interviews showed that nurses found the system useful in terms of enhancing nursing practice by providing better management of medication administration and assurance of safe medication delivery. In addition, nurses explained that their current practice of verifying medication and contacting healthcare providers when a consultation is needed is complex and consumes a lot of the nurses' time. Therefore, the NFC-MACC system will help them to accomplish the medication administration verification task in a timely manner and assist them to do their job more efficiently. Finally, the sufficient information would work as a learning source, especially for new nurses or when the medication is new to nurses.

RQ4: How do nurses perceive the ease of use of the NFC-MACC system?

The answer to this question is derived from both quantitative data and qualitative data. The attributes measured for ease of use were *learnability*, *memorability*, *error prevention*, *competency*, and *general ease of use*. By referring to the quantitative analysis in Chapter 7, it can be observed that the descriptive statistics indicate that the nurses have perceived the ease of use of the NFC-MACC system very favourably. Almost all nurses thought that the system was easy to use, and no negative response was reported. The qualitative analysis showed that the ease of use was related to both the interface of the

application and the equipment and technology used in the system (smartphone and NFC technology). The simplicity and the small number of options in the interface makes it easy to learn and to understand the purpose or the function of each button. In addition, nurses' baseline familiarity with smartphone applications makes the system easy to use with minimal help. This results in nurses' prediction that if they use the system after a period of time, they will be able to recognize its functions and remember how to use it.

Moreover, it was noticed that some nurses were not able to obtain the patient or medication ID from the first tapping attempt and they had to perform multiple tapping attempts. The readability problem arose in three cases: the tapping motion is too fast, the tapping distance is too far, or not tapping on the right spot of the phone where the NFC reader is located. However, they were able to recover from the tapping error easily with minimum effort, and finding the right spot just took some time to get used to. This explains the reason of having one *neutral* response related to the questionnaire statement that learning to scan the patient's and the medication's tag was easy. Finally, the system's ease of use and ease of ability to be learned resulted in nurses' comfort in using it.

RQ5: How do nurses perceive the usefulness of the NFC-MACC system for patients, and what do they believe that patients would think of the system?

The descriptive statistics findings showed that the general impression of perceived usefulness for patient care is positive. The majority of nurses believed that the NFC-MACC system will be useful for patients in terms of reducing medication errors and improving patient care. Even though the system was not tested in a clinical setting, nurses derived this perception from comparing their current method used to verify medication with our proposed system. In other words, the distributed sources of information in their current practice is not effective to prevent medication errors, and the fact that the NFC-MACC system has all the needed information available at their fingertips would reduce the occurrence of errors. However, even though nurses believe that the system will be useful for patients, around 24% did not feel that it would make caring for patients easier. This might be related to the fact that some nurses think that the NFC-MACC system will be an extra step added to their practice, and hence, reduces the ease of patient care. In addition, some nurses think that the use of the system may result in complete dependency on

technology, and accordingly, that it reduces personal judgments and increases the chance of errors.

The second part of the question was answered by the last section of the questionnaire as well as the interviews. The quantitative data showed that the general impression of what the participants believe that patients would think of the system is positive. The majority of participants believed that the patients would like the system, appreciate being scanned, and would understand that the system is used for their benefit to reduce medication errors. However, up to 31.25% of responses neither agreed nor disagreed with the majority of participants. The qualitative data explained the reason behind the nurses' impressions. First, patients will be aware that being tapped prior to the delivery of medication would assure safe delivery of medication. Second, the familiarity with the scanning process (e.g. barcode glucometer scanning) would result in the comfort of the patient towards the tapping process of the NFC-MACC system. They have explained that from their own experience with barcode scanning and Elaps RFID monitoring, patients never complained about wearing the bracelets or being scanned. Third, the ability to share information with patients via smartphone may lead them to be more open to the use of smartphones in clinical settings.

On the other hand, there is a chance that patient might be concerned with the use of NFC-MACC system and being tapped for different reasons. First, the patient population plays an important role in being receptive of the technology used on them in general. For example, nurses mentioned that populations with certain health conditions (e.g. mental health) and elderly populations might fear technology. Second, patients may think that nurses are relying on the technology to perform the checks and that they are not being responsible. Third, having the smartphone in the patient's room may raise a privacy concern (e.g. patients may think that the nurse is taking pictures of them). Fourth, patients may think that nurses are texting or browsing in their smartphones and acting unprofessionally.

RQ6: What are the strengths and weaknesses of the NFC-MACC system from the nurses' points of view?

The qualitative analysis helped us to explore the advantages and strengths of the NFC-

MACC system. The five strengths discussed in the findings are associated with the NFC-MACC system's functions, components, interface, learnability and memorability, and usefulness. First, nurses pointed to some advantages related to the system's functions, which are medication verification, communication, and documentation. The following points summarize the key strengths related to the system functions:

- Improving the bedside medication verification
 - Provides an easy procedure to verify the five rights, allergy, interactions, and contraindication by simply tapping on the patient's and medication's tags.
 - Provides an effective procedure to verify the medication by gathering all of the required data for verification in one trusted source.
 - Provides an efficient procedure to verify the medication that requires less effort and less time by providing an immediate verification right at the bedside and alerts the nurses immediately, before they administer the medication.
 - Provides sufficient medication error alert that can be sent to the desired healthcare provider or can be simply overridden.
- Improving documentation
 - Provides an easy procedure to document the medication by allowing them to perform this task at the bedside and save them trips to the MAR to document every single medication.
 - Reduces the chance of missing documentation by allowing the nurses to immediately document at the bedside.
 - Provides an efficient documentation that requires less effort and no trips outside the patient's room
 - Provides the flexibility of adding notes to the documentation
- Improving clinical communication related to medication administration
 - Provides mobility and accessibility to healthcare providers
 - Provides an easy method of communication and shortens the range of communication (number of people unnecessarily involved in the communication)

- Increases the efficiency of clinical communication by providing a ready-to-go message with sufficient information and instant notification to healthcare providers.
- Eliminates the phone tag issue, hence saves the time spent by the phone waiting for a response
- Decreases interruptions by providing information that allows the healthcare provider to evaluate the urgency of response.
- Provides a convenient method of communication especially for non-urgent situations, contact during night shifts, or during busy shifts.

Second, nurses noted some advantages related to the system's components. The use of smartphones and the NFC technology allowed for accessibility to resources. In contrast to the current sources/equipment used for verification, documentation, and communication, each nurse would be assigned with a smartphone that is accessible during their shift. In addition, the portability of the smartphone helps in navigating through the units and patients' rooms more easily and provides more time for patient care at the bedside. Using the smartphone supports the workflow portability needs where nurses can verify medications, document them, and contact healthcare providers at the bedside. Moreover, the use of NFC technology provides an easy and effective method to identify patients and medication compared with reading names on armbands, verbally asking patients, and performing barcode identification. NFC identification is suitable when patients are not able to verbally confirm their name and date of birth, or at night when the readability of armbands is difficult. Furthermore, using the NFC would streamline the task of identifying the patients because it provides a quick identification by simple tapping and it does not require to be physically pointed at a certain angle to capture the patient's or medication's ID. Also, nurses preferred the NFC tapping to identify patients at the bedside over the barcode scanning because the NFC armband does not easily get damaged; such damage forces the nurse to interrupt his or her work to reprint the armband.

Third, nurses also discussed strengths related to the application interface. It was found to be user-friendly due to its simplicity and few number of clicks required to perform actions. The alert information was clearly presented and drew attention to the important pieces of patient information. The red colour in the alert was appropriately used. It stands

out and gives a sense of warning; hence, it grabs the nurses' attention to stop administering the medication. Healthcare providers' pictures would be also helpful to allow nurses to know who are they actually contacting and recognize them when they see them on an everyday shift. In addition, nurses believed that the interface simplicity and ease of use will make it adaptable and acceptable to an older generation who may not be familiar with smartphones or applications. It is worth mentioning that we had a variety of ages of nurses in this study, and there were no complaints or sense of frustration in relation to the interface.

Fourth, learnability and memorability are usability attributes that were found to be strengths of the system. As discussed in the second research question, the simplicity of the NFC-MAC interface, the ease of use of its functions, and the nurses' existing familiarity with smartphone applications make the system easy to learn and easy to remember how to use it.

Similarly, usefulness is a usability attribute that was found to be one of the main strengths of the system. All of the strengths associated with the NFC-MACC functions, technology used, and interface lead to the usefulness of the system. In other words, based on the nurses' experience during the tasks, they were able to picture and see the value of the system in a clinical setting. It was predicted that the system is going to enable the nurses to achieve the medication verification tasks easily and efficiently, hence enhance nursing practice and improve patient safety. In addition, the previously discussed strengths lead to the nurses' acceptance of the NFC-MACC system and the willingness to use it in a clinical setting.

The second part of the question was also answered by the qualitative analysis of the interview questions. The interview helped us to explore the disadvantages and weaknesses of the NFC-MACC system. The two weaknesses discussed in the findings are associated with the NFC-MACC system's functions and components. The following points summarize the key weaknesses related to the system functions:

- Issues associated with the communicating method:
 - It could raise late or no response issues from healthcare providers
 - Not an appropriate method for a critical and acute situation and could be challenging to communicate the right information.
 - It reduces the opportunity of learning from a verbal clinical conversation

- Alert fatigue for healthcare providers and an increase of interruptions
- Issues associated with the medication verification procedure and alerts:
 - Adding extra tasks to nursing practice and reduces the efficiency of their job
 - Alert fatigue due to a large number of minor alerts or false alerts
 - It could develop an automatic overriding behavior and raise a problem of skipping an important alert.
 - Color and audible alerts are not sufficient in some cases. For example, alerts encoded with color are not effective when the nurse is color blind. In addition, when nurses are exposed to a large number of frequent audible alerts, they become desensitized to them. Therefore, haptic alert (e.g. vibration) can be more effective.

Moreover, there are four main challenges associated with the NFC-MACC components. First, we found that fear of technology can affect the nurses being receptive to NFC-MACC system and information technology in healthcare in general. Two factors discussed by nurses that could result in the rejection of adopting new methods in nursing practice. First, change in routine and the introduction of a new system may feel more burdensome to healthcare providers and lead to an uptake problem. Second, it can be irritating to feel that technology would replace the nurse's role. On the contrary, some nurses have an issue with accepting technology in the workplace due to the fear of becoming completely dependent on it. Being completely dependent on the system may eliminate their clinical judgment and increase the possibility of being irresponsible and blaming the system when errors happen.

The second problem associated with components is tapping difficulty. The readability problem of NFC tags arose in three cases, the tapping is too fast, the tapping distance is too far (distance between the smartphone and the patients or medication tag), or not tapping on the right spot of the phone where the NFC reader is located.

Third, the use of smartphone raised some disadvantages in the NFC-MACC system. Familiarity with smartphone brand and the keyboards may affect on the nurses' performance. Moreover, because smartphones are small and convenient to carry, it is possible to forget them in scrubs' pocket when nurses leave the shift. In addition, using the smartphones constantly from patient to patient will make it subject to breakage.

Finally, Infection transmission is one of the possible issues associated with using the NFC-MACC system, which affects patients safety. Using the same smartphones to tap on a number of patients' ID band would contaminate it and causes a transition of bacteria or viruses, especially if used on patients in isolation.

8.2 Discussion

The steps currently being followed in nursing practice to verify the *five rights*, allergy information, drug interactions, contraindications, and contacting healthcare providers involve a lengthy process that takes a long time to reach the right clinical judgment. We developed a prototype NFC-MACC system that reduces this time by running the verifications electronically using the same sources that nurses usually use, and providing an alert that is supported by factors to help nurses in assessing the situation. It also provides a customized clinical communication that covers the essential information that should be supplied to the healthcare provider.

8.2.1 Efficiency and Effectiveness of NFC-MACC System

Based on the study findings, we believe that the NFC-MACC system would allow nurses to accomplish medication verification much more efficiently than their current practice. The quickness of the system will result in a reduction in the amount of time that is now spent on searching for the right source and information. This time could be used for other important purposes that would benefit the patient. Landman et al. (2014) compared the efficiency of using BCMA with a prototype NFC-based tablet for medication administration (NFCMA) and found that both had similar efficiency. The study recruited 20 nurses with BCMA experience. The nurses performed one task that required them to scan one patient and four medications. The result of their study showed no statically significant difference in medication administration efficiency ($P=09$) (scenario time and scanning attempts) between BCMA and NFCMA [14]. However, we believe that one task is not sufficient to evaluate the efficiency of NFCMA due to nurses' lack of experience with NFC. From our experience in this research, although we administered basic training at the beginning, the first task was the slowest. The reason for this is that the first task works as a solo training for nurses where they explore the technology, trying to reach the desired screen without our help. Therefore, we believe that if Landman's study had

included multiple tasks, nurses would develop the basic skills of using the NFC and would perform faster.

Moreover, we found that even though few participants (6/32) had prior experience with NFC technology, no single participant found our system complicated or difficult to use. On the contrary, they found it easy to learn and highly usable. In addition, the participants compared their experience with barcode scanning (BCMA and/or Barcode glucometer tool) with the NFC-MACC system and indicated that it is much easier to obtain the patient ID via NFC tapping than barcode scanning. The findings of our study showed that some participants had to tap on the patient or medication tag more than once to obtain the ID. The failure of obtaining the ID can be easily avoided with experience of using the NFC technology. However, participants indicated that failure of obtaining the ID using a barcode is burdensome and requires the nurse to physically point at the barcode in an angle that captures all of the barcode lines. In some cases, they are required to reprint the patient's ID tag due to damage or fading. Previous work highlighted the challenges of using BCMA in nursing practice and explained that the difficulties of barcode scanning forces the nurses to use workarounds, which potentially lead to medication errors and reduce the quality of healthcare [12][48][117].

8.2.2 Ease of Use of the NFC-MACC System

Based on the study findings, we believe that the NFC-MACC system would allow nurses to accomplish the medication verification process and contact healthcare providers more easily. It transforms the difficult tasks of looking for the right information to ensure safe delivery of medication into easy ones. It allows for automatic medication verification right at the bedside and provides an instant alert with sufficient information that helps the nurses to achieve complete and accurate verification without significant effort. All nurses agreed upon the simplicity and the ease of verifying the five rights, drug interactions, allergies, and contraindications compared with their current method.

In addition, using the smartphone as the central device to perform the tasks of verification and communication helps in navigating through the units and patients' rooms more easily. It supports the workflow portability needs where nurses can verify medications, document them, and contact healthcare providers at the bedside. Some nurses emphasized that having the device in their pocket makes them capable of accomplishing

the tasks more easily. Landman's study's survey showed that 19/20 (95% of) nurses agreed on the ease of use of the NFC technology; however, one of the main issues with their system is the portability and the size of the tablet [14]. They illustrated that tablets cannot be carried in nurses' pockets, so the chance of leaving it somewhere, losing it, or dropping it is high. Moreover, they found that nurses usually have their hands full during medication administration and that it is inconvenient to carry both the patient's medication and the tablet at the same time. Therefore, they suggested that a smaller device would be helpful.

Furthermore, the findings of this thesis show that nurses preferred the NFC-MACC system over the BCMA in terms of portability. Unlike BCMA, they found that carrying the smartphone is more convenient and does not require too much space. Studies showed that one of the main usability issues of the BCMA system is portability. Because BCMA systems are integrated with computers on carts, it is challenging for a nurse to move from one room to another, especially when the structure of the room impedes bedside access [10][12]. In addition, separating the barcode scanner from the computer could hinder the nurse from hearing or seeing alerts, especially if there is noise in the hallway or in the patient's room. Sometimes, nurses find it easier to enter the 7-digit number manually than to move the large cart into a patient's room just to scan a wristband [45]. Landman's study also showed that, even though nurses were skeptical about the size of the tablet, they still prefer its size over the BCMA [14].

Even though nurses admired the use of smartphone as the primary device for medication verification and communication, tapping on numbers of patients' ID bands would contaminate it and cause transition of bacteria or viruses, especially if used on patients in isolation. The participants of Phase 1 (preliminary study) and Phase 3 (part 2) pointed out the issue of infection control. Previous work has pointed to this issue with the use of mobile devices [14][102][103][118]. A suggested solution to overcome this problem is to have a protective cover that prevents the smartphone surface from directly touching the tags and allows it to be disinfected, and using isopropanol wipes [14]. Also, an ultraviolet light (UV) disinfection system can disinfect smartphones and tablets.

8.2.3 Usefulness of the NFC-MACC System

Nurses have viewed the NFC-MACC system favourably, in anticipation of the benefits of the system on nursing practice and patient safety. The overall *Perceived Usefulness* of the

NFC-MACC system scored 1.44 (on scale of 5 where 1 is most positive), which implies that nurses can see a significant potential of the system. In contrast, Marie VanderKooi (2014) evaluated the usability of BCMA (on a scale of 7 where 7 is most positive) from the nurses' point of view and reported that the mean of *Perceived Usefulness* was a little low (3.69). The reason behind this score was the readability problem of barcode labels. Nurses found the BCMA not useful and reported that it does not improve patient care when it fails to scan the patient or the medication [119]. Barcode labels on medications or patients can be unreadable when they are damaged (e.g., wrinkled, smudged, ripped, curved, or covered) [12][16][46]. As a result, some nurses stray from the intended BCMA procedures and develop workarounds that defeat the purpose of BCMA and affect patient safety [12]. Nurses' acceptance of the medication administration systems is influenced by the characteristics of technology and how easy it is to use. Therefore, given the NFC technology characteristics, the NFC-MACC system may eventually become an alternative to the BCMA.

Moreover, the NFC-MACC system integrates bedside medication verification with a real-time communication feature. This integration allows to electronically generate the essential information needed by healthcare members to aid them in assessing patient condition to ensure safe delivery of medication. The existing medication administration systems lack this integration. Hence, when nurses require a consultation, they have to use different devices. A report published by the Agency for Healthcare Research and Quality (2010) stated that "If health IT is to provide optimum performance, it must be designed to fit the specific context in which it will be used, specifically the type of practice and patients served." [120]. Using different devices during the BMA may increase workflow distractions and decrease the time devoted to patients and medication administration.

The participants in our research appreciated this integration because it would increase their mobility, accessibility, and efficiency, and improve the communication between healthcare providers during the medication administration stage in particular. In other words, the text-based communication in the NFC-MACC system provides efficient and immediate access to healthcare providers. In addition, having a sufficient and ready-to-go message (content) to send would rapidly reduce the time spent typing a message with critical and complete information. Gallot (2015) had found that using a free text-based

mobile application reduces the communication time to 6 minutes [88]. In our research, the time required to explain the condition is already cut down, and we found that the time taken to send a complete message (forward the alert and type a request) is at a maximum 1 minute and 30 seconds. However, it is worth mentioning that this does not include the reply time (by physician or pharmacist).

Even though participants indicated interest in the communication feature, some of them were not sure if the healthcare providers would check their phones in timely manner. This low response rate problem is highly possible because it has appeared with other text-based communication methods [68][75][85][86]. This problem is directly related to how busy healthcare providers are regardless of the method used for communication [90]. However, one of the suggested enhancements we received is adding location information of the healthcare provider to help the nurse in deciding which member she should contact. In addition, with complicated issues that require direct contact with physicians, nurses suggested that we can enhance the application by adding a call feature that can only be used for emergency situations.

In addition, in this thesis we did not test the acceptability and usability of the communication feature from the secondary users' (physicians' and pharmacists') points of view. However, studies have shown that physicians prefer the text-based method of communication over paging and phone calls because it improves workflow efficiency and information exchange between them [121].

8.2.4 Beliefs of Patients' Perceptions

The findings indicate that the majority of participants believed that the patients would like the system, appreciate being scanned, and would understand that the system is used for their benefit to reduce medication errors. It is highlighted that the familiarity with the scanning process (e.g. BCMA, barcode glucometer scanning, and Elaps RFID monitoring) would result in the comfort of the patient towards the tapping process of the NFC-MACC system. However, some concerns around patients' acceptance of the system were raised such as fear of technology, privacy issues with using smartphones (a patient may think that a nurse is taking pictures of him/her), and feeling that nurses are relying on technology and not being professional at their job. It is suggested that educating patients about the purpose of the system would overcome this problem. VanderKooi evaluated patients' perceptions

regarding the use of BCMA. Her study showed that the acceptance of BCMA was moderate due to the lack of educating patients about the system's functionality and purpose [119]. She recommended that nurses should use simple and easy words to explain the procedure to patients: "For safety, I will scan the band on your wrist once and then I will scan the medications to double-check that this is the medication ordered for you at this time." [119]. Educating the patient about the procedure of any medication administration system will ease their understanding and acceptance of the system.

8.2.5 Enhancements

The feedback gathered from the interview provided recommendations to enhance the NFC-MACC system. Most of the recommendations are related to the functionality and the design of the system. The following list highlights the main recommendations.

Integrating Additional Information Sources in the System:

- 1- Integration of the E-MAR with the NFC-MACC system where nurses can access the patient's E-MAR right at the bedside and view his/her prescribed medications.
- 2- Integration of drug information source in the system where nurses can access the information of medication when needed.
- 3- Integration of drug calculation in the system where nurses can access a quick guide to calculate drug dosage.
- 4- Integrate the medication administration time to the system and provide an alert to the nurse with the medication is due.

Documentation and Communication Enhancements:

- 1- Adding an option in the documentation for dropped, spilled, wasted medication.
- 2- Adding a call feature to be used for urgent cases.
- 3- Provide a real time location feature that helps the nurses deciding which physician they need to contact (e.g. if the physician in the OR room then the nurse can contact the second person on the patient's team)
- 4- Provide statuses information of each healthcare providers (e.g. on call or shift starting and ending time)
- 5- Provide an option that prioritize the notification sent to the healthcare providers (i.e. high level notification should be differentiated from a regular notification alert).

- 6- Provide abbreviations that nurses can use to speed up the typing process (i.e. if the nurse types PC, then it comes up 'Please consult this medication')
- 7- Adding a link to the patient's information where the physician can access it if needed more details about the patient condition or history
- 8- Adding the complete medication order information in the forwarded alert where the physician can get a comprehensive information of the ordered medication.
- 9- Adding patient's allergy list in the forwarded alert.
- 10- Modify the staff list where only the patient's team is displayed to avoid sending the information to the wrong healthcare provider. And provide a link to the general staff list where nurses can access staff that are not part of the patient's team.

Alert Enhancement:

- 1- Classify alerts with colors (red, orange and yellow) so nurses can predict the severity of the alert prior to reading the alert information.
- 2- Provide an option for alert tone or haptic feedback (vibration) to draw nurses' attention when an error is triggered.
- 3- Adding a description of medication function in the alert or provide a link to its function where the nurses can access this information if desired.
- 4- Adding the complete medication order information in the alert, and adding information of the last time it was given.
- 5- Adding complete vital signs information to the alert in order to understand why some medications were ordered in certain dosage.

Interface Enhancement:

- 1- Adding alert classification colors.
- 2- Bold the alert title and key information.
- 3- Customize the patient' list where the nurses log in and choose the unit, then choose their patients. According to their selection, the list of patient will only include the patients assigned for them in a certain shift.
- 4- Add the room number, bed number, and admission date to the main screen where nurses view the patient's information.
- 5- The patient verification screen has to be different than the medication screen to avoid confusion.

- 6- Provide search feature when the list is populated with large number of patients.
- 7- Adding the tapping logo next to the textbox that stores the patient's and medication's ID.

Control Options:

- 1- Provide an option that has instructions for every single step and can be disabled if the nurse didn't need it.
- 2- Provide an option for alert sound or vibration to draw nurses' attention and can be disabled if the nurse didn't need it.
- 3- Provide an option to customize the keyboard size and the font size.
- 4- Provide an option to contact technical support in case of technical difficulty.

Tapping Enhancement:

- 1- Consider haptic feedback such as vibration and provide an option to increase the intensity of the haptic alerts. This enhancement is important when a nurse is color blind or a nurse is desensitized to audible alerts.

The provided recommendations by the nurses can be used to refine the design of NFC-MACC system and explore further potentials of the system in clinical settings. In addition, implementing these recommendations can weigh out some of the addressed weaknesses of the system.

Summary

In this chapter, we discussed the answers of the research questions by linking the quantitative and qualitative findings. We also discussed the key findings of the study and compared it with prior work. The chapter was concluded with a list of suggestions for improvement that can be implemented in future work.

Chapter 9. Conclusion

This chapter summarizes the three phases conducted in this thesis. It also discusses the main contributions and implications of the thesis. Limitations and future work are also listed in this chapter.

9.1 Research Summary

In this thesis we designed and evaluated the prototype NFC-MACC system. We used the Information System Research (ISR) Framework by Hevner et al. (2007) to guide our research through the design, implementation and evaluation process of the NFC-MACC system. The thesis was divided into three sequential phases.

Phase 1 was a preliminary study that aimed for understanding whether or not the idea of using an NFC-enabled smartphone application at the bedside is acceptable and usable to nurses during the medication administration stage. We tested the usability of an initial prototype design of two functions of the NFC-MACC system, which are to verify allergy and drug interactions. The overall result showed positive feedback concerning usability and an acceptance of the NFC technology to be used at the bedside. In addition, recommendations for improvements were gathered during this phase and then used as design guidelines in Phase 3 (part 1).

Phase 2 was a qualitative study that aimed for understanding of the bedside medication administration procedure in nursing practice from the NSHA Policy and Procedure (theoretical source of information) and nurses' knowledge and experience (practical source of information). One-on-one semi-structured interviews with 14 nurses were conducted in this study. The findings of this phase provided us a better understanding of the required data and sources used in nursing practice to verify medications and to contact healthcare providers, and assisted us to define the essential functional guidelines for the NFC-MACC system.

In Phase 3 (part 1), the design and functional guidelines obtained from Phase 1 and Phase 2 were utilized to design the prototype NFC-MACC system. We designed the system to reduce the major causes of medication errors by: (1) identifying the patient and the medication; (2) confirming the five rights of medication administration; (3) verifying allergies; (4) verifying drug interactions; (5) verifying contraindications; (6) alerting nurses

and providing sufficient alert information; (7) providing real-time communication between nurses and other healthcare providers; and (8) documenting the administered medication.

Finally, in Phase 3 (part 2), we evaluated the NFC-MACC system to understand the nurses' perception regarding its usability. The findings showed that the system was well received by the nurses and offered promise to ease the steps required to verify medications and improve clinical communication efficiency and mobility. Participants expressed their interest in using the system in clinical setting and believed it would enhance nursing practice and increase patient safety.

9.2 Research Contribution

This research makes contributions in three areas: employment of NFC technology in healthcare, employment of mobile health in the medication administration stage, and usability of medication administration systems.

9.2.1 Employment of NFC Technology in Healthcare.

While there has been increased interest in applying NFC technology in different contexts of healthcare, literature about its application for bedside medication administration in hospitals is limited. This thesis presents a comprehensive research study that emphasizes the significant potential use of NFC technology at the bedside to identify the patient and medication. It adds evidence derived from the end users (nurses) of the NFC use benefits over the existing wireless medication administration systems, BCMA, used for identifying patients and medication at the bedside.

9.2.2 Employment of Mobile Health in the Medication Administration Stage

This thesis contributes to the area of NFC application and nursing practice by introducing an NFC-based novel solution (the NFC-MACC system) to streamline the process of medication administration and reduces the major causes of medication errors (failure to confirm the 'five rights' of medication administration, failure to verify contraindications, and failure to effectively communicate with other healthcare providers). The existing wireless technology interventions, BCMA and RFIDMA, focus on verifying the *five rights* of medication administration and allergies; however, they ignore the verification of drug interactions and contraindications, which are among core nursing responsibilities. The introduced system in this research not only overcomes the usability problems of the

barcode and RFID platforms, but it also considers triggering alerts concerning drug interactions and contraindications.

Furthermore, the research to date has focused on improving tools for general communication between healthcare providers. However, none of them have been customized to effectively fit the medication administration stage nor have considered the content of the communication. Proposing a novel idea of customized communication that precisely applies to the medication administration stage is an important contribution. It draws the attention to the significance of the clinical communication content between the healthcare providers, and it introduces the potential of integrating clinical communication with medication administration systems.

9.2.3 Usability of Medication Administration Systems

Little attention has been paid to the adoption of NFC technology at the bedside; hence, usability evaluations for the medication administration systems integrated with NFC technology is limited. In this research, we tested the usability of the NFC-MACC system from the nurses' perspective. The result of this testing provides a comprehensive picture of the nurses' perceptions regarding the acceptability and usability of NFC-based medication administration systems. Understanding the nurses' perceptions regarding the usability and acceptability of the system will be an important contribution to building health information systems integrated with NFC technology in similar (medication administration stage) or different contexts. In addition, the result of our study indicates how the customized communication to facilitate bedside medication administration is promising and can be applied to different contexts of healthcare.

9.3 Research Implication

This research has implications for both computer science and the healthcare domain and will be of particular interest to those who research and develop emerging wireless technology applications and systems in healthcare. The design and functional guidelines presented in this research can be used to design similar systems for the medication administration stage that targets nurses. In addition, this research indicates positive result regarding the acceptability and usability of the NFC technology at the bedside, which may lead to developing similar systems integrated with NFC in different contexts in healthcare.

In addition, this research highlighted the potential of the NFC technology which could eventually be an alternative to the barcode system.

In addition, his research highlighted the potential of the NFC technology which could eventually be an alternative to the barcode system. The promising result of the NFC-MACC system usability and the nurses' interest in using the system could be an encouragement for researchers to take it to another level and test it in a clinical setting. Furthermore, evidence from this research indicates the importance of integrating the drug interactions and contraindications in the medication administration systems. Researchers and developers can improve the existing systems, BCMA and RFIDMA, by adding these verification features.

Moreover, the result of this research emphasizes the benefit of using the smartphone for medication verification and clinical communication. The nurses highlighted the portability and accessibility of this device. These findings may encourage adoption of NFC-enabled smartphones and leverages its capabilities in a clinical setting. Further, we designed a customized communication that precisely applies to the medication administration stage. It generates the essential content of communication between the nurse and other healthcare members, which helps in assessing patient condition and providing consultation. The result of our research regarding this feature was promising and may lead researchers or developers to adopt it in similar or different context. It may also encourage the adoption of new methods or tools that consider the content of the communication.

9.4 Limitations

The findings of the final study (Phase 3 Part 1) provided us with sufficient information to generate some conclusions regarding the usability of the NFC-MACC system, however, it is important to note the limitation of this phase. First, the system usability was tested in a lab setting (meeting room), the findings may not be the same if the system was tested in a real clinical setting. Thus, the result cannot be generalizable to a clinical setting. Second, due to conditions laid out by The School of Nursing and the IWK Health Centre, the result does not represent the nursing practice at certain institutions, units, or patient population. It only represents the participants of the study who have medication administration experience. Third, due to the small sample size, the result cannot be generalizable to the nurses' population. However, the initial testing of the NFC-MACC system has provided a

comprehensive understanding of nurses' perception regarding its' usability with the consideration of both qualitative and quantitative data analysis. Fourth, the duration of the study was short, which may have limited the participants' ability to discover other weaknesses that might be discovered if the study duration was longer. Fifth, we tested the usability of NFC-MACC with nurses only and their acceptance of the communication feature may not reflect the physician and pharmacist opinion. Finally, the prototype NFC-MACC system performs basic tasks with one form of medication (oral/tablet). More complicated tasks with multiple and different forms of medications may discover more weakness and strengths.

9.5 Future Work

We have identified different areas for potential future work listed below:

- 1- Refine the NFC-MACC system design.
- 2- Improve the communication feature and explore its usability from the physician and pharmacist perception.
- 3- Integrate the NFC-MACC system with E-MAR interface.
- 4- Conduct a comparative usability testing with advance medication administration systems.
- 5- Consideration for future NFC-MACC system implementation in clinical setting.
- 6- Expanding the system to be used at homes.

9.5.1 Refine the NFC-MACC system design

The initial prototype NFC-MACC system design has different features that can be improved through an iterative design and implementation. The listed enhancements in section (8.2.5) can be used to refine the system and improve its functionality. Further, testing the usability of the refined NFC-MACC system with different forms of medication and more complex scenario may uncover new potentials and limitations. The iteration of the system design may result in more reliable and effective replacement to the BCMA system.

9.5.2 Improve The Communication Feature and Explore Its Usability from The Physician and Pharmacist Perception

A potential future work can include the enhancement of the communication feature and the consideration of prioritizing the notifications to avoid the alert fatigue issue. It can also include the integration of call and location services. Further, in this study we tested the

usability of the communication feature from the nurses' point of view, however, due to recruitment challenges, we did not include other healthcare providers. Physicians and pharmacist are the secondary users of the NFC-MACC system and their perception regarding the communication feature is important. Therefore, a future work could test the usability of this feature with different healthcare providers to add a comprehensive understanding of the acceptability and usability of this feature.

In addition, more research on customized communication for different clinical context with different healthcare members may encourage the adoption of new methods or tools that consider the content of the communication.

9.5.3 Integrate the NFC-MACC system with E-MAR interface.

In this thesis, we linked the NFC-MACC system with the E-MAR to run the patient and medication verifications. However, we didn't provide the nurse with a direct access to the patient's E-MAR (i.e. the system was not integrated with E-MAR interface). Thus, future work can integrate the E-MAR with the NFC-MACC system and provide the nurse with a better access to the patient's medication information at the bedside.

9.5.4 Conduct a Comparative Usability Testing with Advance Medication Administration Systems.

A potential future work can include a comparative usability testing between the NFC-MACC system and other advance medication administration systems such as BCMA and RFIDMA. The comparative usability may provide a statistical analysis to comprehend the pros and cons of the NFC-MACC against different systems. Also, further research can be done in a clinical setting to determine if NFC technology would reduce medication errors and improve patient safety.

9.5.5 Considerations for Future NFC-MACC System Implementation

In this thesis we proposed an initial prototype design of the NFC-MACC system. The scope of this thesis focuses on the human factor side by testing the acceptability and usability of the system from the nurses' point of view. Future work for implementing such system in a clinical setting should consider different factors such as security, privacy, and compliance with hospitals policy. First, the system should be compliant with the privacy and security regulations of Personal Health Information Act (PHIA) and Personal Information

Protection Electronic Documents Act (PIPEDA) in Canada. Second, considerations regarding the modification of the medication administration and communication workflow should be studied. Third, introducing a new method of communication in a clinical setting should be combined with reply guidelines to streamline the communication process and avoid the late response issue. Fourth, limitations of applying the NFC technology in hospitals have to be addressed before this technology can be implemented (e.g. labeling medications with NFC tags). Introducing a mechanism of incorporating the NFC tags into the unit dose is a very important research area that can be studied in future.

9.5.6 Expanding The System to be Used at Homes.

The system proposed was intended for employment in a clinical setting, however, the positive feedback from the end users encouraged us to consider modifying the system in the future to be employed in homes. The system can be modified and the patient will be the end user. In this case, the patients will not be required to use an NFC tag (patient tag) to identify themselves, and they are only required to identify their medications using NFC tags. The verification of medication at homes can be altered to meet the patients need. For example, confirming the “right patient” should not be part of the system since there is only one patient. However, the rest of the verifications (does, time, allergies, and drug interactions) can be integrated with the system. In addition, a method of integrating the patient health information with the system should be identified in order to run the verifications.

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Appendices

Appendix 1.A – List of Publications

M. Alabdulhafith and S. Sampalli, "NFC-based Framework for Checking the Five Rights of Medication Administration." *Procedia Computer Science* 37 (2014): 434-438.

M. Alabdulhafith, A. Alqarni, and S. Sampalli, "Understanding Nurses' Perception Regarding the Use of NFC Application During Medication Administration," in *CHI 2016, ACM, 2016*, pp. 2976–2983. DOI:10.1145/2851581.2892473

M. Alabdulhafith and S. Sampalli, "Defining the Functional Requirements for the NFC-Based Medication Administration and Communication System", in *The Sixth IEEE International Conference on Healthcare Informatics (ICHI 2018)*, New York City, NY, 2018.

M. Alabdulhafith and S. Sampalli, "Customized Communication Between Healthcare Members During The Medication Administration Stage", in *The 20th ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI 2018)*, Barcelona, Spain, 2018.

M. Alabdulhafith and S. Sampalli, "Near Field Communication-Based System For Bedside Contraindication Verification", in *The 8th ACM MobiHoc 2018 Conference on Pervasive Wireless Healthcare (MobileHealth 2018)*, Los Angeles, CA, 2018. DOI: 10.1145/3220127.3220132

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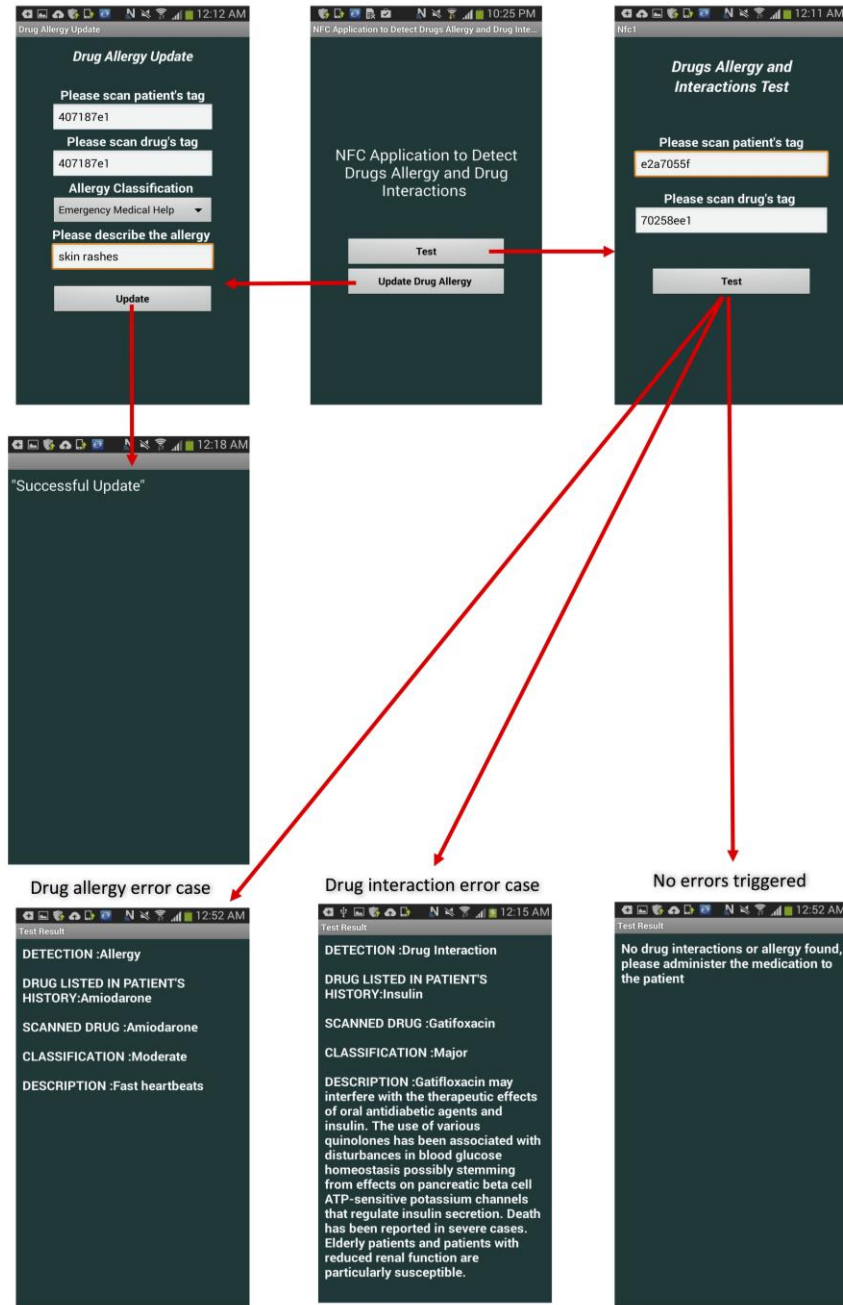
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Appendix 4.A – The Application Interface



Appendix 4.B – Phase 1: Capital Health Research Ethics Board Approval



Capital Health Research Ethics Board
 Centre for Clinical Research, Room 118
 5790 University Avenue
 Halifax, Nova Scotia, Canada B3H 1V7
 Phone: 473-5639 Fax: 473-5620

May 14, 2014

Maali Alabdulhafith
 Primary Health Care
 6960 Mumford Road, Room 0265
 Halifax, NS
 B3H 4P1

*Delegated Review
 Full Approval Letter
 (May 14, 2014 to May 14, 2015)*

ATTENTION: Ms. Tara Sampalli

Dear Mr. Alabdulhafith:

RE: Usability Testing for a Drug Allergy and Drug Interaction Mobile Application

REB FILE #: CDHA-RS/2014-306

Thank you for your response dated April 30, 2014, received on May 13, 2014 regarding your proposed study.

Document Name	Version No.	Version Date
Cover Letter	n/a	2014/04/30
	n/a	2014/04/23
Letter of Support from the Principal Investigator's Department/Division/Program/Service • <i>Signed by Dr. Michael Shepherd</i>	n/a	2014/04/29
Letter of Support from Supervising Investigator's CDHA Department/Division/Program/Service • <i>Signed by Lynn Edwards</i>	n/a	2014/05/13
Letter of Support from a Collaborating CDHA Department/Division/Program/Service • <i>Signed by Lynn Edwards</i>	n/a	2014/04/28
Ethics Approval Submission Form	n/a	2014/04/23
Consent Form	2	2014/04/23

Healthy People, Healthy Communities

Supporting Materials:		
• Online Background Questionnaire	4	2014/05/13
	3	2014/04/30
	2	2014/04/23
• Semi-Structured Short Interview	2	2014/04/24
Research Protocol	2	2014/04/23
Principal Investigator's Current CV	n/a	2014/04/23
Supervising Investigator's Current CV	n/a	2014/04/21

I have reviewed these documents on behalf of the Research Ethics Board (REB) and note that all requested changes have been incorporated.

I am now pleased to confirm the Boards full approval for this research study, effective today. This includes approval / favourable opinion for the following study documents:

Document Name	Version No.	Version Date
Cover Letter	n/a	2014/04/30
	n/a	2014/04/23
Researchers Checklist for Submissions	n/a	2014/03/07
Researcher's Commitments - Principal Investigator	n/a	2014/03/07
Letter of Support from the Principal Investigator's Department/Division/Program/Service	n/a	2014/04/29
• <i>Signed by Dr. Michael Shepherd</i>		
Letter of Support from Supervising Investigator's CDHA Department/Division/Program/Service	n/a	2014/05/13
• <i>Signed by Lynn Edwards</i>		
Letter of Support from a Collaborating CDHA Department/Division/Program/Service	n/a	2014/04/28
• <i>Signed by Lynn Edwards</i>		
Ethics Approval Submission Form	n/a	2014/04/23
Consent Form	2	2014/04/23
Supporting Materials		
• Semi-Structured Short Interview	2	2014/04/24
• Tasks	1	2014/03/07
• Post-Task Questionnaire	1	2014/03/07
• Online Background Questionnaire	4	2014/05/13
Research Protocol	2	2014/04/23
Principal Investigator's TCPS 2: Core Certificate	n/a	2014/02/05
Supervising Investigator's TCPS 2: Core Certificate	n/a	2011/12/24
Principal Investigator's Current CV	n/a	2014/04/23
Supervising Investigator's Current CV	n/a	2014/04/21

Continuing Review

1. **The Boards approval for this study will expire one year from the date of this letter (May 14, 2015).** To ensure continuing approval, submit a Request for Annual Approval to the Board 2-4 weeks prior to this date. If approval is not renewed prior to the anniversary date, the Board will close your file and you must cease all study activities immediately. To reactivate a study, you must submit a new Initial Submission (together with the usual fee) to the REB and await notice of re-approval.
2. Please be sure to notify the Board of any:
 - * Proposed changes to the initial submission (i.e., new or amended study documents or supporting materials),
 - * Additional information to be provided to study participants,
 - * Material designed for advertisement or publication with a view to attracting participants,
 - * Serious unexpected adverse reactions experienced by local participants,
 - * Unanticipated problems involving risks to participants or others,
 - * Sponsor-provided safety information,
 - * Additional compensation available to participants,
 - * Upcoming audits / inspections by a sponsor or regulatory authority,
 - * Premature termination/closure of the study (within 90 days of the event).
3. Approved studies may be subject to internal audit. Should your research be selected for audit, the Board will advise you and indicate any other requests at that time.

Important Instructions and Reminders

1. Submit all correspondence to Ethics Coordinator, Starla Burns at the address listed at the top of this letter (do not send your response to the REB Chair or Co-Chair).
2. Be sure to reference the Boards assigned file number, CDHA-RS/2014-306, on all communications.
3. Highlight all changes on revised documents, and remember to update version numbers and/or dates.
4. Print and electronic advertisements are to be submitted to the Audio Visual Department for placement in the appropriate Capital Health template. Complete a Request for Graphic Services form (Form CD 0019, available on the Intranet) and fax to Audio Visual Services together with the REB approved advertising materials and confirmation of REB approval.

Best wishes for a successful study.

Yours very truly

Co-Chair, Research Ethics Board

cc: Dr. Tara Sampalli (Primary Health Care, 6960 Mumford Road, Suite 0265, Halifax, NS, B3L 4P1)

/sb

Appendix 4.C – Phase1: Usability Testing Tools



Appendix 4.D – Phase 1: Background Questionnaire

Background Questionnaire

1. General Information

1. Participant's ID

2. Gender:

Male
 Female

3. Age:

20-29
 30-39
 40-49
 50-59
 60+

4. Position:

Physician
 Nurse
 Nurse Practitioner
 Other

5. Years of experience:

2 years or less
 3-6 years
 7-9 years
 10+ years

6. The average number of patients that you daily administer medication to is:

1-4 patients
 5-8 patients
 9-12 patients
 13+ patients

Background Questionnaire

2. The Process of Checking for Drug Allergy During the Medication Administration

Consider the following scenario and answer the questions (7-12):

You are administering a prescribed medication X to the hospitalized patient Mr. John. You want to check whether or not Mr. John is allergic to this medication before you give it to him. In such a case:

7. To avoid giving the hospitalized patient a prescribed drug that he/she is allergic to, which bedside check process do you use?

- Check paper record
- Check electronic record
- Ask the patient
- Other

8. On average, how long does it take to complete the drug allergy bedside check?

- Less than 1 minute
- 1-2 minutes
- 3-4 minutes
- 5-6 minutes
- 7+ minutes

9. How satisfied you are with the time required to complete the bedside check process for **drug allergies**?

- 1 2 3 4 5
Very dissatisfied Very satisfied

10. In your opinion, the accuracy of the bedside check for **drug allergies** (you selected above) is:

- 1 2 3 4 5
Poor Excellent

11. Please explain why did you choose this level of accuracy (please number your reasons if there are more than one).

12. How satisfied you are with this level of accuracy (selected above)

- 1 2 3 4 5
Very dissatisfied Very satisfied

Back

Next

Background Questionnaire

Consider the following scenario and answer the questions (13-17):

You detected that Mr. John is allergic to the prescribed medication X before you give it to him. In such a case:

13. Who do you notify if you detected an allergy?

- Physician
- Pharmacist
- Nurse
- Other

14. What process do you use to notify him/her? Please check all that apply.

- Phone call
- Talk in person
- Write a report
- Other

15. On average, how long does it take to complete the **notification** process (selected above)?

- Less than one minute
- 1-3 minutes
- 4-6 minutes
- 7-9 minutes
- 10+ minutes

16. In your opinion, what are the disadvantages of the **notification** process (selected above)?

17. In your opinion, what are the advantages of the **notification** process (selected above)?

Back

Next

Background Questionnaire

3. The Process of Checking for Drug Interactions During the Medication Administration

Consider the following scenario and answer the questions (18-22):

You are administering a prescribed medication Y to Mr. John. You want to check whether or not the prescribed medication will interact with other medications that Mr. John had before (patient's history). In such a case:

18. To avoid giving the patient a prescribed medication that may **Interact** with other medications (in patient's history), which check process do you use?

- Check paper record
- Check electronic record
- Check drug-drug interaction resources
- Other

19. On average, how long does it take to complete the **drug interactions** bedside check?

- Less than one minute
- 1-3 minutes
- 4-6 minutes
- 7-9 minutes
- 10+ minutes

20. How satisfied you are with the time required to complete the bedside check process for **drug interactions**?

- 1 2 3 4 5
- Very dissatisfied Very Satisfied

21. In your opinion, the accuracy of the bedside check for **drug interactions** (you selected above) is:

- 1 2 3 4 5
- Poor Excellent

22. Please explain why did you choose this level of accuracy (please number your reasons if there are more than one).

Back

Next

Background Questionnaire

Consider the following scenario and answer the questions (23-27):

You detected that the prescribed drug Y may cause a drug interaction before you give it to Mr.John. In such a case:

23. Who do you notify if you detected a possible **drug interaction** ?

- Physician
- Pharmacist
- Nurse
- Other

24. What process do you use to notify him/her? Please check all that apply.

- Phone call
- Talk in person
- Write a report
- Other

25. On average, how long does it take to complete the **notification** process (selected above)?

- Less than one minute
- 1-3 minutes
- 4-6 minutes
- 7-9 minutes
- 10+ minutes

26. In your opinion,what are the disadvantages of the **notification** process (selected above)?

27. In your opinion,what are the advantages of the **notification** process (selected above)?

Back

Next

Background Questionnaire

4. The Process of updating the patient's drug allergies' list during the medication administration

Consider the following scenario and answer the questions (28-30):

You gave Mr.John a prescribed medication Z. After a while, you noticed that the medication caused an adverse drug reaction, which means that Mr.John is allergic to that medication. In such a case:

28. To **update** the patient's records for drug allergies, which bedside processes do you use?

- A paper and a pen to update the patient's paper-based file
- An electronic health record to update the patient's electronic file
- Other

29. On average, how long does it take to complete the **updating** process (selected above)?

- Less than one minute
- 1-3 minutes
- 4-6 minutes
- 7-9 minutes
- 10+ minutes

30. How satisfied you are with the time required to complete the **updating** process

- 1 2 3 4 5
- Very dissatisfied Very satisfied

Back

Finish

Appendix 4.E – Phase 1: Tasks Scenario

Participant ID:.....

Checking for a Drug Allergy or Drug Interaction

Please read the following scenario and then perform the tasks.

Scenario #1:

The doctor prescribed drugs A, drug B, and drug C to the hospitalized patient Mr. John. You are responsible for administering these drugs to Mr. John. During the process of administering the prescribed drugs, you want to check whether or not:

- 1 Mr. John is allergic to any of the prescribed drugs.
OR
- 2 any of the drugs (A, B, and C) may interact with other drugs that Mr. John has already taken (patient's history).

Now you will start checking the drugs through the smartphone application.

Task 1. Checking if drug A would cause allergy or interaction:

- 1- Open the NFC smartphone application.
- 2- Find the right button to check for drug allergy/drug interaction.
- 3- Read (tap) Mr. John's tag (patient's tag).
- 4- Read (tap) the drug A tag.
- 5- Check if drug A would cause allergy or interaction
- 6- What would drug A cause? (Choose one of the following options)
 - Drug allergy.
 - Drug interaction.
 - Nothing.

Task 2. Checking if drug B would cause allergy or interaction:

- 1- Start over.
- 2- Repeat steps 1 to 5 from Task (1).
- 3- What would drug B cause? (Choose one of the following options)
 - Drug allergy.
 - Drug interaction.
 - Nothing.

Task 3. Checking if drug C would cause allergy or interaction:

- 1- Start over.
- 2- Repeat steps 1 to 5 from Task (1).
- 3- What would drug C cause? (Choose one of the following options)
 - Drug allergy.
 - Drug interaction.
 - Nothing.

Updating the Patient's Drug Allergies List/Record

Please read the following scenario and then perform the tasks.

Scenario #2

You have given drug C to Mr. John. After a while, you noticed that the drug has caused **skin rashes** to him, which means that he has a **moderate** allergy to drug C (new allergy that is not recorded in his file).

You want to update the Mr. John's file (located at the hospital's database) immediately by adding drug C to his drug allergies' list.

Now you will start updating Mr. John's allergies information through the proposed smartphone application

Task 4. Update the patient's drug allergies:

- 1- Open the application.
- 2- Find the right button to update Mr. John's drug allergies.
- 3- Read the Mr. John's tag.
- 4- Read the drug C tag.
- 5- Fill out the necessary information and update his list.
- 7- What did the application display after updating the patient's allergies list/record?
 - The application displays a successful update message.
 - The application displays a failure to update message.

To ensure that you have added drug C to Mr. John's drug allergies list/record, you need to check drug C for allergic reactions.

Task 5. Checking drug C for an allergic reaction in this patient:

- 1- Start over.
- 2- Repeat steps 1 to 5 in Task (1).
- 3- Did the application detect the allergy you added in task 4?
 - Yes, it did
 - No, it did notIf No, please review with the principle investigator why it did not update the file successfully

Thanks for Completing the Tasks

Appendix 4.F – Phase 1: Semi-Structured Interview Questions

1- Do you like the idea of using the NFC-enabled smartphone application to check for drug allergy/interaction and updating drug allergy during the medication administration?

2- What do you like about the NFC app? Why?

3- What do you dislike in the NFC app? Why?

4- What do you recommend to add/delete/change to improve the NFC app in terms of its content and functions?

5- What do you recommend to add/delete/change to improve the NFC app in terms of its interface?

With question 4 & 5, the following graphs will be presented for the participants to help them remember each interface and make the improvement notes on them.

Appendix 4.G - Correlation Tables

Relation Ship between Performance and Rating for Usefulness

Q #	Simplified Question	Time T5	Time T4	Attempts T5
01	Willing to try the application in real world scenario	.18	-.72	.19
02a	Improve Quality of: checking drug interaction	.25	-.61	.13
02b	Improve Quality of: checking drug allergy	-.02	-.22	.19
02s	Improve Quality of: reporting drug allergy	-.02	-.22	.19
03a	Give More Control over: checking drug interaction	.38	-.56	.19
03b	Give More Control over: checking drug allergy	.25	-.61	.13
03c	Give More Control over: reporting drug allergy	.25	-.61	.13
04a	Enabling Faster Accomplishment of: checking drug interaction	-.32	-.74	-.66
04b	Enabling Faster Accomplishment of: checking drug allergy	-.32	-.74	-.66
04c	Enabling Faster Accomplishment of: reporting drug allergy	-.12	-.74	-.50
05a	Improve Performance in: checking drug interaction	.38	-.56	.19
05b	Improve Performance in: checking drug allergy	.38	-.56	.19
05c	Improve Performance in: reporting drug allergy	.38	-.56	.19
06a	Easier Process to: check drug interaction	.03	-.79	-.29
06b	Easier Process to: check drug allergy	.03	-.79	-.29
06c	Easier Process to: report drug allergy	-.08	-.75	-.35
07a	Faster Process to: checking drug interaction	.03	-.79	-.29
07b	Faster Process to: checking drug allergy	.03	-.79	-.29
07c	Faster Process to: reporting drug allergy	.03	-.79	-.29
08	Reduce Known Allergies and Interaction Errors	-.55	-.41	-.32
09	Improve Patient safety	-.02	-.22	.19
10	Notification: Faster to inform the physician/pharmacist	-.02	.14	.19
11	Notification: Accurate Information	-.28	.32	.13
12	Feedback: Provides accurate information about drug interaction	-.29	-.11	.25
13	Feedback: Provides accurate information about drug allergy	-.55	-.41	-.32
14	Enhance knowledge about the drug-interactions	-.08	-.75	-.35
15	Enhance knowledge about the drug allergies	-.32	-.74	-.66
16	Enabling to: insert adequate information in reporting drug allergy	-.47	-.44	-.50
17	Overall, the NFC application would be useful	.15	-.28	.25

Relation Ship between Performance and Rating for Ease of Use

Q#	Simplified Question	Time T5	Time T4	Attempts T5
18a	Comfortable: using the smartphone to check for drug interaction	.38	-.56	.19
18b	Comfortable: using the smartphone to check for drug allergy	.25	-.61	.13
18c	Comfortable: using the smartphone to reporting drug allergy	.38	-.56	.19
19a	Few steps required to check for drug interaction	.03	-.79	-.29
19b	Few steps required to check for drug allergy	-.09	-.64	-.23
19c	Few steps required to report drug allergy	.35	-.64	.18
21	Consistent steps for checking and updating	-.15	-.72	-.23
22	Easy to read/tap tags	.08	-.29	-.18
23	Easy to read the feedback information	.25	-.61	.13
24	Confident about use	.25	-.61	.13
26	Overall it was easy to use	.25	-.61	.13

Relation Ship between Performance and Rating for Learnability

Q#	Simplified Question	Time T5	Time T4	Attempts T5
20	No need for instructions	-.02	-.30	-.10
25	No need to learn a lot of things	-.12	-.47	-.13
27	Easy to learn	.25	-.61	.13
28	Fast to learn	.25	-.61	.13
29	Low memory load	.25	-.61	.13

Relation Ship between Performance and Rating for Satisfaction

Q#	Simplified Question	Time T5	Time T4	Attempts T5
30	Not dependent on the application	-.35	-.38	-.18
31	Pleasant to use	-.30	-.71	-.32
32	Useful in work	-.39	-.21	-.08
33	Recommend	-.03	-.45	.23
34a	Satisfaction of the ease to: complete a drug interaction check	.35	-.64	.18
34b	Satisfaction of the ease to: complete a drug allergy check	.35	-.64	.18
34c	Satisfaction of the ease to: report a drug allergy	.35	-.64	.18
35a	Satisfaction of the time to complete a drug interaction check	.03	-.94	-.23
35b	Satisfaction of the time to complete a drug allergy check	.03	-.94	-.23
35c	Satisfaction of the time to complete reporting drug allergy	.03	-.94	-.23
36a	Satisfaction of the feedback about drug interaction	.13	-.48	.32
36b	Satisfaction of the feedback about drug allergy	.13	-.48	.32
36c	Satisfaction of the information required to report allergy	.13	-.48	.32
37	Overall satisfaction	-.03	-.10	.25

Appendix 5.A – Phase 2: Dalhousie Research Ethics Board Approval



**Health Sciences Research Ethics Board
Letter of Approval**

November 29, 2016

Maali Alabdulhafith
Computer Science\Computer Science

Dear Maali,

REB #: 2016-4028
Project Title: Defining the Functional Requirements of the NFC-Based Medication Administration and Communication System (NFC-MAC)

Effective Date: November 29, 2016
Expiry Date: November 29, 2017

The Health Sciences Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans*. This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Tannis Jurgens, Chair

Appendix 5.B – Phase 2: Semi-Structured Interview

Required assessment and evaluation

Q1 - What are the required assessment and evaluation to the patients that nurses do prior to administer medications to a certain patient?

Five rights and contraindication

Q2 - How do nurses confirm the five rights of medication administration:

right patient:

right dose:

right route:

right time:

right drug:

Allergy:

Interaction:

Q3 - How do nurses verify contraindications?

Alerting System

Q4 - How **does the alerting system work** (if applicable)?

Q5 - What are the information or feedback that the alert system would provide?

Communication Process

Q6- If the nurse needed a consultation during the bedside medication administration, whom she/he would contact? And how? **What type of information a nurse would provide when seeking a consultation?**

Documentation Process

Q7- What type of information that nurses document during the bedside medication administration?

Appendix 5.C: Pyxis System Description

Initial procedure:

- 1- The physician writes a prescription (paper-based prescription)
- 2- The nurse scans the prescription and sends it to pharmacy
- 3- The pharmacist enters the prescription electronically in the pharmacy's system

Med preparation

- 1- The pharmacy uses a system that pack and seal the medication

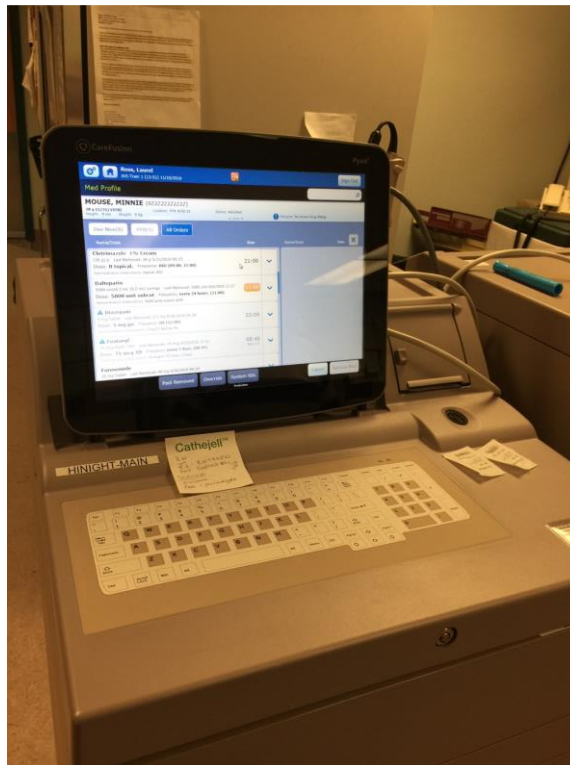


- 2- The system is linked to the Pyxis system. When the Pyxis' drawers in the units are low or empty. The pharmacy system gets notified and prepare the meds to fill up the drawers.
- 3- After preparing all the meds the pharmacist go to the units and fill up the drawers.
- 4- Each pack has a description of the med



Pyxis'

- 1- The nurse log in to the Pyxis System (username + finger print)
- 2- The screen shows a list of all the patients in the unit
- 3- The nurse chooses the patient
- 4- The screen shows the patient's basic demographic information, active medication and allergies



- 5- The nurse chooses the medication
- 6- The screen shows information about the medication time, dose, route, and strength
- 7- The nurse clicks on (remove) to obtain the medication
- 8- The Pyxis Drawer system will automatically open up, it contains number of containers each one has a certain medication

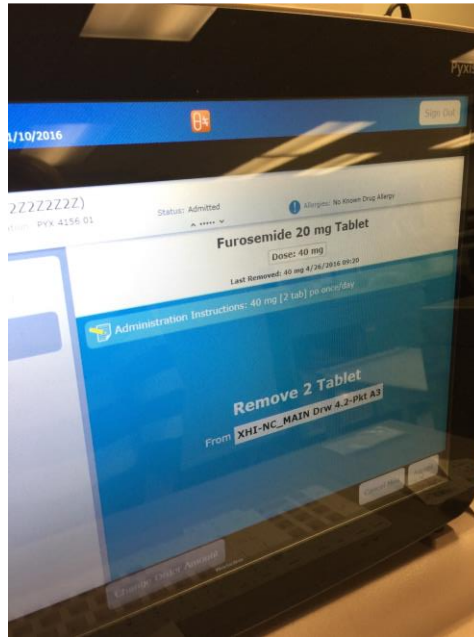


- 9- Only the medication the nurses choose will open up. The rest of the containers will remain locked

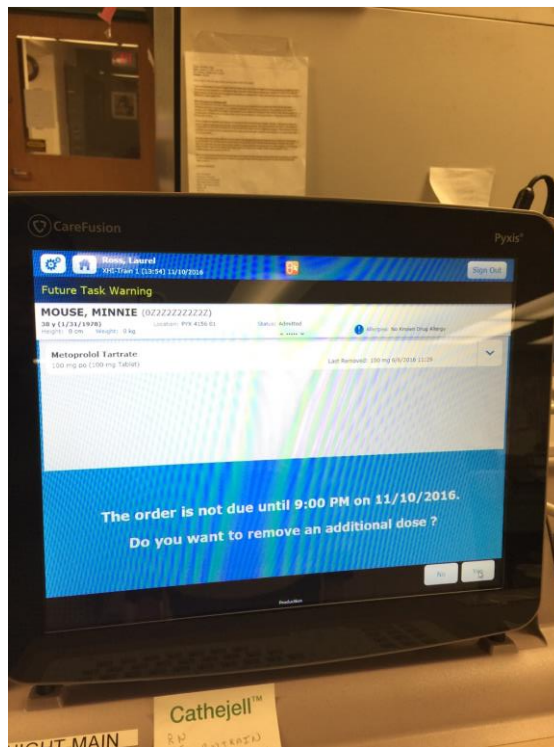


- 10- All the medications are already prepared and previously packed and sealed

11- Some medication requires the nurse to take two packs. This depends on the dose amount required for the patient



12- If the nurse forgot that she gave the patient the medication and she request to remove the medication again the system will display a warning with options to skip or stop.



Pyxis Benefits:

- Warning with high alert medication
- Warning when giving a med that was recently administered
- Override medication, pharmacy can review later
- Pharmacy get notified when the med is low
- Reliable
- Takes 2 weeks to learn
- Global find (if the unit ran out of a certain med, a nurse can search for it in other units, go there and access her patient's file, and remove the medication from there. The med will be posted in the patient's history)

Appendix 7.A – Phase 3: Dalhousie Research Ethics Board Approval



**Health Sciences Research Ethics Board
Letter of Approval**

July 20, 2017

Maali Alabdulhafith
Computer Science\Computer Science

Dear Maali,

REB #: 2017-4257

Project Title: Testing the Usability of the NFC-Based Medication Administration and Communication System (NFC-MAC)

Effective Date: July 20, 2017

Expiry Date: July 20, 2018

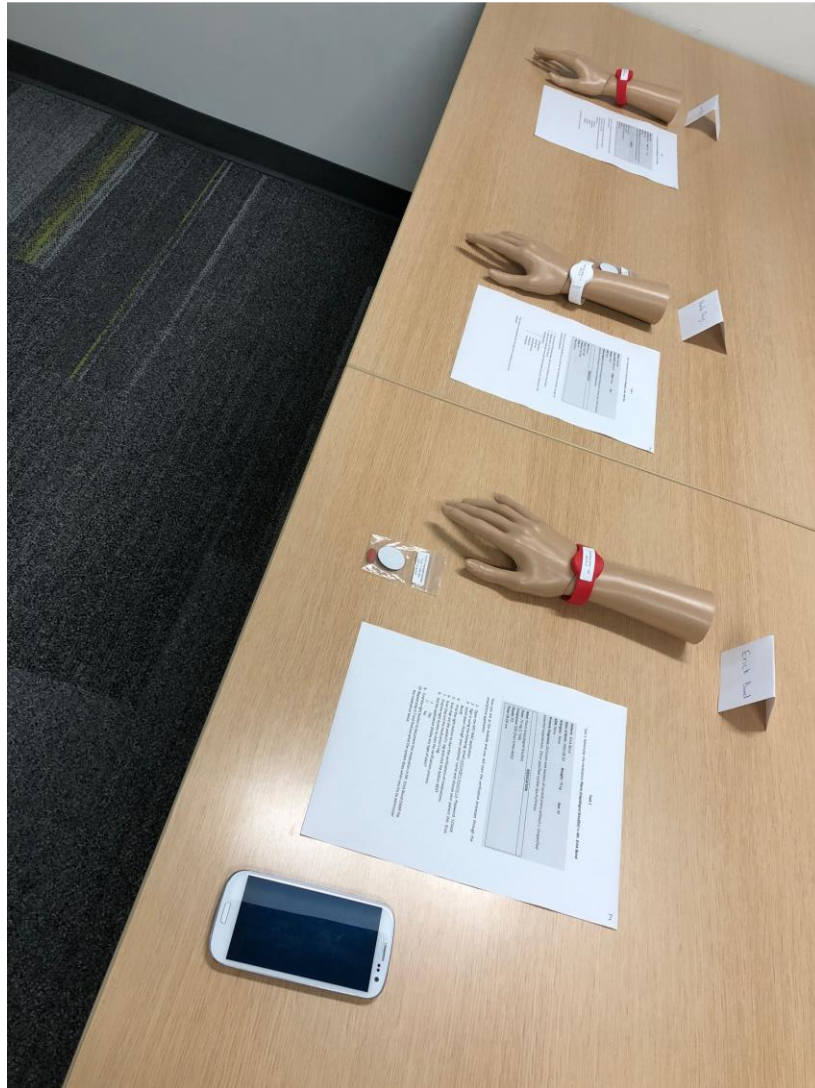
The Health Sciences Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans*. This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Tannis Jurgens, Chair

Appendix 7.B – Phase 3: Usability Testing Tools and Setting

The following pictures shows the set up for the first three tasks. The participant starts with the first task and then move to the second tasks and so on.



Appendix 7.C – Phase 3: Background Questionnaire

Demographic Questions

GENERAL INFORMATION

Participant ID:

Gender:

Male Female Other

Age:

20-29 30-39 40-49 50-59 60-69
 70+ years

Employment:

RN LPN Other _____

Years of experience (in years):

Less than 2 3-4 5-6 7-8 9-10 10+ years

Do use smartphone?

Yes No

If yes:

Do use any type of medication-related application as a source of information?

Yes No

If yes, please specify (optional) : _____

Have you ever used the Near Field Communication (NFC) feature in your smartphone? (e.g. using the phone tap to pay at a store)

Yes

No

I am not aware of this feature

MEDICATION ADMINISTRATION-RELATED INFORMATION

Average number of medications administered to patients per shift:

1-5 6-10 11-15 16-20 20-25 30+

Current method/methods you use for administrating medication:

Paper-based MAR E-MAR Barcode Scanning Pyxis Other

FIVE RIGHTS OF MEDICATION ADMINISTRATION

Current method/methods you use to check the five rights of medication administration (for a single patient):

Right Patient

- Arm Band Ask Patient DOB Patient ID number Paper-based MAR E-MAR
 Other _____

Right Medication

- Paper-based MAR E-MAR Physician order Pyxis Medication Package
 Ask Patient Other _____

Right Dose

- Paper-based MAR E-MAR Physician order Pyxis Medication Package
 Ask Patient Other _____

Right Time

- Paper-based MAR E-MAR Physician order Pyxis Medication Package
 Ask Patient Other _____

Right Route

- Paper-based MAR E-MAR Physician order Pyxis Medication Package
 Ask Patient Other _____

Average time spent to confirm the five rights of medication administration (for a single patient)

- Less than 1 minute 1-2 minutes 3-4 minutes 5- 6 minutes 7-8 minutes 9-10 10+
-

MEDICATION ALLERGY

Current method/methods you use to check allergies (for a single patient):

- E-MAR Paper-based MAR Arm band Physician order Ask patient
 Chart Other _____

Average time spent to confirm patient's medication allergy

- Less than 1 minute 1-2 minutes 3-4 minutes 5- 6 minutes 7-8 minutes 9-10 10+
-

DRUG INTERACTIONS

Current method/methods you use to check drug interactions (for a single patient):

- E-MAR Paper-based MAR Paper poster (Grid) Drug guide (book)
- Computer software/ web Phone app Other _____

Average time spent to confirm drug interactions

- Less than 1 minute 1-2 minutes 3-4 minutes 5- 6 minutes 7-8 minutes 9-10 10+
-

CONTRAINDICATION

Current method/methods you use to verify contraindication (i.e. medication interacts with patient condition, vital science or disease) (for a single patient):

- E-MAR Paper-based MAR Drug guide (book) Other _____

Average time spent to verify contraindications

- Less than 1 minute 1-2 minutes 3-4 minutes 5- 6 minutes 7-8 minutes 9-10 10+
-

DOCUMENTATION

Current method/methods you use for documenting the administered medication (for a single patient):

- Paper-based MAR E-MAR Other _____

Average time spent to document an administered medication (from giving it to the patient until it gets documented):

- Less than 1 minute 1-2 minutes 3-4 minutes 5- 6 minutes 7-8 minutes 9-10 10+
-

COMMUNICATION WITH STAFF DURING THE MEDICATION ADMINISTRATION STAGE

Current method/methods you use to communicate with physician when a consultation is needed (e.g. clarification on a medication order is needed):

- Phone call Page email Text messaging in person other _____

Average time spent to contact/reach a physician and get a reply

- Less than 1 minute 1-2 minutes 3-4 minutes 5- 6 minutes 7-8 minutes 9-10 10+

Current method/methods you use to communicate with pharmacist when a consultation is needed:

- Phone call Page email Text messaging in person other _____

Average time spent to contact/reach a pharmacist and get a reply

- Less than 1 minute 1-2 minutes 3-4 minutes 5- 6 minutes 7-8 minutes 9-10 10+

Appendix 7.D – Phase 3: Tasks

Participant ID:.....

Please read the following scenario and then perform the tasks.

Scenario:

Your shift has just started and you have 9 patients. You reviewed your patients' Electronic MAR, and now you are ready to administer the medications to each one of them. You will be using the NFC-MAC system to help you in:

- 1- Confirming the five rights of medication administration
- 2- Verifying drug allergies
- 3- Verifying drug interactions
- 4- Verifying contraindication
- 5- Initiate a real time communication with the physician (prescriber) and/or pharmacist
- 6- Electronically documenting the administered medication

1. Confirming The Five Rights of Medication Administration

Purpose:

- **To experience how the NFC-MAC system confirms the five rights of medication administration and alert the nurse if there is a medication error.**
- **To experience the two-way communication feature in the NFC-MAC application**

Task 1

Task 1: Administer the medication *Plavix (clopidogrel bisulfat)* to *Mr. Erick Bond*

Patient: Erick Bond **MRN:** 118
Date of Birth: 1962-08-20 **Weight:** 79 kg **Sex:** M
Allergies: None
ADR: None
Primary Diagnosis: Occlusion and stenosis of carotid artery without c. Unspecified essential hypertension. Other specified cardiac dysrhythmias.

MEDICATION
Med: Plavix (clopidogrel bisulfat) Dose: 75 mg (1 TAB) Frequency: QID (four times daily) Route: PO Time: 08:00 am

You dispensed the patient's medication and now you are at the bedside and you will start the verification processes through the NFC-MACC application.

- Open the NFC-MAC application.
- Sign in using the following: email nichole@rn.hospital.ca. Password: 123456
- Scroll down through your patients' name and choose your patient (Mr. Erick Bond)
- Click the right button to start the identifying process.
- Tap on the patient's bracelet and click the right button to proceed
- Tap on the medication's tag
- Click the right button to verify the medication.
- Did the application display any type of alert?
 - Yes
 - No
- Find the right button to document the medication in Mr. Erick Bond EMAR file.

Task 2

- Repeat step 3-7 and find out what the system does when you try to administer the medication twice.

Task 3

Task 3: Administer the medication **Ramipril** to **Mrs. Keely Roy**

Patient: Keely Roy

MRN: 212

Date of Birth: 1977-01-11

Weight: 80 kg

Sex: F

Allergies: None

ADR: None

Primary Diagnosis: Subdural hemorrhage following injury without open. Open wound of scalp without complication. Pure hypercholesterolemia.

MEDICATION
Med: Ramipril Dose: 5 mg (1 TAB) Frequency: Once Daily Route: PO Time: 09:00 am

You dispensed the patient's medication and now you are at the bedside and you will start the verification processes through the NFC-MACC application.

- 1- If you are not in the home screen, start over by clicking on the right button
- 2- Repeat steps 3 to 7 from Task #1.
- 3- What type of medication error alert did the system show you? Choose one of the following options:
 - Wrong Patient
 - Wrong Time
 - Wrong Medication
 - Wrong Dose
 - Wrong Route

If you receive a *wrong patient alert*, the application will not proceed to the *Medication Verification* screen where you tap on the medication ID!

Task 4

Task 4: Administer the medication *Cyanocobalamin* to *Mrs. Sara Mike*

Patient: Sara Mike **MRN:** 112
Date of Birth: 1955-09-05 **Weight:** 59 kg **Sex:** F
Allergies: None
ADR: None
Primary Diagnosis: Acute posthemorrhagic anemia. Diverticulosis of colon (without hemorrhage). Benign neoplasm of stomach. Unspecified essential hypertension.

MEDICATION
Med: Cyanocobalamin Dose: 5 mg (1 TAB) Frequency: Q12H (every twelve hours) Route: PO Time: 08:00 am

You dispensed the patient's medication and now you are at the bedside and you will start the verification processes through the NFC-MACC application.

- 1- If you are not in the home screen, start over by clicking on the right button
- 2- Repeat steps 3 to 7 from Task #1.
- 3- What type of medication error alert did the system show you? Choose one of the following options:
 - Wrong Patient
 - Wrong Medication
 - Wrong Time
 - Wrong Dose
 - Wrong Route

- 1- Click Home button to go back to main interphase

Task 5

Task 4: Administer the medication ***Pantoprazole*** to ***Mrs. Phoebe Morris***

Patient: Phoebe Morris **MRN:** 115
Date of Birth: 1945-09-13 **Weight:** 71 kg **Sex:** F
Allergies: None
ADR: None
Primary Diagnosis: Malignant neoplasm of body of stomach. Chronic or unspecified gastric ulcer with hemorrhage.

MEDICATION
Med: Pantoprazole Dose: 40 mg (1 TAB) Frequency: Q12H (every twelve hours) Route: PO Time: 08:00 am

You dispensed the patient's medication and now you are at the bedside and you will start the verification processes through the NFC-MACC application.

- 2- If you are not in the home screen, start over by clicking on the right button
- 3- Repeat steps 3 to 7 from Task #1.
- 4- What type of medication error alert did the system show you? Choose one of the following options:
 - Wrong Patient
 - Wrong Medication
 - Wrong Time
 - Wrong Dose
 - Wrong Route
- 5- You want to administer the medication and document that the medication was delivered a little late. Click on Override button and add your comments regarding the late administration of medication.
- 6- Find the right button to document the medication in Mrs. Phoebe Morris EMAR file.
- 7- Click Home button to go back to main interface

Task 6

Task 6: Administer the medication **Morphine** to **Mr. Walter Fay**

Patient: Walter Fay

MRN: 117

Date of Birth: 1971-07-22

Weight: 92 kg

Sex: M

Allergies: None

ADR: None

Primary Diagnosis: Atrial Fibrillation. Pure Hypercholesterolemia. Knee joint replacement.

MEDICATION
Med: Morphine Dose: 0.5 mg Frequency: Q12H (every twelve hours) Route: IV Time: 08:00 am

You dispensed the patient's medication and now you are at the bedside and you will start the verification processes through the NFC-MACC application.

- 1- If you are not in the home screen, start over by clicking on the right button
- 2- Repeat steps 3 to 7 from Task #1.
- 3- What type of medication error alert did the system show you? Choose one of the following options:
 - Wrong Patient
 - Wrong Medication
 - Wrong Time
 - Wrong Dose
 - Wrong Route

Now, you will notify the pharmacy of this error, and ask them to send a Morphine Syringe for MR. Walter Fay. To do that, follow the next steps

- 4- Click on Send Notification button, by clicking the button the alert content will be copied to the phone memory
- 5- Choose **Pharmacy** from the contact list
- 6- Hold the indicator in the text box and choose **Paste**
- 7- Send the alert content to the pharmacy and ask them to send a Morphine Syringe for MR. Walter Fay.

Task 7

Task 7: Administer the medication *Clopidogrel Bisulfate* to *Mr. Smith Dukes*

Patient: Smith Dukes **MRN:** 114
Date of Birth: 1985-09-21 **Weight:** 70 kg **Sex:** M
Allergies: None
ADR: None
Primary Diagnosis: Acute myocardial infarction of other anterior wall. Cardiogenic shock. Cardiac arrest. Primary pulmonary hypertension.

MEDICATION
Med: Clopidogrel Bisulfate Dose: 75 mg (1 TAB) Frequency: Once Daily Route: PO Time: 09:00 am

Now you are at the bedside and you will start the verification processes through the smartphone application.

- 1- If you are not in the home screen, start over by clicking on the right button
- 2- Repeat steps 3 to 7 from Task #1.
- 3- What type of medication error alert did the system show you? Choose one of the following options:
 - Wrong Patient
 - Wrong Medication
 - Wrong Time
 - Wrong Dose
 - Wrong Route

Now, you will notify the pharmacy of this error, and ask them to send a 75 mg (1 TAB) for Mr. Smith Dukes.

- 4- Repeat steps 4-6 in Task 5
- 5- Send the alert content to the pharmacy and ask them to send a 75 mg (1 TAB) for Mr. Smith Dukes.

2. Verifying Allergies

Purpose:

- To experience how the NFC-MAC system verifies known (recorded) allergies, and alert the nurse if the patient is allergic to the medication.
- To experience the two-way communication feature in the NFC-MAC application

Task 8

Task 8: Administer the medication *Aspirin* to *Mr. John Patterson*

Patient: John Patterson **MRN:** 113
Date of Birth: 1970-09-12 **Weight:** 60 kg **Sex:** M
Allergies: Aspirin
ADR: None
Primary Diagnosis: Fracture of intertrochanteric section of femur CIO. Cerebral embolism with cerebral infarction. Acute posthemorrhagic anemia.

MEDICATION
Med: Aspirin Dose: 325 mg (1 TAB) Frequency: Once Daily Route: PO Time: 09:00 am

You dispensed the patient's medication and now you are at the bedside and you will start the verification processes through the NFC-MACC application.

- 1- If you are not in the home screen, start over by clicking on the right button
- 2- Repeat steps 3 to 7 from Task #1.
- 3- Did the system display allergy alert?

Now you will notify the physician on shift (Dr. Lisa Brown) about the allergy alert and ask for a consultation or a new prescription.

- 4- Click on Send Notification button, by clicking the button the alert content will be copied to the phone memory
- 5- Choose **Dr. Lisa Brown** from the contact list, send the alert content to her and ask for a consultation (you are free to type whatever suitable for the case)

3. Verifying Drug Interactions

Purpose:

- To experience how the NFC-MAC system verifies drug interactions, and alert the nurse if there is a potential of interactions.
- To experience the two-way communication feature in the NFC-MAC application

Task 9

Task 9: Administer the medication *Warfarin* to *Mrs. Marina Fox*

Patient: Marina Fox **MRN:** 116
Date of Birth: 1980-04-13 **Weight:** 66 kg **Sex:** F
Allergies: None
ADR: None
Primary Diagnosis: Atrial fibrillation. Congestive heart failure unspecified. Hepatitis unspecified. Other malignant lymphomas unspecified site.

MEDICATION
Med: Warfarin Dose: 2 mg (1 TAB) Frequency: Once Daily Route: PO Time: 09:00 am

Now you are at the bedside and you will start the verification processes through the smartphone application.

1. If you are not in the home screen, start over by clicking on the right button
2. Repeat steps 3 to 7 from Task #1.
3. Did the system display interactions alert?

Now you will notify the physician on shift (Dr. John Ross) about the interaction alert and ask for a consultation or a new prescription.

4. Click on Send Notification button, by clicking the button the alert content will be copied to the phone memory
5. Choose **Dr. John Ross** from the contact list, send the alert content to him and ask for a consultation (you are free to type whatever suitable for the case)

4. Verifying Contraindications

Purpose:

- To experience how the NFC-MAC system verifies contraindications, and alert the nurse if the patient condition serves as a reason to stop the medication.
- To experience the two-way communication feature in the NFC-MAC application

Task 10

Task 10: Administer the medication *Warfarin* to *Mr. Glenn Ross*

Patient: Glenn Ross **MRN:** 119
Date of Birth: 1977-08-08 **Weight:** 83 kg **Sex:** M
Allergies: None
ADR: None
Primary Diagnosis: Congestive heart failure unspecified. Primary cardiomyopathies.
Primary pulmonary hypertension. Mitral valve disorders.

MEDICATION
Med: Warfarin Dose: 2 mg (1 TAB) Frequency: Once Daily Route: PO Time: 09:00 am

Now you are at the bedside and you will start the verification processes through the smartphone application.

6. If you are not in the home screen, start over by clicking on the right button
7. Repeat steps 3 to 7 from Task #1.
8. Did the system display interactions alert?

Now you will notify the physician on shift (Dr. Alex Sanders) about the contraindication alert and ask for a consultation or a new prescription.

9. Click on Send Notification button, by clicking the button the alert content will be copied to the phone memory
10. Choose **Dr. Alex Sanders** from the contact list, send the alert content to him and ask for a consultation (you are free to type whatever suitable for the case)

Thank You!

Appendix 7.E – Phase 3: Semi-Structured Interview

1- What do you think of our system as a method of MA in comparison to your current method of MA?

2- What do you like about the NFC app? Why?

Probes: *information, layout, tapping, features (verifying med, patient and communication), alerts, documentation . Can you tell more about that?*

3- What do you think of the NFC technology (tapping on the patient and med ID tags) as a method of identification?

4- Can you tell me what you thought about the information provided on the app?

Probes: *What do you think about the amount of information that was provided in the alert documentation/ communication? Was the information provided helpful? Was the information on the application clearly presented? Do you think this information will help you better manage the administration of medication, why?*

5- What do you dislike in the NFC app? Why?

Probes: *What were the challenges you faced while using the app? Use of smartphone problems? Tapping problems? information-related problems? layout, features (verifying med, patient and communication), alerts, documentation. Can you tell more about that?*

6- In your opinion, do you think the system would improve patient care? Why?

7- In your opinion, do you think patients would like the system and appreciate being scanned before medication administration?

8- Would you want to use it in an actual practice? Why?

Probes: *What would motivate you to use it?*

9- What do you recommend to improve (add, delete, change) the NFC-MAC system in terms of its content, functions, interface? How?

Probes: *Was there any information, function, or feature that you thought should be on the application but was not there? Was there any information, function, or feature that you think we should exclude or include? Should we re-arrange the order of information or interfaces? Should we add more options in the alert? How can we organize the patient's list and staff to fit with your need?*